  

DRAINAGE SYSTEMS ANALYSIS

Flooding Topic Area | Sea Level Rise Analysis

October 5, 2020

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Flooding Topic Area

Technical Memorandum

Project: Drainage Systems Analysis

Topic Area: Flooding

Deliverable: Sea Level Rise Analysis

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Table of Contents

Figures

Tables

Appendices

Abbreviations

BC	Brown and Caldwell
City	City of Seattle (organization)
CMIP	Coupled Model Intercomparison Project
CMIP5	Coupled Model Intercomparison Project, Fifth Phase
CRS	Climate Resiliency Study
CSO	combined sewer overflow
DEM	digital elevation model
DSA	Drainage System Analysis
DWW	Drainage and Wastewater
GIS	geographic information system
HARN	High Accuracy Reference Network
IPCC	Intergovernmental Panel on Climate Change
ISP	Integrated System Plan
LOB	line of business within Seattle Public Utilities
NAD 83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NRC	National Research Council
MHHW	mean higher high water
OSE	Office of Sustainability and Environment
ROW	right of way
SDOT	Seattle Department of Transportation
SHIVA	Seattle Hazard Identification & Vulnerability Analysis
SLR	sea level rise
SPU	Seattle Public Utilities
TM	technical memorandum
WWPS	wastewater pump stations
WCRP	Washington Coastal Resiliency Project

1. Introduction

Seattle Public Utilities (SPU) is completing a Drainage System Analysis (DSA) to provide data collection and technical analyses that support the development of the *Vision Plan* and *Integrated System Plan (ISP)* for the Drainage and Wastewater (DWW) line of business (LOB). The DSA will compile and update existing information related to SPU's drainage system and receiving waters, as well as perform new analyses that focus on flooding, climate change impacts, and water quality issues. The DSA efforts are divided into multiple topic areas, including a flooding topic area.

SPU contracted with Brown and Caldwell (Consultant) to perform technical analyses for the DSA flooding topic area. Key objectives for the flooding topic area include:

- Develop a prioritized inventory of drainage system capacity risk areas.
- Define Performance Thresholds for the drainage system and complete modeling to evaluate the capacity under existing and future conditions.
- Estimate inundation extent and develop risk maps for extreme storm events, sea level rise, and creek flooding.
- Estimate runoff and flow in areas served by ditches and culverts.
- Calculate flow metrics in creek watersheds and prioritize areas for runoff reduction to reduce erosive flows to creeks.

While some of the analyses completed for the flooding topic area are specific to the performance of SPU's drainage system, some, including this analysis, identify risks to the City that are beyond drainage system performance. SPU worked with the Consultant team to map the areas at risk of inundation due to sea level rise (SLR). The Consultant performed the following activities to support risk area mapping:

- Reviewed published predictions of the SLR likely to be experienced in Puget Sound to inform SPU's selection of SLR scenarios.
- Reviewed static water inundation mapping data for three selected SLR scenarios.
- Compared static water inundation mapping with similar results from the *Climate Resiliency Study* (Aqualyze 2015) to assess confidence and determine whether some inundated areas should be screened out of the SLR analysis.
- Calculated static water depth grids for each of the three SLR scenarios based on digital elevation data.
- Performed geospatial analyses based on existing data to develop spatially distributed risk area mapping.
- Examined the overall area-weighted distribution of the risk scores and adjusted the depth scoring factors to achieve a broad distribution of risk scores.

This technical memorandum (TM) summarizes the methodology and highlights the main findings of the SLR analysis. Section 2 provides background on studies and projections for SLR in Seattle. Sections 3 and 4 describe the analytical process used to evaluate inundation mapping and calculate risk scoring. Section 5 discusses the results of the evaluation. Section 6 describes the limitations of the analysis.

2. SLR Projections

Three recent studies have examined how global and local trends interact to produce predictions of SLR over the next century for western Washington. These studies are:

- *Sea Level Rise in the Coastal Waters of Washington State* (Mote et al. 2008)
- *Sea Level Rise for the Coasts of California, Oregon and Washington: Past, Present & Future* (NRC 2012)
- *Projected Sea Level Rise for Washington State – A 2018 Assessment* (Miller et al. 2018)

All three of these studies rely upon the work of the Intergovernmental Panel on Climate Change (IPCC) within the Work Climate Research Program. The World Climate Research Program facilitates climate change research through the Coupled Model Intercomparison Project (CMIP), which provides a framework for coordinated climate change modeling experiments.

Of the three recent local studies, the earliest effort, *Sea Level Rise in the Coastal Waters of Washington State* by the Climate Impacts Group at the University of Washington (Mote et al. 2008), presented very low, medium, and very high SLR scenarios based on global climate model projections included in the IPCC's fourth assessment report (IPCC 2007). These projections were used in two subsequent hazard assessments for Seattle and King County:

- *Vulnerability of Major Wastewater Facilities to Flooding from Sea-Level Rise* (King County 2008)
- *Seattle Hazard Identification & Vulnerability Analysis (SHIVA)* (City of Seattle 2014)

SLR projections by Mote et al. (2008) were superseded by a report from the National Research Council (NRC) titled *Sea Level Rise for the Coasts of California, Oregon and Washington: Past, Present & Future* (NRC 2012). The NRC report was also based on the climate projections included in the IPCC's fourth assessment report and presented very low, medium and very high SLR scenarios. This work was the basis for three assessments of Seattle's vulnerability to SLR:

- *Tidal Impacts on Wastewater Pump Stations and CSO Facilities.* (Seattle University 2014)
- *Climate Preparedness: A Mapping Inventory of Changing Coastal Flood Risk* (GGLO Design 2015), which presents results for a range of sea levels mapped by SPU, rather than making a specific sea-level prediction for a particular planning horizon
- *Climate Resiliency Study* (Aqualyze 2015)

The 2018 Washington Coastal Resiliency Project (WCRP) provides the most recent SLR projections (Miller et al. 2018) and the basis for the risk mapping described herein. Projections by Miller et al. (2018) are based on climate models from the IPCC's fifth assessment report (Church et al. 2013). The WCRP developed SLR projections for 171 locations along Washington's coastline and presented SLR for low and high greenhouse gas emissions scenarios. Miller et al. (2018) developed probabilistic[1] estimates of absolute SLR for Washington, based on regional SLR work by Kopp et al. (2014). Miller et al. (2018) converted absolute SLR projections to relative SLR projections for specific locations based on variations in the rate of vertical land movement across the state. Figure 2-1 shows the SLR projections for Elliot Bay under a high greenhouse gas emissions scenario.

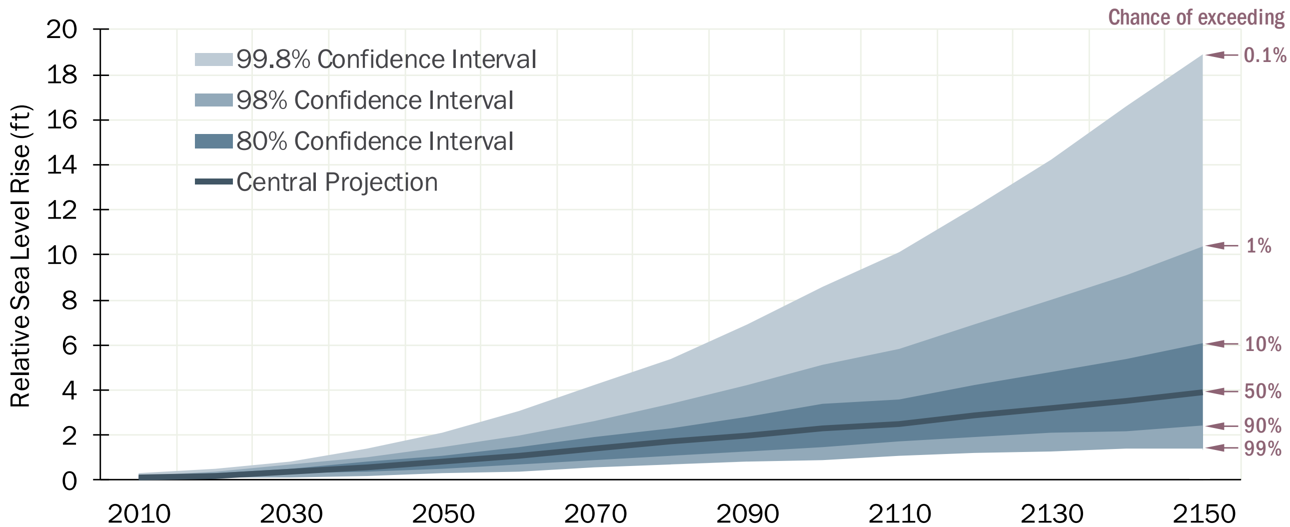

Figure 2-1. Relative SLR projections at Elliot Bay for high emissions scenario

Data obtained from online repository for Miller et al. (2018) for coordinates: 47.6N, 122.4W

3. Inundation and Depth Mapping

Rising sea levels will have multiple impacts on sewer and drainage infrastructure, including reduced hydraulic capacity near outfalls and corrosion of equipment (Seattle University 2014). Extreme tide levels and coastal flooding can also impact transportation routes, human mobility, and access to critical facilities. The Consultant team performed geospatial analyses to develop citywide SLR risk maps based on potential inundation areas combined with consequence, likelihood, and equity factors. SPU selected three future sea levels for which inundation mapping data are available, and the Consultant team used those data to perform spatial overlays and calculate risk scores.

[1] Miller et al. (2018) assessed the likelihood that, for a given greenhouse gas emissions scenario, sea level rise will reach or exceed a certain level relative to the present, which is well-suited for risk management and planning.

3.1 Selection of Future Sea Levels

SPU's Climate Resiliency Group developed inundation mapping for four SLR increments: 2 feet (ft), 3 ft, 4 ft, and 5 ft added to an average daily high tide or mean higher high water (MHHW) of 9.01 ft above the North American Vertical Datum of 1988 (NAVD88). Figure 3-1 shows how these levels of sea rise compare to NAVD88 and the highest observed water level of 12.14 ft above NAVD88 (NOAA, January 27, 1983). The City provides an on-line viewer for planning purposes (City of Seattle 2019).

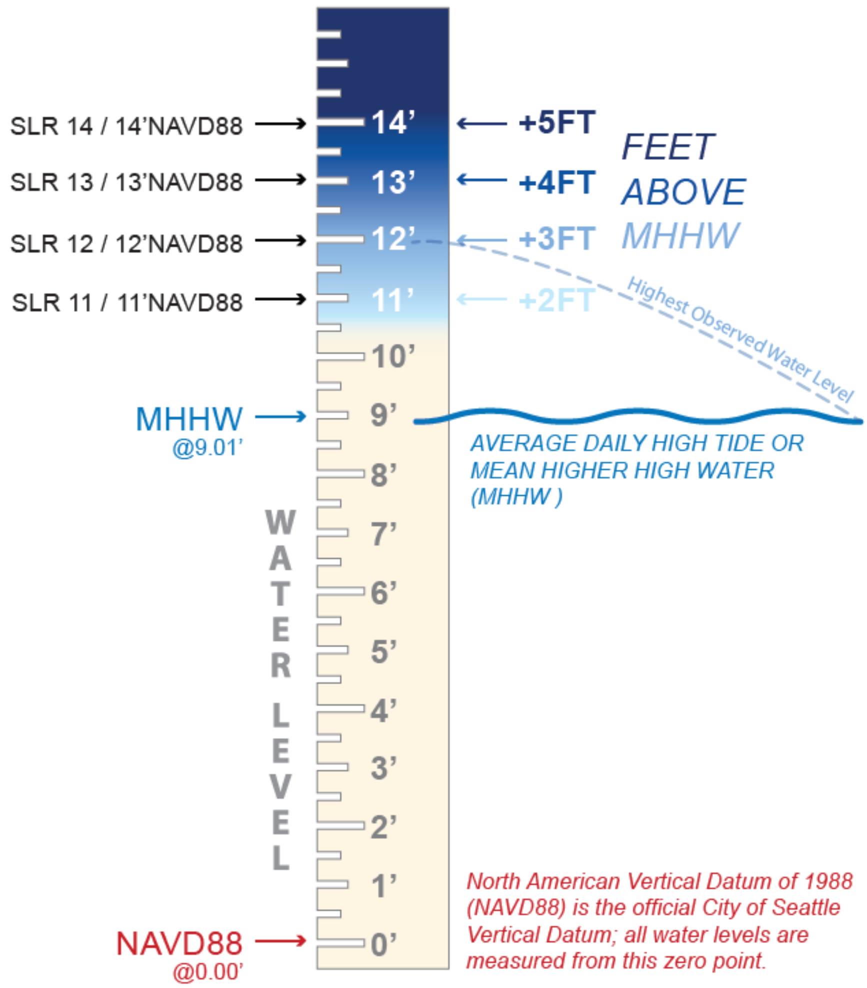

Figure 3-1. Future sea levels referenced to NAVD88

Source: Climate Preparedness Mapping Inventory prepared for OSE by GGLO (2015)

SPU selected three future sea levels to represent SLR scenarios for this study. Of the four levels of SLR rise inundation data available, SPU selected the following three:

- 2 ft of rise, which is a condition that Seattle currently experiences
- 3 ft of rise, which is more likely than high-end or extreme scenarios
- 5 ft of rise, which is the maximum inundation data available and an approximate upper limit to SLR over a 60-year time horizon.

SPU estimated the time frames over which the selected SLR scenarios might occur based on the 50-percent confidence level (i.e., 50th percentile or the mean estimate) of the high-emissions SLR projections. Using the data from Figure 2-1:

- 2 feet of rise, at the 50-percent confidence level, is projected to occur around the year 2090
- monthly high tide is approximately 1 foot higher than MHHW; at 50 percent confidence level 1 foot of rise is projected to occur around year 2050
- annual extreme high tide is approximately 2 feet higher than MHHW or zero feet of rise.

Table 3-1 provides estimated time frames for various tide levels.

Table 3-1. Future Sea Levels and Approximate Time Frames for Occurrence

Future Sea Level		Tidal level occurrences and time frame[2] (years)		
Increase above MHHW[1] (ft)	Elevation relative to NAVD88 (ft)	MHHW	Monthly high tide	Annual extreme high tide
2	11	2090	2050	current
3	12	2120	2090	2050
5	14	2170	2150	2120

1. *A mean higher high tide (MHHW) lever of 9.01 ft NAVD88 was used based on current data from the National Oceanic and Atmospheric Administration for station 9447130 (Seattle WA https://tidesandcurrents.noaa.gov/datums.html?id=9447130.*
2. *Time frames based on the 50th percentile (mean) for high-emissions SLR projections from Miller et al. (2018).*

3.2 Review of Inundation Mapping

SPU provided the Consultant team with SLR inundation data in digital format. These data are polygons representing inundated areas for each of the three selected SLR scenarios. SPU's inundation data were developed based on a comparisons of land elevation (using data from the 2016 regional program by King County and the Puget Sound LiDAR[2] Consortium) with the three sea elevations considered (11 ft, 12 ft and 14 ft NAVD88; Seattle Public Utilities 2019).

Inundation polygons that appear in isolated depressions away from the coastline are not necessarily impacted by a higher sea level unless a direct flow path exists. To address this concern, the Consultant team compared the inundation polygons with inundation mapping results from SPU's Climate Resiliency Study (CRS) (Aqualyze 2015). For the CRS, Aqualyze (2015) performed 2-dimentional hydraulic modeling of high tide levels combined with rainfall-runoff and collection system modeling to determine inundation extents for nine drainage basins[3] with low-lying areas. The CRS analysis accounted for hydraulic connectivity and is a good check on the isolated polygons found in SPU's SLR inundation data. Figure 3-2 shows the nine basins studies for the CRS with example inundation-depth results.

[2] Light Detection and Ranging (LiDAR) is a remote sensing method that uses an airborne scanning laser rangefinder to measure variable distances to the ground surface. Raw LiDAR survey data are processed to develop "bare earth" high-resolution digital terrain models such as DEMs.

[3] A total of 9 drainage basins were modeled for the CRS based on their proximity to tidally influenced waterways such as the Duwamish Waterway and Puget Sound. The 9 basins were selected to provide a good mix of land-use characteristics ranging from residential to light industrial, and variety of runoff generating impervious surface areas (Aqualyze 2015).

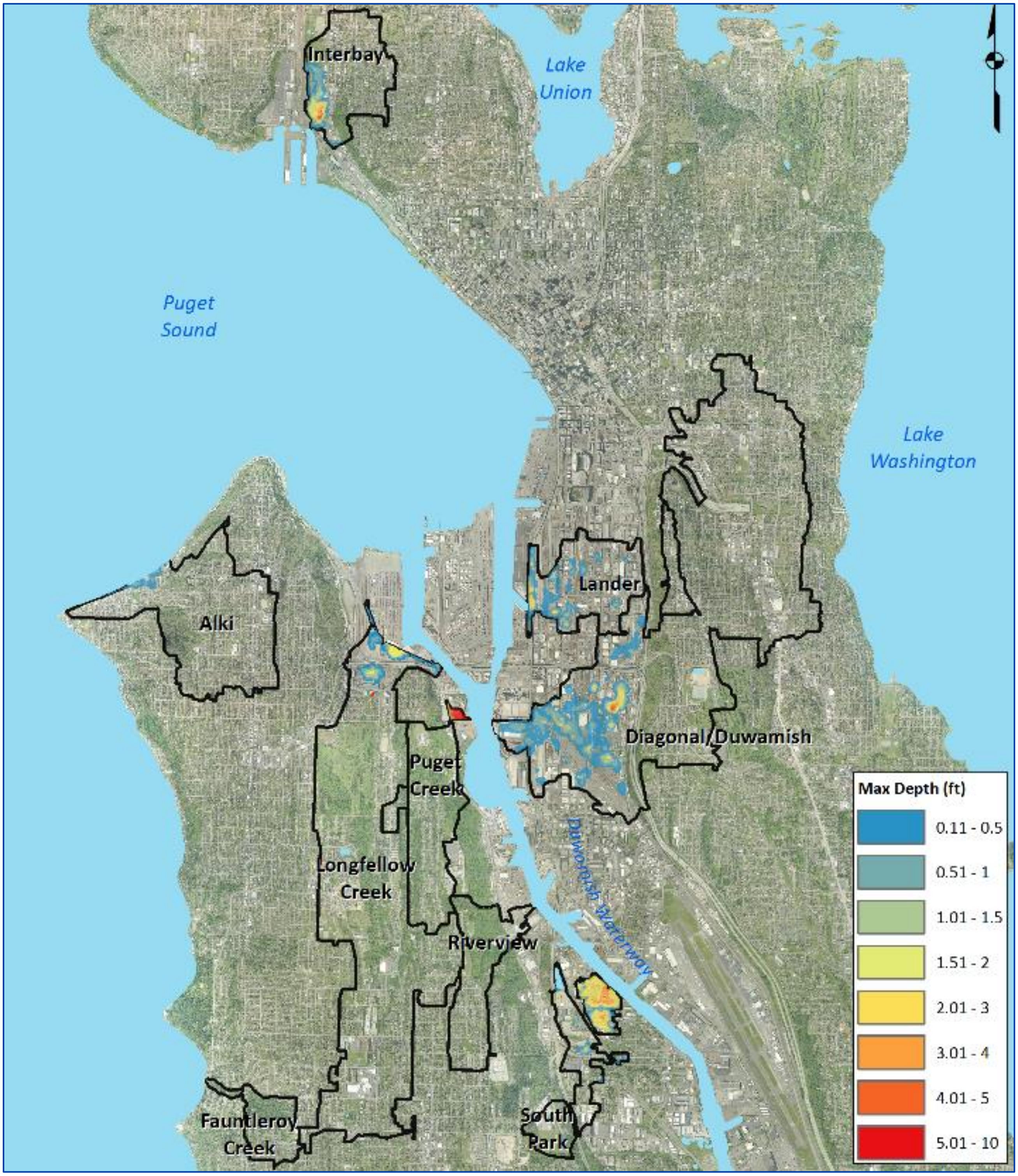

Figure 3-2. Basins and inundation mapping from the CRS

Scenarios for the CRS simulations were based on the maximum recorded high tide level (December 17, 2012) and projections available at the time (NRC, 2012). SLR scenarios for the CRS were defined follows:

- 11.43 ft NAVD88: equivalent to the 2013 maximum high tide
- 13.43 ft NAVD88: 2.00-ft higher than the 2013 maximum high tide projected to occur by year 2050

- 16.10 ft NAVD88: 4.67-ft higher than the 2013 maximum high tide projected to occur by year 2100.

Figure 3-3 compares the sea levels used for the CRS with the SLR scenarios selected for this analysis, which are based on the recent WCRP assessment. While considering the differences, the Consultant team used the CRS results to gauge "confidence" in the inundation areas associated with isolated depressions for which a connection to the coast is unknown. The simulation results from a set of "sunny day" CRS simulations (i.e., no rainfall) were used because the results are comparable to SPU inundation mapping based on static water levels. Each SLR scenario was assessed by examining isolated inundation polygons in the SPU inundation data and assigning one of the following categories:

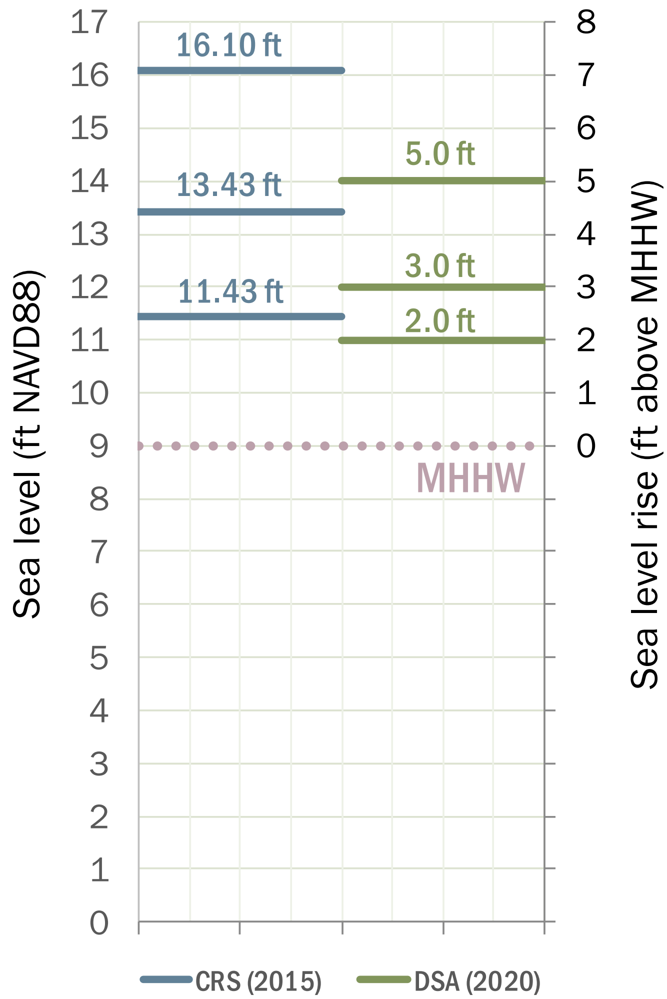

Figure 3-3. SLR scenarios for this study (DSA 2020) compared with sea levels in the CRS

SLR added to MHHW of 9.01 ft NAVD88

- *More confidence:* areas that are connected to the coast or are shown as flooded in a less-extreme SLR CRS scenario than the inundation level
- *Less confidence:* areas that have no coastal connection within a CRS basin and do not flood in a more-extreme SLR CRS scenario than the inundation level
- *Unknown:* areas that have no coastal connection and were not modeled for the CRS, or areas that are shown as flooded in a more-extreme CRS scenario than the inundation level but are not flooded in a less-extreme CRS scenario than the inundation level.

For example, if an inundation polygon observed in the SPU data overlaps with an inundated area from the CRS results for a lower sea level, then this validated the polygon and provides a greater level of confidence in the SPU mapping for that location. Conversely, if an inundation polygon shown in the SPU data is not observed in the CRS data, then the inundation polygon is questionable, providing less confidence.

Figure 3-4 shows examples of assigned confidence categories based on the inundation mapping for 3 ft above MHHW. Citywide maps showing the spatial distribution of inundation area confidence categories and overlap between the CRS results and the inundation extents are provided in Appendix A.

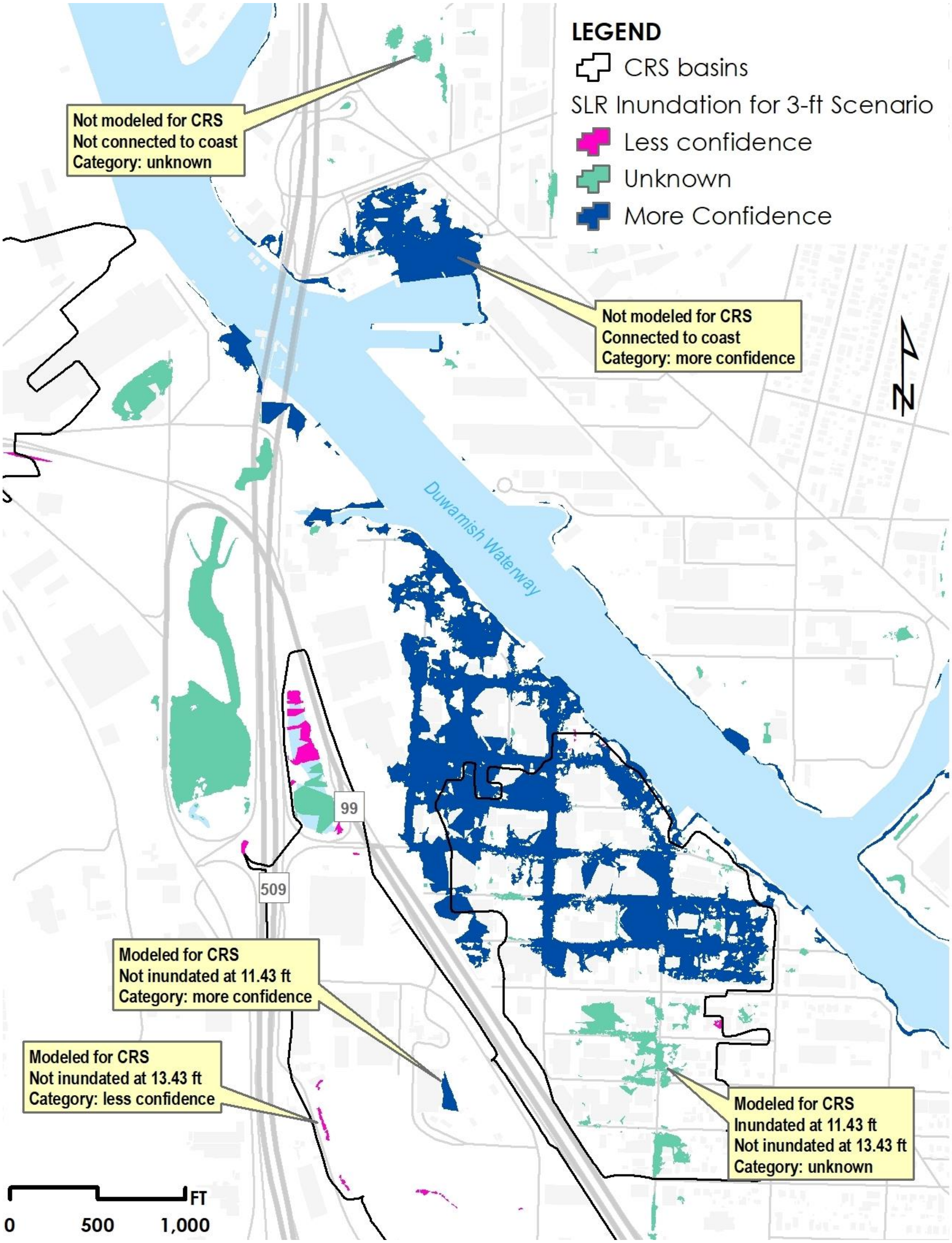

Figure 3-4. Examples of areas with different confidence categories for 3-ft SLR Scenario (12 ft NAVD88)

Confidence assessment depicted in figure was similarly performed for the other two SLR scenarios at elevations of 11 ft and 14 ft.

After performing the confidence assessment described above, the Consultant team found general agreement between the two data sets in the basins where they could be compared. A large portion of the city's coastal areas could not be assessed (marked as "unknown") because the CRS only covered areas deemed highly vulnerable. Inundation polygons marked as "unknown" confidence were included in the risk map. Only a small percentage of the SPU inundation polygons was determined to have "less confidence" and removed from the inundation area used for risk mapping (Table 3-3). Removing the small isolated areas of "less confidence" focuses attention on the areas with clear evidence for hydraulic connections to rising seas.

Table 3-2. Area in each Confidence Category and Used in Risk Mapping

SLR Scenario (ft above MHHW)	Inundation area in acres (percent of total)			
	Less confidence	Unknown	More confidence	Retained for Risk Mapping
2	7.6 (5.2%)	64 (44%)	75 (51%)	138.7 (94.8%)
3	2.2 (0.7%)	131 (44%)	162 (55%)	293.1 (99.3%)
5	2.0 (0.2%)	286 (32%)	605 (68%)	890.5 (99.8%)

3.3 Depth Calculations

The Consultant team calculated potential depths of inundation by creating static water surface elevation grid[4] for each SLR scenario (2, 3, and 5 ft above MHHW) and subtracting a ground surface elevation grid, or digital elevation model (DEM) representing topography across the city. SPU provided the DEM data, which was obtained from King County and the Puget Sound LiDAR Consortium as compiled and processed by Quantum Spatial (2016). While the original DEM was provided as a grid with a 2-ft cell resolution, the Consultant team performed spatial analyses at a 4-ft grid resolution[5]. Therefore, the DEM was resampled from the 2-ft grid to a 4-ft grid using the average elevation within the encompassed cells. Figure 3-5 is a schematic example showing how inundation depths were calculated at different spatial locations (cells) on the DEM.

[4] The Consultant team used ESRI ArcGIS software as a platform for geospatial data management and analyses. ArcGIS uses grids or "raster" datasets, where space is defined as an array of discrete cells and arranged in uniform rows and columns. Cells contain values representing characteristics of that location, such as a water surface elevation or the elevation of the earth surface.

[5] The Consultant team used the following coordinate system for geospatial data and analyses: Washington State Plane North, North American Datum of 1983 (NAD 83), adjusted for High Accuracy Reference Network (HARN), and units of feet.

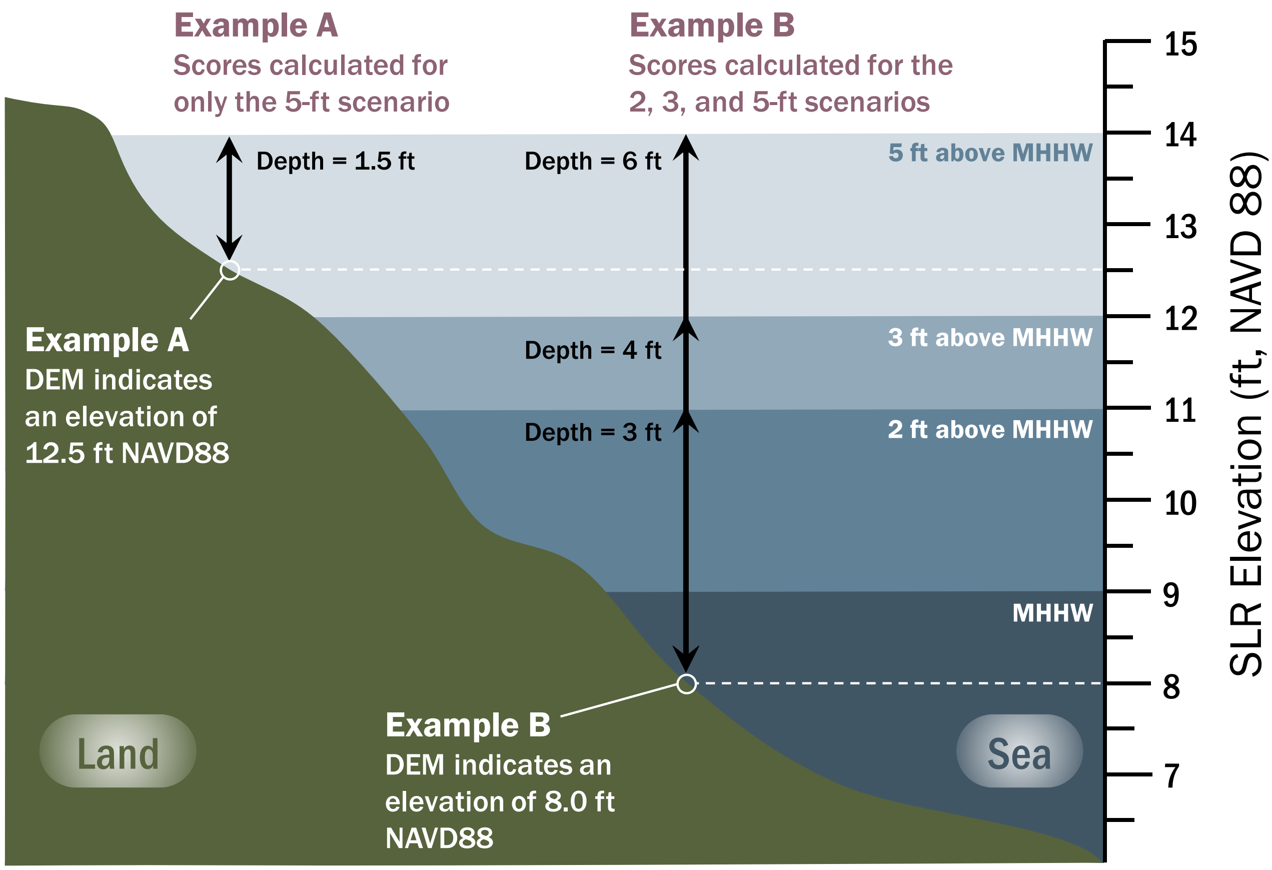

Figure 3-5. Illustration of Depth Estimation for Each Sea Level Inundation Extent

The extent of the spatial analysis and depth calculations was limited to the "land area" identified by SPU for this analysis. The boundary of the land area coincides with a minimum land surface elevation of 8 feet NAVD88. However, the data source used to delineate the land area does not consistently align with the elevations reflected in the DEM (at either a 2-ft resolution or a 4-ft resolution). As a result, there are narrow areas along the shoreline with calculated depths that are greater than what would be expected for a land area that does not fall below 8 ft NAVD88. For example, we would not expect to find inundation depths that exceed 3 ft for the 2-ft SLR scenario (11 ft minus 8 ft is approximately 3 ft). However, inundation depths for the 2-ft SLR scenario exceed 3 ft along the shoreline in several locations.

4. Risk Scoring

SPU developed an approach to calculating risk scores based on factors of consequence, likelihood, and equity. The prioritization criteria were developed based on SPU's *Risk Assessment Framework* (SPU 2007), staff subject matter expertise, and a review of past prioritization criteria developed and applied by SPU (SPU 2020). For any given risk area, a risk score is calculated as follows:

$$Risk\ Score\ = (Consequence\ Score\ \times\ Likelihood\ Score) + Equity\ Score$$

where the sum of all consequence scores does not exceed 5; the likelihood score ranges between 1 and 5, and the equity score ranges between 1 and 5. Resultant risk scores consequently range between 1 and 30. The following sections describe the process used to develop consequence, likelihood, and equity scores. Section 5 describes the calculation, mapping, and area-weighted distribution of these risk scores. Detailed GIS workflow processes of the scoring and risk mapping are provided in Appendix B.

4.1 Consequence Score

The Consultant team used the depth and inundation grids described in Section 3 and other consequence data to calculate consequence scores. The consequence score for any single location (i.e., a 4-ft-by-4-ft cell within the spatial grid) was calculated by adding a score associated with the depth of inundation (depth score) with three other component scores related to areas with potentially high consequences of flooding: high-use areas, critical facilities, and major transportation routes.

$$\begin{aligned} &Consequence\ Score \\ &\quad = Depth\ Score + High\text{-}use\ Area\ Score + Critical\ Facility\ Score \\ &\quad + \ Major\ Transportation\ Route\ Score \end{aligned}$$

The Consultant team calculated depth scores using the relationship shown in Figure 4-1, where a depth of 0.0 ft received a score of 0 and a depth of 3 ft or greater received a score of 3. Inundation depths between 0.0 ft and 3.0 ft were determined by linear interpolation.

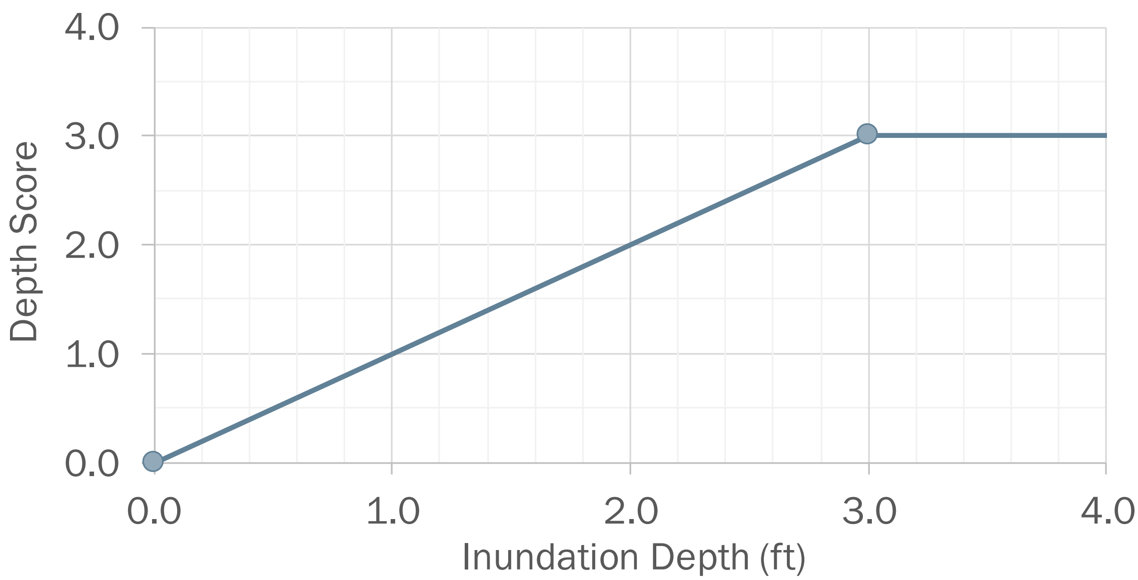

Figure 4-1. Relationship between inundation depth and depth score for use in risk scoring

Using the same 4-ft grid system as the inundation data, the Consultant team developed citywide geospatial grids with scores for each of the three other consequence component datasets:

- **High-use areas.** SPU provided the Consultant team with geospatial data representing areas likely to have a large number of pedestrians traveling through, relative to other areas of the city. These data consist of polygons representing areas with high pedestrian usage and polylines representing Neighborhood Greenways. The Consultant converted the latter to polygons based on the width of the right-of-way (ROW) and then merged with the high pedestrian usage areas to create a single high-use areas dataset. A binary grid was developed by giving grid cells with centroids falling within the mapped high-use areas a value of one (1) and all other cells were given a value of zero (0). Spatially distributed scores were then calculated by multiplying the binary grid by a value of 0.5, assigning high-use areas a consequence score of 0.5.
- **Critical facilities.** SPU provided the Consultant team with geospatial point locations representing critical facilities. The Consultant team downloaded polygons comprising King County's parcel data (King County 2018). Parcel polygon features containing one or more critical facility data points were selected. A binary grid was developed by giving grid cells with centroids falling within the selected parcel areas a value of one (1) and all other cells were given a value of zero (0). Spatially distributed scores were then calculated by multiplying the binary grid by a value of 1.5, assigning critical facilities a consequence score of 1.5.
- **Major transportation route.** SPU provided the Consultant with geospatial polylines representing snow and ice routes for Seattle Department of Transportation, which are indicative of the major arterials within the city. In addition, lines associated with freeways (e.g., Interstate 5, Interstate 90, and State Route 520) were selected from the City's streets geodatabase. All polylines were converted to polygons using the ROW width. A binary grid was developed by giving grid cells with centroids falling within the resulting polygons a value of one (1) and all other cells were given a value of zero (0). Spatially distributed scores were then calculated by multiplying the binary grid by a value of 1.5, assigning major transportation routes a consequence score of 1.5.

Table 4-1 summarizes the component scores used to calculate combined consequence score.

Table 4-1. Summary of Components of Consequence Score

Component	Score
High-use area	0.50
Critical facility	1.5
Major transportation route	1.5

By definition, parcel data (used to map critical facilities) do not overlap with ROW areas (used to map major transportation routes); therefore, a maximum score between critical facilities and major transportation routes is 1.5. Appendix C contains a memorandum describing the data SPU provided for this analysis. Appendix B provides additional information on the GIS processes used to develop citywide geospatial grids for calculating risk scores.

The Consultant team used the component scores described above to perform geospatial analyses and calculate a citywide grid representing the consequence score for each SLR scenario. The consequence score varies from 0 (representing an area outside the SLR inundation extent) to maximum of 5, which represents an area (a) with an inundation depth of at least 3 ft, (b) on a parcel with a critical facility or within the ROW of a major transportation route, and (c) within a high-use area.

4.2 Likelihood Score

Risk increases with the probability or "likelihood" of occurrence. Events that have a higher likelihood are expected to occur more frequently over a given time. Accordingly, SPU assigns higher likelihood scores to events that have a higher probability, or recurrence frequency, and lower likelihood scores to events that have a lower probability, or recurrence frequency.

Sea levels fluctuate with complex tidal cycles. While MHHW represents the daily high tide, more extreme tides are caused by longer-period lunar and solar orbits, which generate monthly and annual extremes. When looking at future tide levels, it is helpful to either select a future point in time to evaluate the likelihood at which specified water levels are expected to occur, or one can select a likelihood and evaluate the approximate timeframe over which that likelihood will manifest.

Using either frame of reference, a 2-ft rise in sea level is expected to occur more frequently, sooner than a 3-ft rise. Similarly, a 3-ft rise in sea level is expected to occur more frequently, sooner than a 5-ft rise. Accordingly, SPU assigned a maximum likelihood score of 5 to the SLR scenario with a 2-ft rise above MHHW, and a low score of 1 to the SLR scenario with a 5-ft rise above MHHW. The SLR scenario with a 3-ft rise above MHHW was assigned of score of 3.5 based on the projected year of occurrence for the elevation associated with 3 ft of rise to become MHHW (year 2020), relative to the projected year of occurrence for the elevation associated with 5 ft of rise to become MHHW (year 2170). Table 4-1 lists the SLR scenarios, approximate timeframes, and the selected likelihood scores.

Table 4-2. Likelihood Scores for SLR Risk Mapping

Future Sea Level		Tidal level occurrences and time frame			Frequency Score
Increase above MHHW[1] (ft)	Elevation relative to NAVD88 (ft)	MHHW	Monthly high tide	Annual extreme high tide	
2	11	2090	2050	current	**5**
3	12	2120	2090	2050	**3.5**
5	14	2170	2150	2120	**1**

1. *MHHW of 9.01 ft NAVD88 based on current data from: https://tidesandcurrents.noaa.gov/datums.html?id=9447130.*

4.3 Equity Score

An equity score is included to acknowledge that areas of racial and socioeconomic disparity are at a relative disadvantage to recover from an extreme event. SPU provided the City's Racial and Social Equity Composite Index geospatial mapping which has polygons representing 136 census tracts throughout the city. In these data, tracts were assigned an index based on racial diversity, demographics, health outcomes, and socioeconomic factors. The range of indices was divided into five equity categories which reflect levels of disadvantage. The tracts categorized as having the highest level of disadvantage were assigned a score of 5. The areas categorized as having the lowest level of disadvantage were assigned a score of 1. No areas were given a score of zero. Table 4-2 provides the equity score for each level of disadvantage.

Table 4-3. Equity Scores for the DSA	
Level of Disadvantage	**Equity Score**
Highest	**5**
Second highest	**4**
Middle	**3**
Second lowest	**2**
Lowest	**1**

All inundation areas given a score; no areas received a zero score.

When the risk score method was developed for the wastewater system capacity evaluation completed as part of the Wastewater System Analysis (WWSA), the equity score could have been incorporated into the consequence criteria. However, SPU decided to separate it out so that it could have greater influence on the risk score. SPU adopted the same risk score method for the DSA.

5. Results Summary

Sea levels will continue to rise in the coming decades, increasing the extent of potential coastal flooding and the likelihood that such flooding could occur. While the rates and timeframes of these changes are uncertain, the risk scoring method incorporates a range of SLR scenarios and likelihoods. This section summarizes the risk scores, mapping results, and areas that stand out as clusters of SLR risk. In addition, SPU and the Consultant team compared the potential future sea elevations (11 ft, 12 ft and 14 ft) with the elevations of tidally-influenced drainage and wastewater facilities.

5.1 Risk Map

The highest SLR scenario (5-ft rise above MHHW) extends furthest inland, and therefore, is the dominant factor in determining the extent of the risk area. Static water level inundation mapping for the 5-ft SLR scenario results in a total risk area of 750 acres, or approximately 1.4 percent of the city. The Consultant team applied the risk scoring methods described in Section 4 to the inundation areas (all three SLR scenarios) to calculate and map spatially variable risk scores at a 4-ft grid resolution. While areas inundated by a 2-ft rise are less extensive than areas inundated by a 5-ft rise, these areas tend to result in higher risk scores because they are multiplied by the maximum likelihood score of 5. Figure 5-1 shows the area-weighted distribution of risk scores for the SLR risk area.

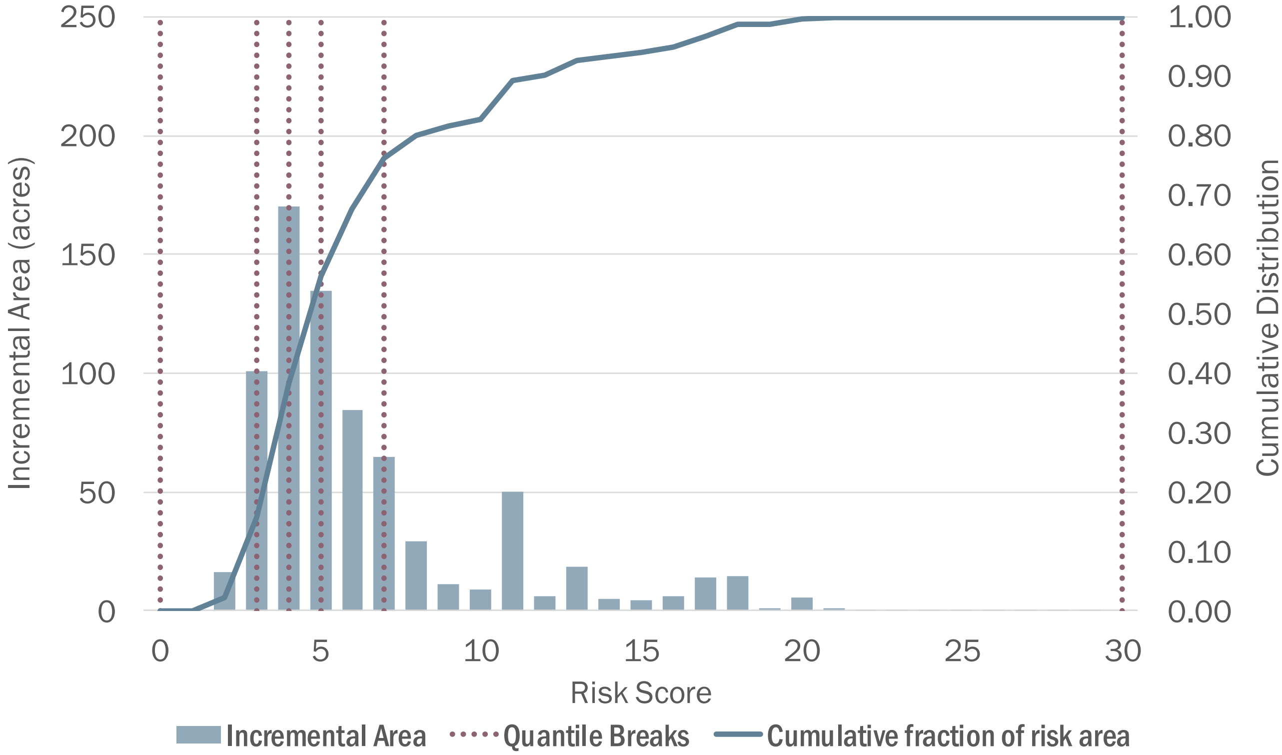

Figure 5-1. Distribution of risk scores within the SLR risk area

Once the scoring was complete, the Consultant team calculated the quantile breaks to map five categories of relative risk: low, medium low, medium, high, and critical. Figure 5-2 is an example map showing the risk categories. Table 5-1 lists the risk score ranges for each risk category. Citywide mapping of the SLR risk area and spatial distribution of risk scores are provided in Appendix D.

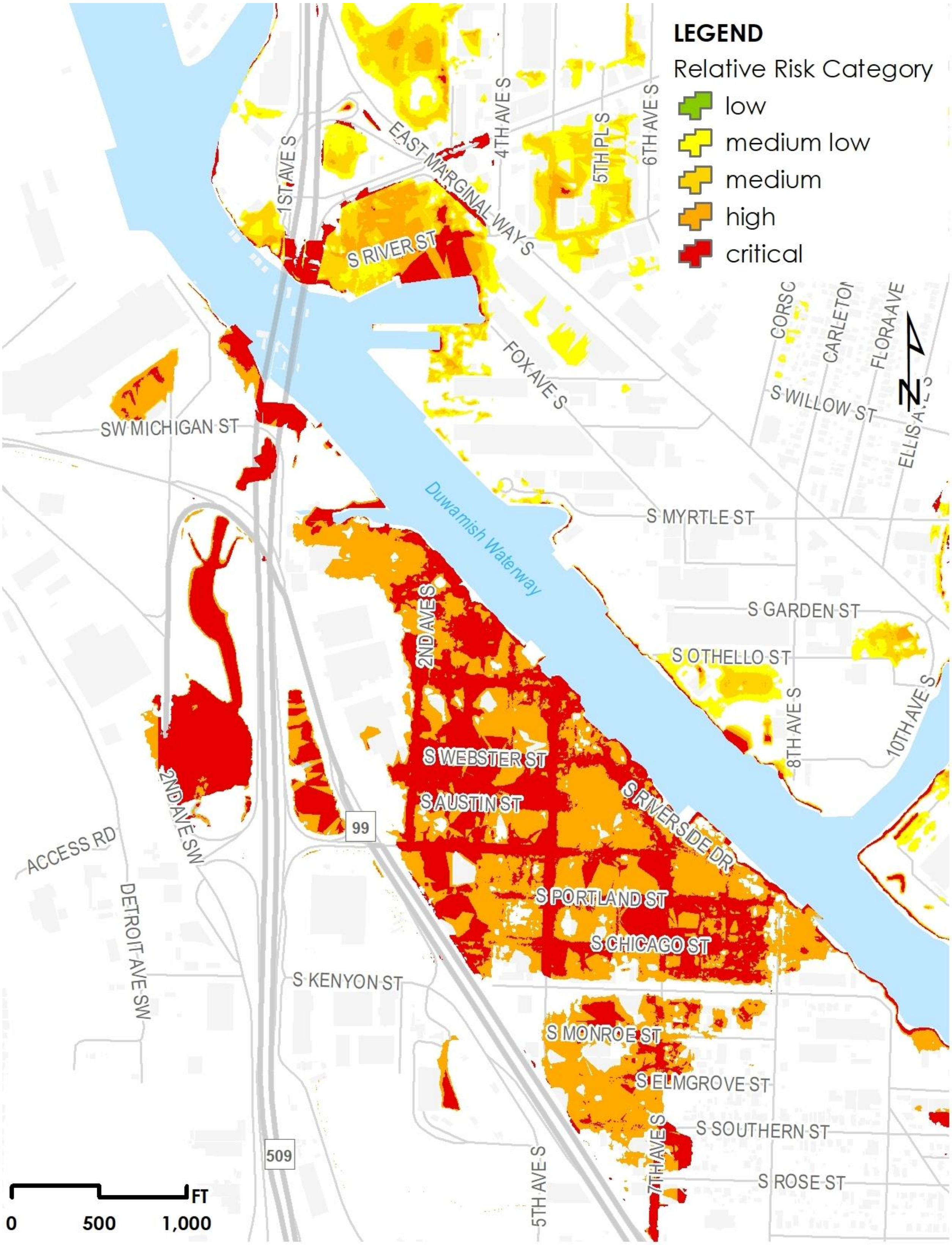

Figure 5-2. Example risk score map based on the SLR analysis

Table 5-1. SLR Risk Categories and Scores	
Risk category	**Risk score range**
Low	1 – 3
Medium low	3 – 4
Medium	4 – 5
High	5 – 7
Critical	7 – 30

The Consultant team prepared a GIS-compatible digital map package to accompany this TM. The digital map package contains the following citywide datasets:

- Inundation depth grids for 2-ft, 3-ft, and 5-ft SLR scenarios (floating point format)
- High-use areas, critical areas, major transportation routes (binary raster format)
- Equity categories (integer raster format)
- Risk area and risk scoring grid (floating point format)
- Risk categories (integer raster format)

5.2 Risk Area Clusters

Several low-lying areas within the city stand out as clusters of potential SLR risk. The following paragraphs briefly discuss such notable areas and explain why the risks may be mapped as high or critical.

- **Brace Point.** The SLR analysis and risk mapping indicate that land near Brace Point may be at risk to future SLR flooding due to low elevations and possible backwater through storm drains. There are no high-use areas, critical facilities, or major transportation routes in the Brace Point area; thus, the higher risks are primarily due to the depth of flooding. Some of the critical risks along the shoreline are influenced by land surface elevations below 8 ft NAVD88 as described in Section 3.3. Risk mapping for Brace Point is shown on the southwest area map in Appendix C.
- **Harbor Island.** The SLR analysis and risk mapping indicate that much of Harbor Island may be at risk to future SLR flooding due to low elevation. There are no high-use areas or critical facilities on Harbor Island and nearby major transportation routes are not inundated; thus, the high and critical risks are primarily due to inundation depths. Some of the critical risks along the piers are influenced by land surface elevations below 8 ft NAVD88 as described in Section 3.3. Risk mapping for Harbor Island is shown on the southwest and southeast area maps in Appendix C.
- **Duwamish Waterway south of Harbor Island.** The SLR analysis and risk mapping indicate that several locations along the Duwamish Waterway may be at risk to future SLR flooding due to low elevations. Critical risks near West Marginal Way and on Kellogg Island are due to the depth of inundation. On the east side of the Duwamish Waterway near Diagonal Ave S, SLR inundation encroaches on the parcel associated with Federal Center South, which is identified as a critical facility. Some of the other critical risks along the shoreline are influenced by land surface elevations below 8 ft NAVD88 as described in Section 3.3. Risk mapping for the Duwamish Waterway is shown on the southwest and southeast area maps in Appendix C.

- **South Park.** The SLR analysis and risk mapping indicate that several blocks in the northern portion of South Park may be at risk to future SLR flooding due to low elevations and possible backwater through storm drains. The high and critical risks shown in this area are primarily due to the depth of inundation. However, there is a major transportation route located along S Holden St and 5th Ave S. There are also some isolated critical risks in the portion of South Park mapped as a high-use area, and some of these areas touch critical facilities such as the South Park Branch Library. Risk mapping for the South Park area is shown on the southwest and southeast area maps in Appendix C.
- **Georgetown, Michigan Street.** The SLR analysis and risk mapping indicate that areas of Georgetown near 1st Ave S, East Marginal Way S, and along Michigan Ave may be at risk to future SLR flooding due to low elevations and possible backwater through storm drains. High and critical risks are primarily due to the depth of inundation; however, there are some fringe areas along major transportation routes. There is also a small critical risk area mapped at the St Vincent De Paul Georgetown Foodbank, which is a critical facility. Risk mapping for the Georgetown area is shown on the southwest and southeast area maps in Appendix C.
- **Georgetown, Boeing Field.** The SLR analysis and risk mapping indicate that areas along the west side of Boeing Field may be at risk to future SLR flooding due to low elevations and possible backwater through storm drains. Boeing Field is identified as a critical facility, which leads to critical risks in this area. Risk mapping for the Georgetown and Boeing Field area is shown on the southeast area map in Appendix C.
- **Interbay, Smith Cove.** The SLR analysis and risk mapping indicate that areas of Interbay near Smith Cove may be at risk to future SLR flooding due to low elevations and possible backwater through storm drains. There are no high-use areas or critical facilities on in the Smith Cove area of Interbay and nearby major transportation routes are not inundated; thus, the high and critical risks are primarily due to inundation depths. Some of the critical risks along the shoreline are influenced by land surface elevations below 8 ft NAVD88 as described in Section 3.3. Risk mapping for this location is shown on the northwest area map in Appendix C.
- **West Point.** The SLR analysis and risk mapping indicate that areas near the West Point lighthouse may be at risk to future SLR flooding due to low elevation. There are no high-use areas, critical facilities, or major transportation routes in this area; thus, the higher risks are primarily due to the depth of flooding. Only the lighthouse and historical buildings appear to be in the inundation extent. Some of the critical risks along the shoreline are influenced by land surface elevations below 8 ft NAVD88 as described in Section 3.3. Risk mapping for this location is shown on the northwest area map in Appendix C.
- **Meadow Point.** The SLR analysis and risk mapping indicate that areas near Meadow Point may be at risk to future SLR flooding due to low elevations along the shoreline. There are no high-use areas, critical facilities, or major transportation routes in this area; thus, the higher risks are primarily due to the depth of flooding. The only structure that appears to be in the inundation extent is the Golden Gardens Bathhouse. Some of the critical risks along the shoreline are influenced by land surface elevations below 8 ft NAVD88 as described in Section 3.3. Risk mapping for this location is shown on the northwest area map in Appendix C.

5.3 Tidally Influenced Facilities

Combined sewer systems can be influenced by high water levels at the outfalls. Elevations of tidally influenced wastewater facilities operated by SPU were compared to the sea level rise scenario elevations. These comparisons and when impacts could occur are provided in Table 5-2 and Table 5-3. The actual determination of occurrence would need to include the presence or absence of downstream preventative measures like flap gates. Table 5-2 lists wastewater pump stations (WWPS) and the National Pollution Discharge Elimination System (NPDES) basin the pump station is located in. It shows four WWPS may be experiencing impacts of SLR on an annual basis, due to water overtopping an overflow weir that is downstream of the pump station. With 5 ft of SLR above MHHW, all but two facilities are project to be impacted.

Table 5-2. Tidally Influenced Wastewater Pump Stations operated by SPU

WWPS ID	NPDES Basin	Approximate Location/Address	Overflow Weir Elevation (ft NAVD88)	SLR Scenario (ft above MHHW)		
				2	3	5
WWPS47	56	7242 Seaview Ave. NW 56	11.77		yes	yes
WWPS46	57	6541 Seaview Ave. NW 57	11.65		yes	yes
WWPS43	59	Seaview Ave. NW & NW 57th St	11.83		yes	yes
WWPS22	60	W. Cramer St. 5400 38th Ave. W. 60	11.42		yes	yes
WWPS77	64	32nd Ave. W at Logan Ave. W	12.07			yes
WWPS37	78	1751 Harbor Ave. SW at Fairmont Av SW	12.23			yes
WWPS36	80	1122 Harbor Ave. SW & SW Maryland Pl	10.81	yes	yes	yes
WWPS38	83	1411 Alki Ave. SW & SW Arkansas St	11.54		yes	yes
WWPS75	85	Alki Ave. SW & Point Pl SW	11.82		yes	yes
WWPS39	88	5080 Beach Dr. SW	10.78	yes	yes	yes
WWPS76	90	7025 Beach Dr. SW	12.01			yes
WWPS42	91	8617 Fauntleroy Way SW	11.78		yes	yes
WWPS70	94	Barton 2 4890 SW Barton St. 94	10.94	yes	yes	yes
WWPS72	-	SW Lander 2600 13th Ave. SW	10.44	yes	yes	yes
WWPS73	-	SW Spokane St. 1190 SW Spokane St.	11.05		yes	yes
WWPS71	-	SW 98th St. 5190 SW 98th St.	11.74		yes	yes
WWPS30	-	Esplanade 3206 NW Esplanade St.	15.89			
WWPS1	-	Fort Lawton 5645 45th Ave. W.	24.91			

Table 5-3 lists combined sewer overflow (CSO) facilities with their NPDES overflow ID. It shows six facilities may be experiencing impacts of SLR on an annual basis, due to water overtopping a downstream overflow weir. With 5 ft of SLR above MHHW, most facilities are projected to be impacted.

Table 5-3. Tidally Influenced CSO facilities operated by SPU

NPDES Overflow	Approximate Location/Address	Overflow Weir Elevation (ft NAVD88)	SLR Scenario (ft above MHHW)		
			2	3	5
61	2603 Perkins Lane W	12.03			yes
62	2603 Perkins Lane W	>37.18[a]			
68A	15th Av W & W Amour St	53.48			
68B	15th Av W & W Boston St	33.42			
69	Alaskan Way & Vine St	12.05			yes
70[b]	Alaskan Way & University St	11.94		yes	yes
71A[b]	Alaskan Way & Madison St	11.96		yes	yes
71B[b]	Alaskan Way & Columbia St	8.16	yes	yes	yes
72[b]	Alaskan Way & S Washington St	12.1			yes
95	Fauntleroy Way SW & SW Brace Pt Dr.	32.66			
99	26th Ave SW & SW Andover St	20.57			
107	S Spokane St & E Marginal Way	10.78	yes	yes	yes
111A	E Marginal Way & S Oregon St	8.78	yes	yes	yes
111B	S Oregon St & Ohio Av S	5.16	yes	yes	yes
111C	Colorado Av S & Denver Ave S	9.55	yes	yes	yes
111D	1st Av S & Diagonal Av S	10.3	yes	yes	yes
111H	10th Av S & S Oregon St	169.09			

a. NPDES 62 weir was raised and survey has not been completed yet, but it would not be impacted by any of the sea level rise scenarios.

b. NPDES 70, 71A, 71B, 72 will be consolidated into a single overflow point, NPDES 71, with an elevation of 12.0 ft (Waterfront Seattle Alaskan Way 100% Drawings, construction 2020-2021). With an elevation of 12.0 ft it would be impacted by SLR scenarios of 3 and 5 ft above MHHW.

The Consultant team performed a simple comparison of the water surface elevations for the 2-ft, 3-ft, and 5-ft SLR scenarios with the invert elevations for the drainage pipes in SPU's drainage models. The results indicate that approximately 6 percent of the drainage system is impacted by a 5-ft rise above current MHHW, and about 1 percent is impacted by a 2-ft rise (or the current annual extreme high tide). Table 5-4 shows the assets at risk under each level of inundation. The level of protection these assets receive from existing flap gates should be determined.

Table 5-4. Drainage Infrastructure potentially vulnerable to SLR

Inundation Level	Length of Pipe (mi)[a]	% of modeled system[b]
5 ft SLR above MHHW or 14 ft NAVD88	27.6	6%
3 ft SLR above MHHW or 12 ft NAVD88	2.5	1%
2 ft SLR above MHHW or 11 ft NAVD88	3.9	1%

a. "Pipes" were defined as a model conduit with a circular, filled circular or custom cross section.

b. Using the definition in 'a', 475 miles of pipe were modeled as part of DSA.

6. Limitations

The SLR risk maps and risk scoring data have been developed for informational purposes and to support the development of the ISP for SPU DWW. These data identify areas of the city that may be at higher risk of inundation due to sea level rise. Use and interpretation of these results requires an understanding of the assumptions and limitations associated with the analysis. As planning progresses and focuses more narrowly on specific areas of interest (e.g., clusters of risk), SLR assessments may need to be more advanced and refined to meet specific objectives. The following limitations have been identified for consideration:

- **Inundation areas are approximate and based on static water levels.** Areas impacted by coastal flooding depend on numerous factors including sea levels, tidal fluctuations, storm surge, wave setup, wave run-up, and dynamic wave conditions as rising water interacts with land and structures. Coastal flooding conditions could also be exacerbated by runoff from inland areas when high water levels coincide with rainfall events. However, results from the CRS (Aqualyze 2015) suggest that extreme tide levels are the dominant factor in coastal flooding, even during a 100-year rainfall event.

  Site-specific mitigation strategies or improvements should consider more detailed hydrologic and hydraulic analyses. For example, a project to reduce flooding risk at Brace Point (not studied in the CRS), may need to investigate the combined contributions of rising extreme tides, wave action, and inland stormwater runoff to determine design criteria and identify the most appropriate mitigation alternative for the project at the time of implementation and for the intended lifecycle.
- **Wastewater and drainage infrastructure were not explicitly evaluated.** Drainage and combined sewer systems are influenced by high water levels at the outfalls, and backwater can lead to inland flooding where prevention measures such as flap gates are not in place. The Consultant team used inundation mapping from the CRS (which did evaluate infrastructure) to check the inundation mapping used for this study; however, the CRS did not cover all areas of the city with drainage systems. For example, Brace Point was neither evaluated for the CRS nor have the physical conditions of the drainage infrastructure (e.g., inlets, outfalls, elevations, and potential flow paths) have been assessed for this study.
- **Factors contributing to impacts and consequences are simplified for relative scoring.** Risk scores are relative and should not be used for risk cost analysis. Flooding risk is often quantified in terms expected annual damage for project planning. In such cases, flooding damage is estimated based on a wide range of event frequencies and a wide range of structural and economic impacts. A detailed risk cost analysis is impractical at a city scale and is generally not necessary for mapping relative risk areas. As mitigation or resiliency strategies are developed, detailed estimates of expected annual damages may be beneficial.
- **Inundation areas were not compared to known or possible soil contamination sites.** The risk scoring method did not include a consequence score associated with inundation of soil contamination. Future work could include accounting for risk associated with these areas.

- **Topographic data and geospatial processes used to calculate risk scores are approximate.** Inundation depths were calculated using LiDAR-based DEM data. The accuracy of LiDAR airborne surveys can be limited by thick vegetation, dense clouds, high-reflectance surfaces, or water bodies. In addition, DEMs produced as 2-ft grids were reduced to a 4-ft grid resolution for geospatial processing. At 2-ft and 4-ft resolutions, DEMs may not reflect minor structures, small surface features, or microtopographic variations.
- **Equity score has less influence, when compared to capacity analyses completed for the WWSA and DSA, on the risk score.** When the risk score method was developed for the WWSA, SPU decided to separate it out from the consequence component of the score, so that it could have greater influence on the risk score. For the sea level rise risk map, however, it has less influence on the final score when compared to the individual scores of the few consequence score components. For example, for highest frequency events, a critical facility contributes more than the equity score, to the risk score.

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Appendix A: Inundation Confidence Review

Northeast quadrant not included because there are no inundation areas mapped within that area.

ArcGIS map package for these figures provided in digital format.

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Figure A-1. 2-ft SLR Inundation Review, SW

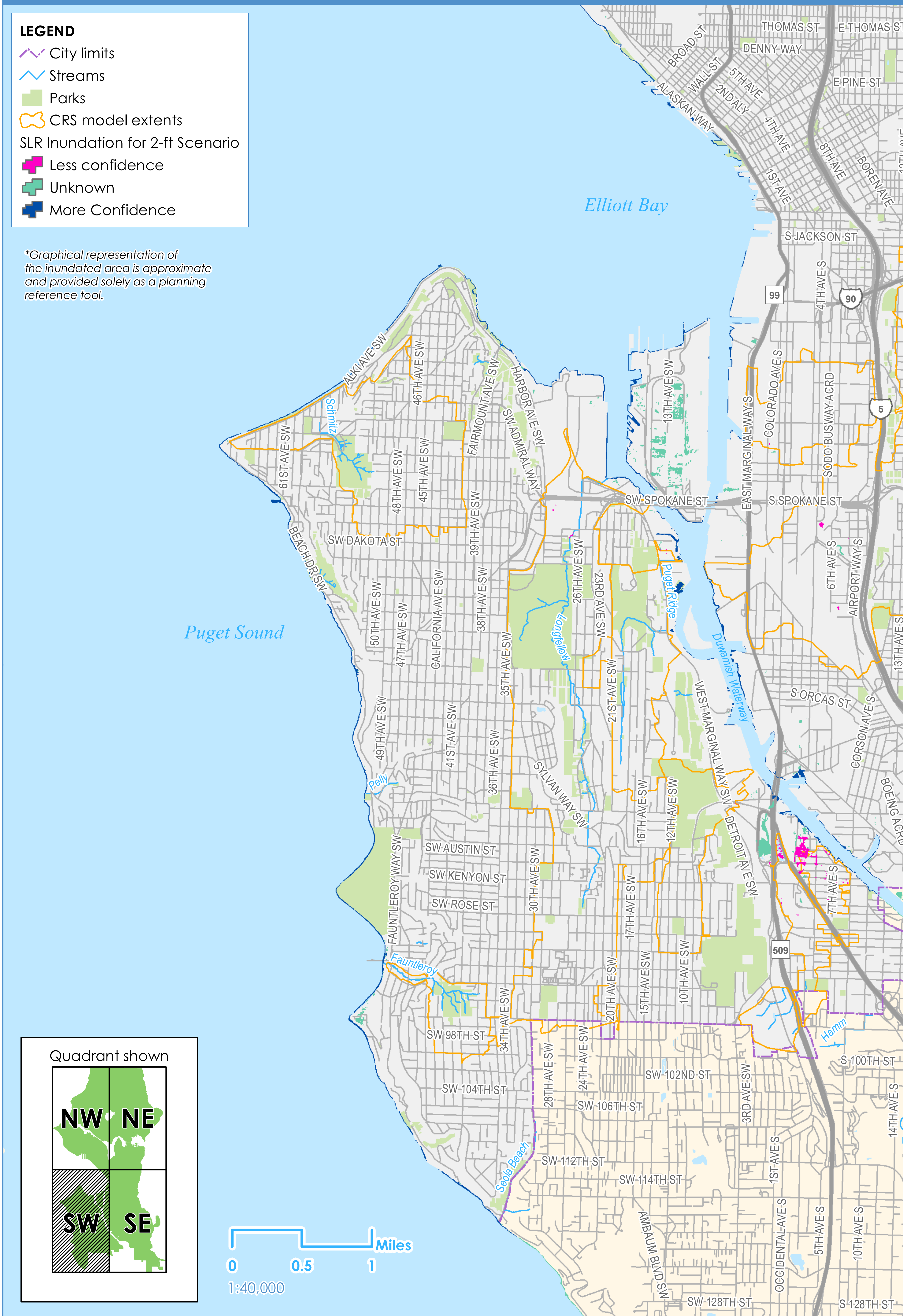

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Figure A-2. 2-ft SLR Inundation Review, SE

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Figure A-3. 2-ft SLR Inundation Review, NW

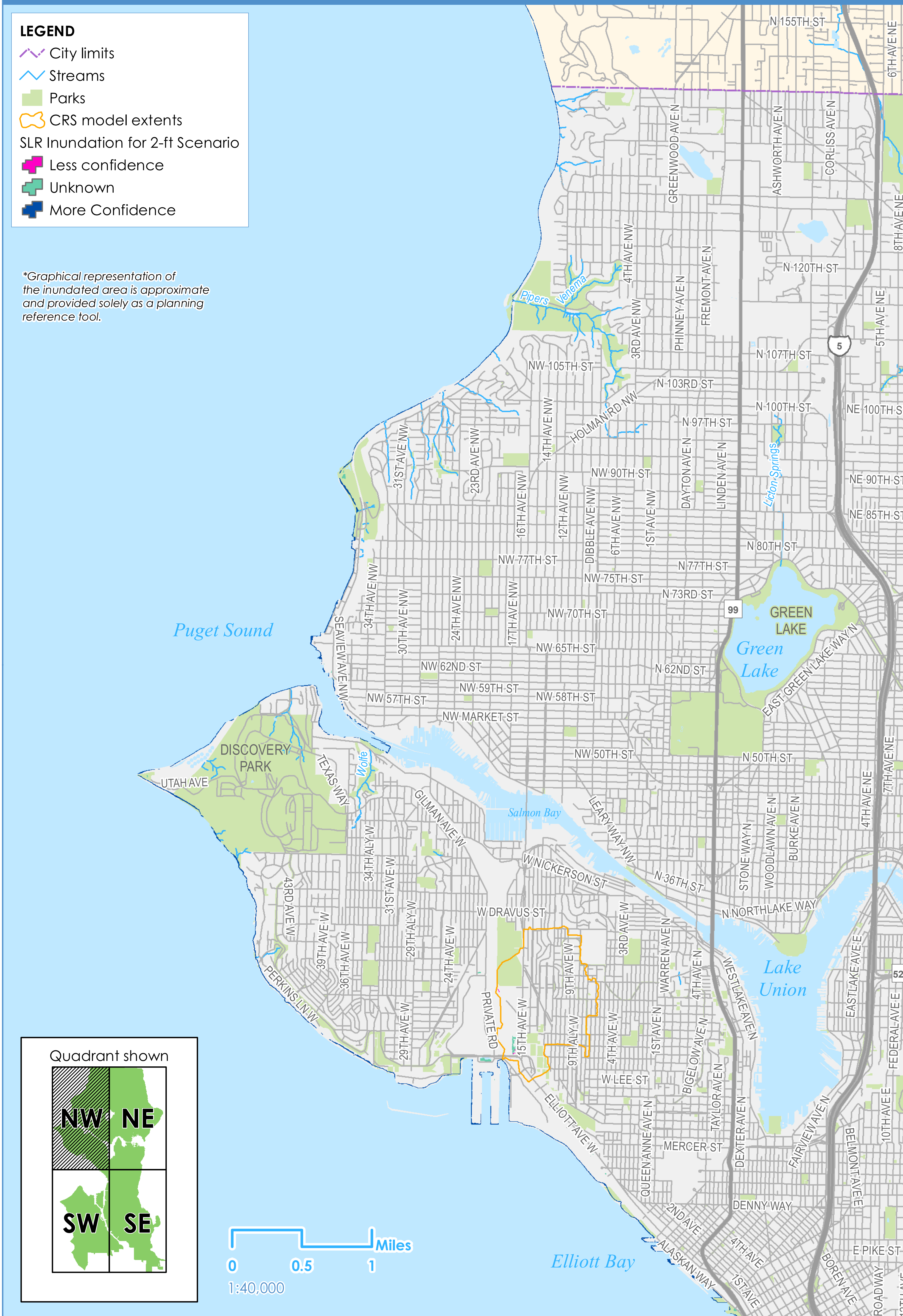

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Figure A-4. 3-ft SLR Inundation Review, SW

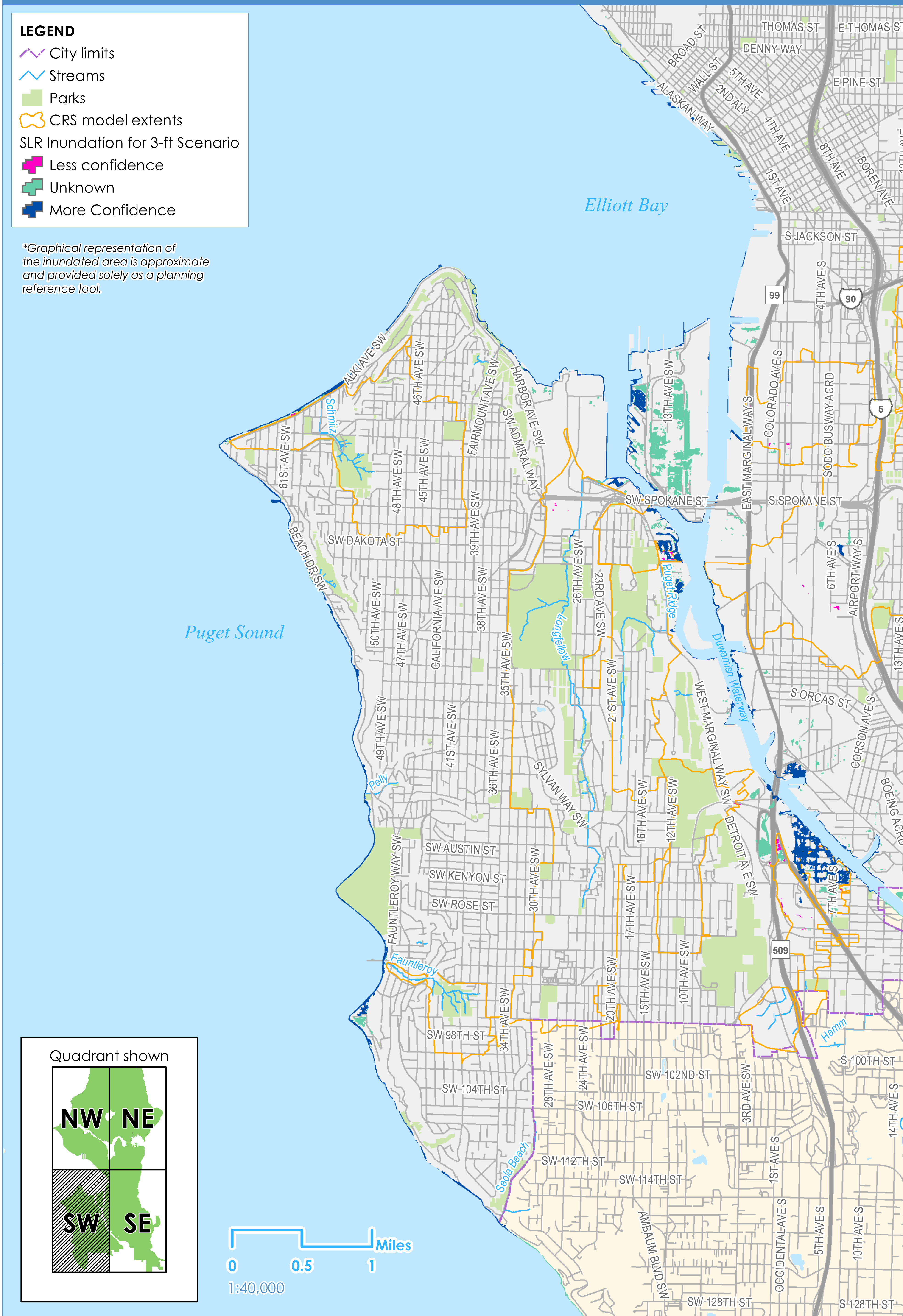

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Figure A-5. 3-ft SLR Inundation Review, SE

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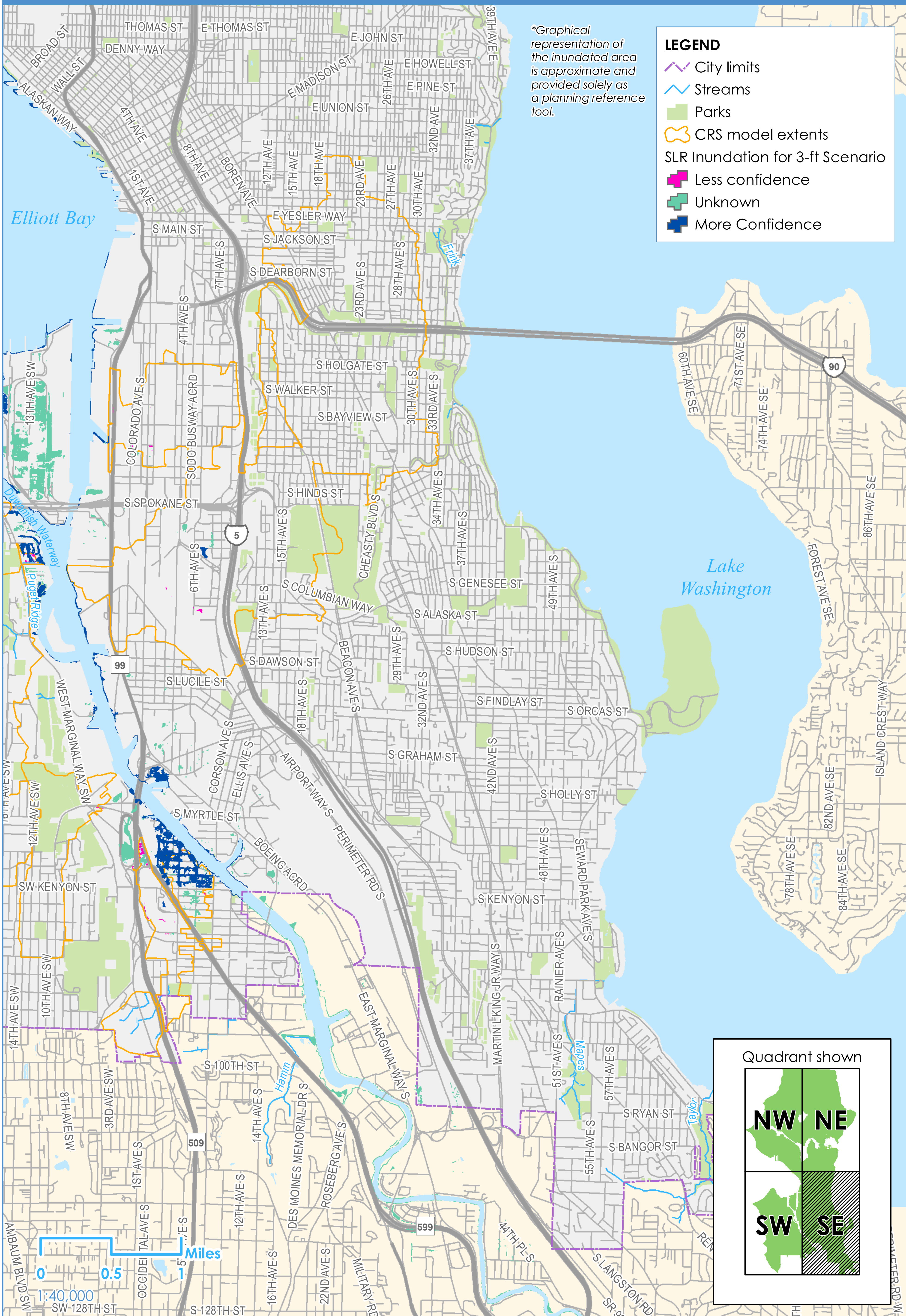

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Figure A-6. 3-ft SLR Inundation Review, NW

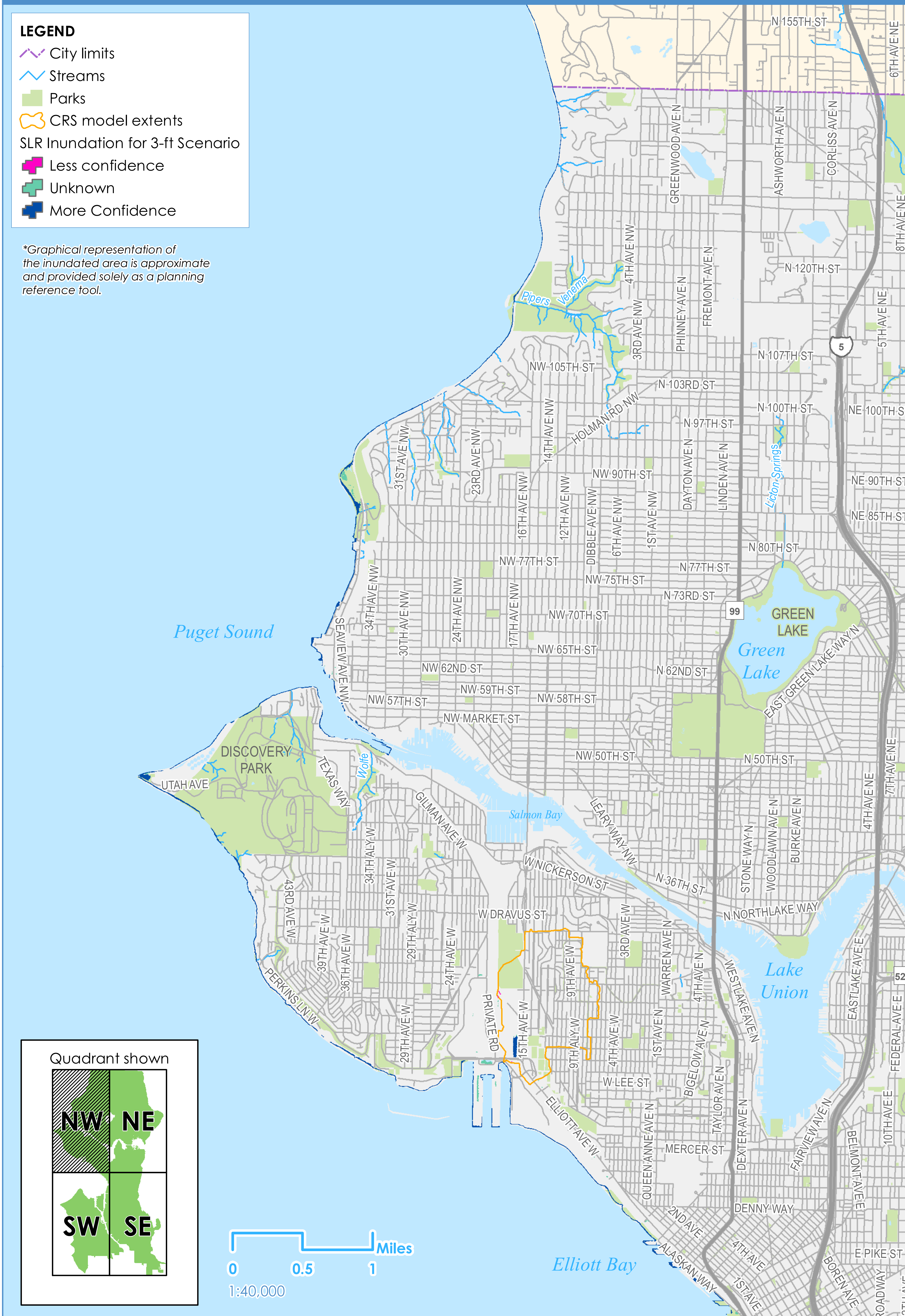

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Figure A-7. 5-ft SLR Inundation Review, SW

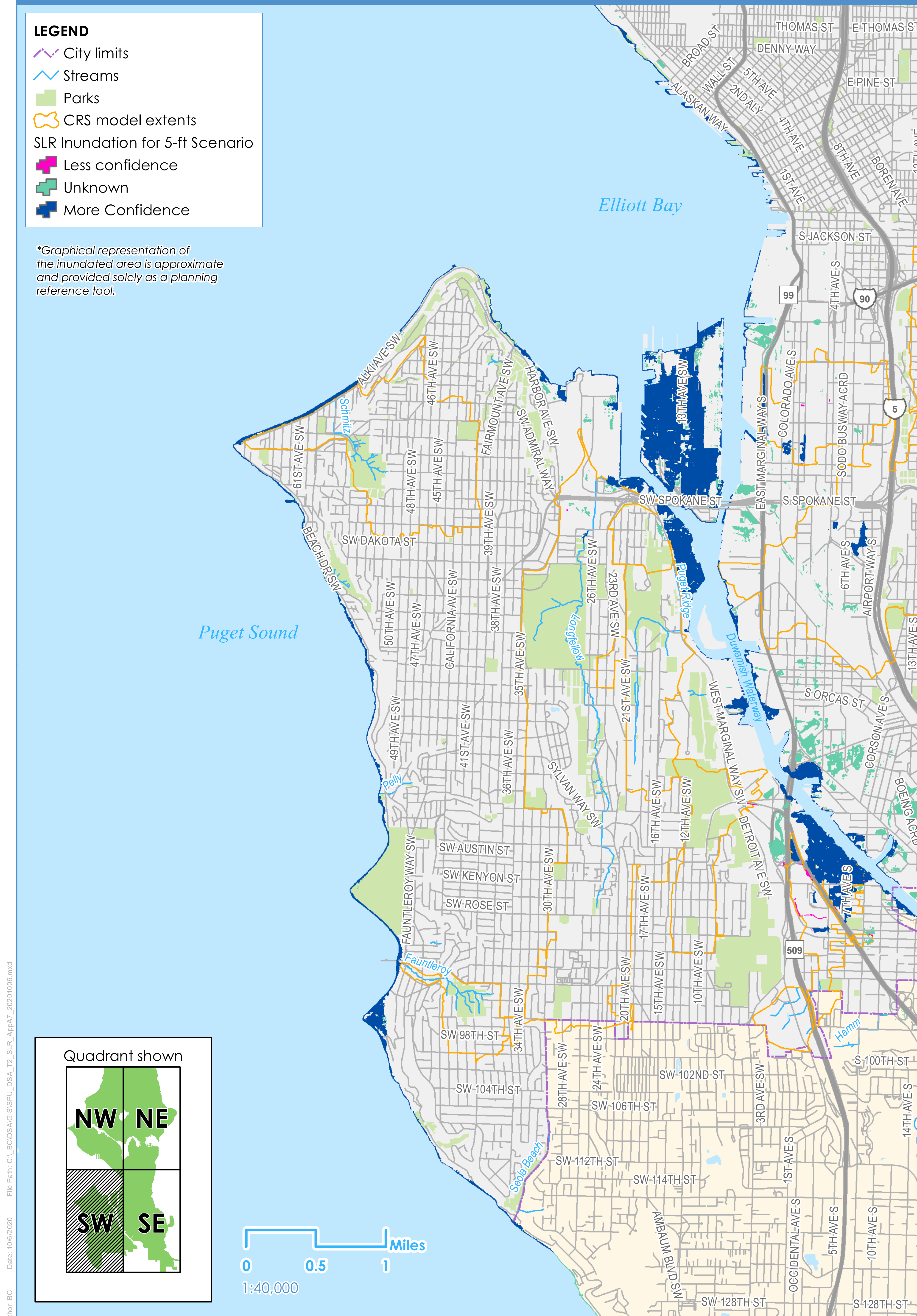

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Figure A-8. 5-ft SLR Inundation Review, SE

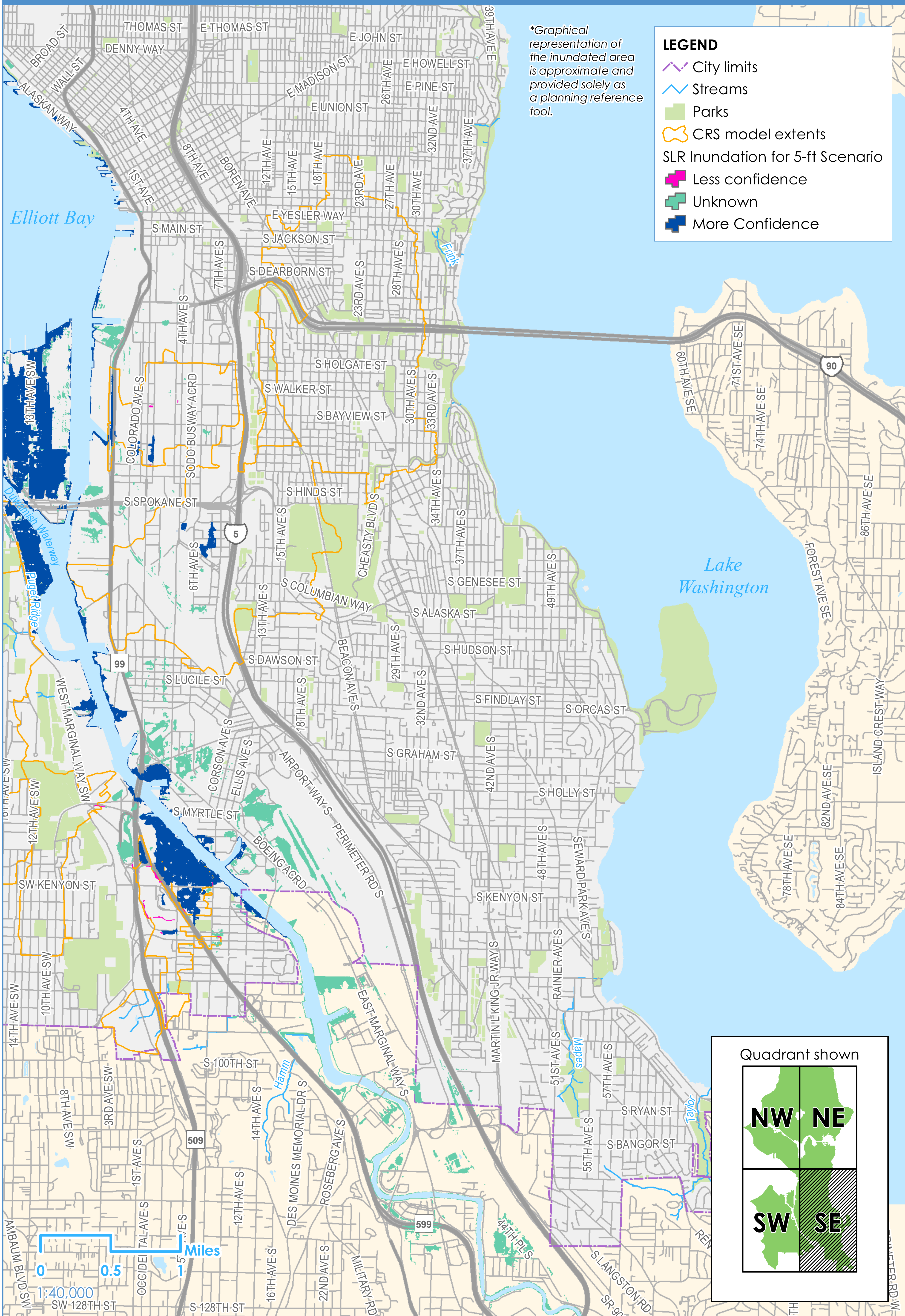

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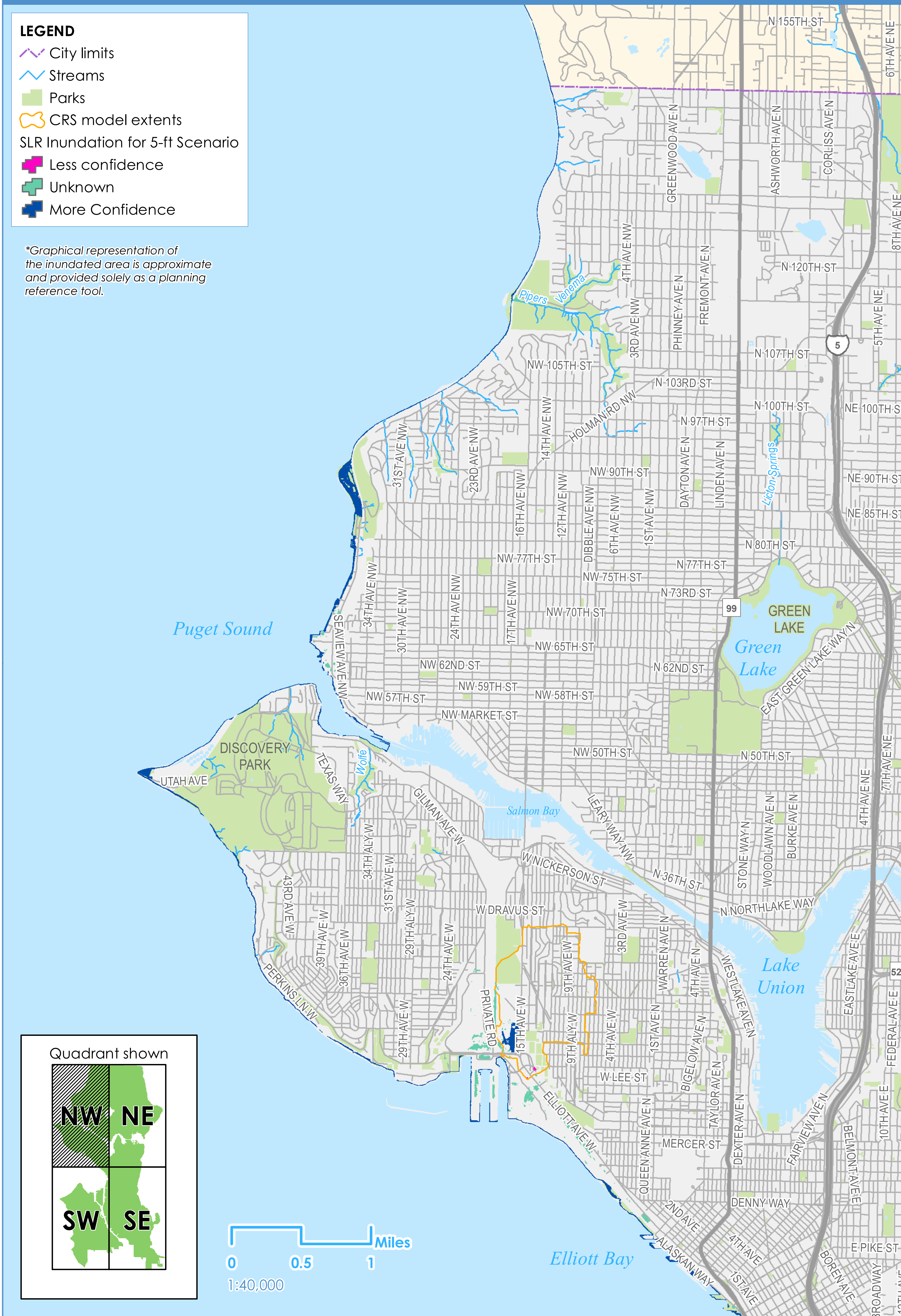
Figure A-9. 5-ft SLR Inundation Review, NW



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Appendix B: Geospatial Analysis

Geoprocessing Coordinate System
NAD_1983_HARN_StatePlane_Washington_North_FIPS_4601_Feet
WKID: 2926 Authority: EPSG
Projection: Lambert_Conformal_Conic
False_Easting: 1640416.666666667
False_Northing: 0.0
Central_Meridian: -120.8333333333333
Standard_Parallel_1: 47.5
Standard_Parallel_2: 48.73333333333333
Latitude_Of_Origin: 47.0
Linear Unit: Foot_US (0.3048006096012192)
Geographic Coordinate System: GCS_North_American_1983_HARN
Angular Unit: Degree (0.0174532925199433)
Prime Meridian: Greenwich (0.0)
Datum: D_North_American_1983_HARN
Spheroid: GRS_1980
Semimajor Axis: 6378137.0
Semiminor Axis: 6356752.314140356
Inverse Flattening: 298.257222101

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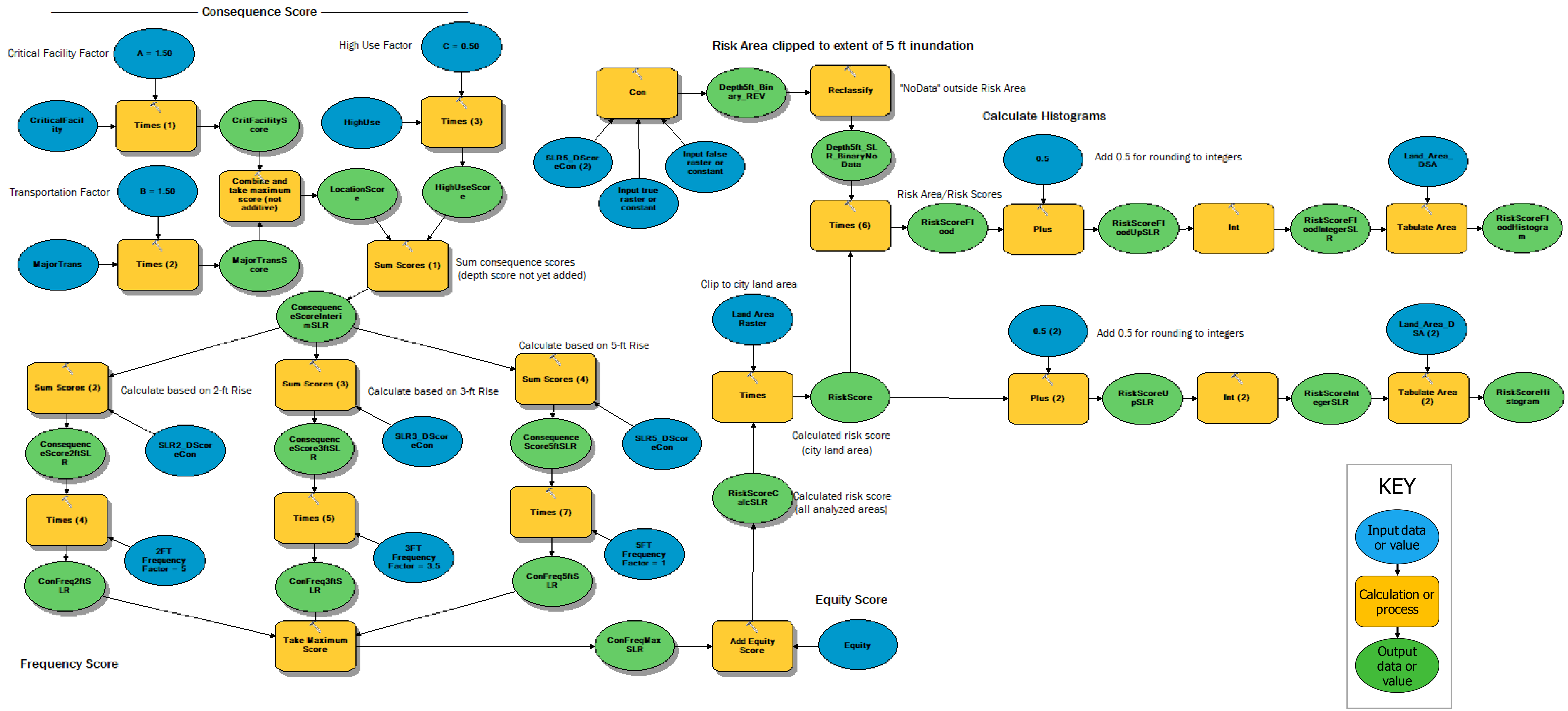

Figure B-1. ArcGIS Model Builder for SLR Risk Scoring

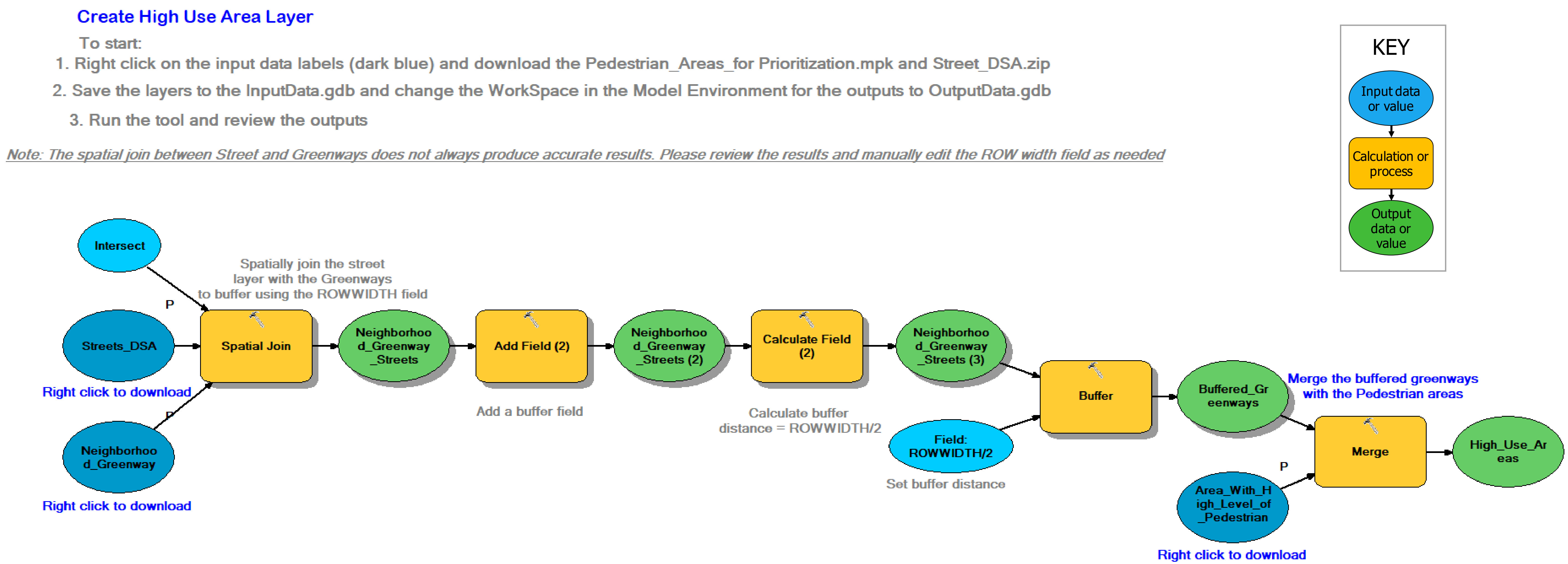

Figure B-2. ArcGIS Model Builder for Developing High-Use Area Raster

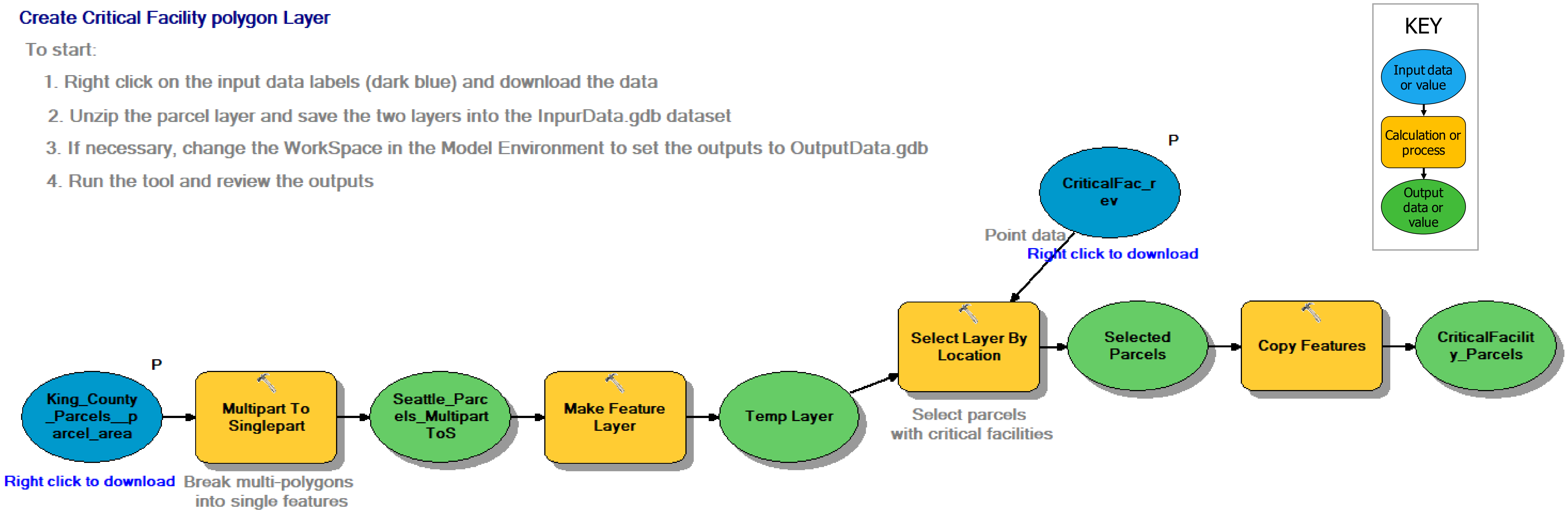

Figure B-3. ArcGIS Model Builder for Developing Critical Facility Area Raster

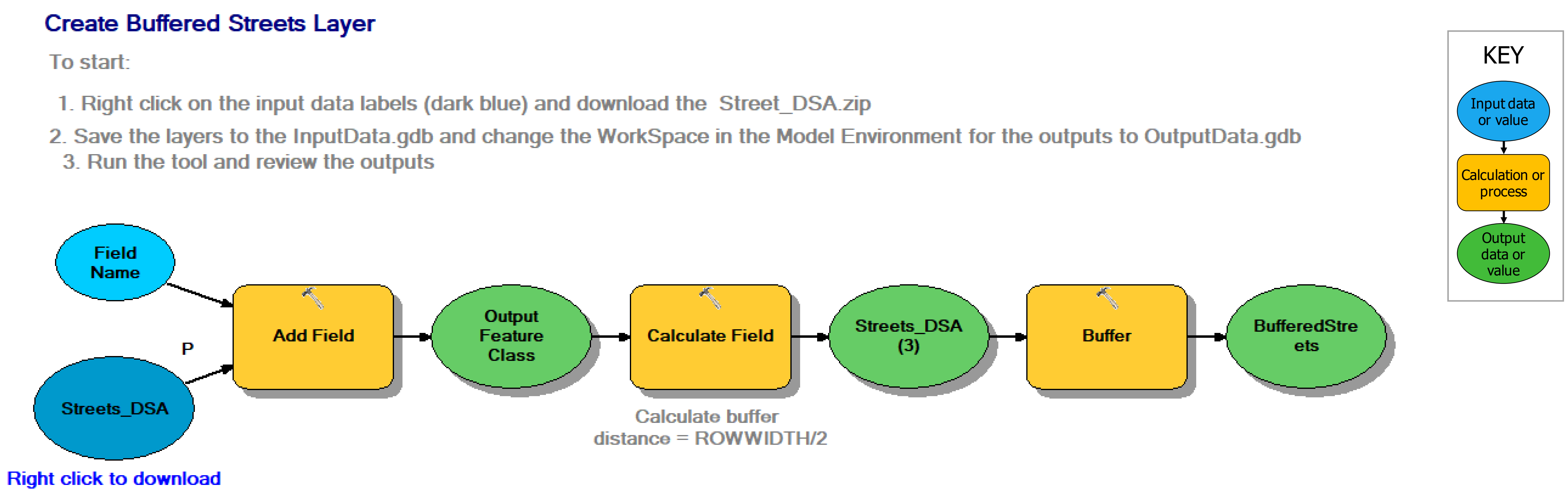

Figure B-4. ArcGIS Model Builder for Developing Street Buffers for Major Transportation Routes Raster

Create Equity Layer:

To start:

1. Right click on the input data labels (dark blue) and download Racial and Social Equity Composite Index - 2018.zip
2. Unzip the shapefile and add to the InputData.gdb database
3. If necessary, change the WorkSpace in the Model Environment to set the outputs to OutputData.gdb
4. Run the tool and review the outputs

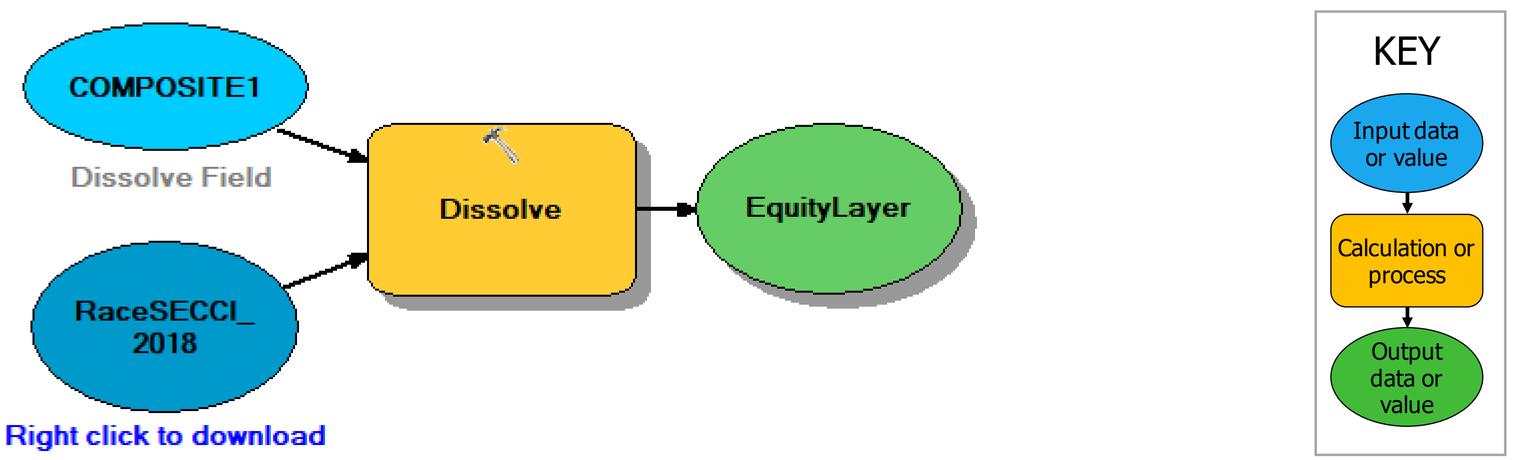

Figure B-5. ArcGIS Model Builder for Developing Street Equity Raster

Appendix C: Risk Map Spatial Data

Seattle Public Utilities (SPU). 2020. GIS data for Risk Mapping and Prioritization for the System Analyses Projects. Memorandum from Colleen O'Brien to project file, dated July 17, 2020.

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Seattle Public Utilities

Memorandum

Date: 7/17/20

To: Project File

From: Colleen O'Brien

Re: GIS data for Risk Mapping and Prioritization for the System Analyses Projects

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This memorandum describes the GIS data used in developing risk scores for the Wastewater System Analysis (WWSA) and Drainage System Analysis (DSA), particularly the DSA Sea Level Rise risk map.

For each data set it includes:

- For the source data, summarized in Table 1:
  - Description
  - Source and date
  - Storage location
  - What data set it became part of or was used to create (process data) for an analysis or map
- For processed data, summarized in Table 2:
  - Description, including how it was modified from the source data
  - Storage location (includes network drive location and may include a SharePoint location)
  - Date of the file
  - Which analysis it was used in

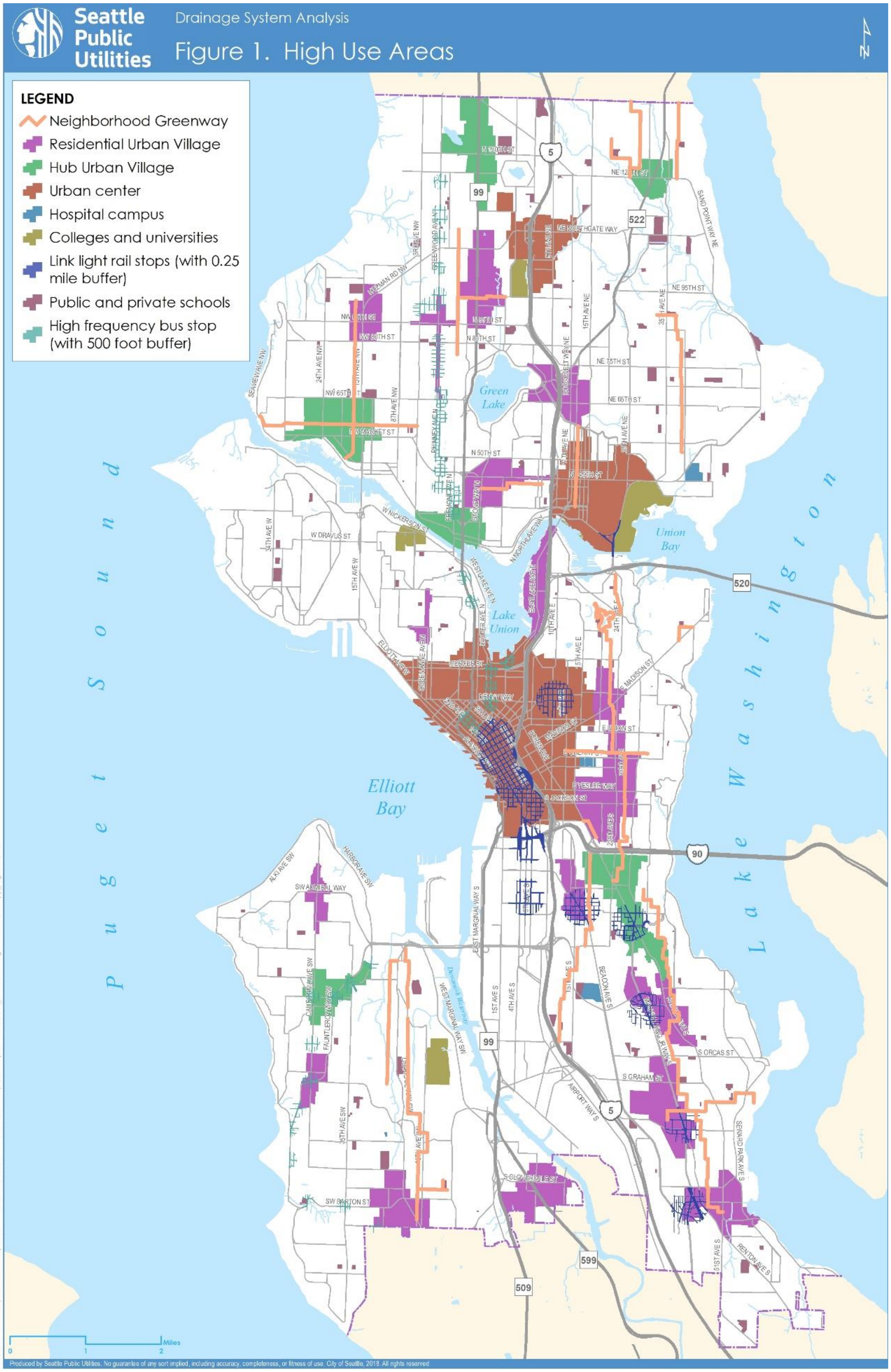
Table 1. GIS Source Data used in Risk Mapping and Prioritization for the System Analyses Projects

Name	Description	Source	Date	Storage Location	Name of Analysis Data Set Used In
City of Seattle	Polygons of city limits, land, and water bodies. Does not extend far enough east to include Mercer Island or Bellevue landforms. This feature class reflects the visual interface between land and water based upon our 1993 ortho photos. It essentially follows the 8 foot contour line, except where the ortho offered further clarification. That 8 foot contour line matches closest to what NAVD88 shows as "mean high water" (see official definition below) at 7.97 feet. MEAN HIGH WATER (MHW): "A tidal datum. The average of all the high water heights observed over the National Tidal Datum Epoch. For stations with shorter series, simultaneous observational comparisons are made with a control tide station in order to derive the equivalent datum of the National Tidal Datum Epoch."	City	3/18/20 (downloaded from Seattle Tools)	*Seattle Tools*, Streets (CARTO.SHORE)	land area
Colleges and universities (Figure 1)	Boundaries of colleges and universities in the city of Seattle.	City	Sept 2018	*Seattle Tools*, Colleges and Universities (CARTO.COLLEGE)	high use area
Critical facilities (Figure 2)	Provide services and functions essential to a community, especially during and after a disaster.	OEM	10/8/2018 (received from OEM)	*X:\Separated Systems\Business_Areas\Planning\DSA\analysis\CriticalFacilities* Critical Facilities (OEM).txt	critical facilities
High frequency bus stops (Figure 1)	On-street location where transit vehicles stop inline to pick-up and discharge passengers.	KC Metro	Sept 2018	*Seattle Tools*, King County Metro Bus Stop, Active & In Service (KCGIS.TransitStop_point)	high use area
Hospital campuses (Figure 1)	Boundaries of licensed acute care hospitals and associated buildings.	City	Sept 2018	*Seattle Tools*, Hospitals (CARTO.HOSPITAL)	high use area
King County parcels	Tax parcels polygons in King County.	KC	1/14/2018 (downloaded from website)	*https://gis-kingcounty.opendata.arcgis.com/datasets/8058a0c540434dadbe3ea0ade6565143_439*	properties and critical facilities
Link light rail stops (Figure 1)	Contains the entire set of existing Central Link, University Link, and Airport Link light rail station points located in the City of Seattle from Northgate Mall to SeaTac Airport.	ST	Sept 2018	*Seattle Tools,* Sound Transit Link Light Rail Stations (CARTO.LinkStations)	high use area
Neighborhood Greenways (Figure 1)	Safer, calmer residential streets that can include: • easier crossings of busy streets with crosswalks, flashing beacons, or crossing signals • speed humps to calm traffic • stop signs for side streets crossing the greenway • signs and pavement markings to help people find their way • 20 mph speed limit signs	SDOT	Sept 2018	*P:\PrjMgmt\C316073 2018 Wastewater System Analysis\02-Plan Inputs\G-GIS\To Aqualyze* Prioritization-Layers.mpk	high use area
Public and private schools (Figure 1)	Parcels that contain kindergarten through 12th grade public and private schools approved through the Washington State Board of Education.	City	Sept 2018	*Seattle Tools*, Public School and Private School (CARTO.PRIV_SCH and CARTO.PUB_SCH)	high use area

Name	Description	Source	Date	Storage Location	Name of Analysis Data Set Used In
Racial and Social Equity Composite Index (Figure 3)	Census tract-based data that consists of a composite of the following sub-indices: • Race, English Language Learners, and Origin Index ranks census tracts by an index of three measures weighted as follows: (shares of population who are) - persons of color (weight: 1.0) - English language learners (weight: 0.5) - foreign born (weight: 0.5) • Socioeconomic Disadvantage Index ranks census tracts by an index of two equally weighted measures: (shares of population with) - income below 200 percent of poverty level - educational attainment less than a bachelor's degree • Health Disadvantage Index ranks census tracts by an index of seven equally weighted measures: - no leisure-time physical activity - diagnosed diabetes - obesity - mental health not good - asthma - low life expectancy at birth - disability	OPCD	2018 (DSA) 2017 (WWSA)	DSA *DWW GIS Library (DSA) on SharePoint* Racial and Social Equity Composite Index – 2018.zip (RaceSECCI_2018.shp) *X:\Separated Systems\Business_Areas\Planning\DSA\data\Impacts* RaceSECCI_2018.shp WWSA *P:\PrjMgmt\C316073 2018 Wastewater System Analysis\02-Plan Inputs\G-GIS\To Aqualyze* Prioritization-Layers.mpk	Racial and Social Equity Composite Index
Residential and Hub Urban Villages (Figure 1)	Areas in the city with residential development as well as a broad mix of uses with lower densities than urban centers. (See the Comprehensive Plan 20-year Growth Strategy, http://www.seattle.gov/Documents/Departments/OPCD/OngoingInitiatives/SeattlesComprehensivePlan/CouncilAdopted2016_CitywidePlanning.pdf)	OPCD	Sept 2018	*Seattle Tools*, Urban Centers, Villages, Manufacturing Industrial Centers (CITYPLAN.URBAN_VILLAGE_CENTER_MIC)	high use area
Snow and ice routes (Figure 4)	City of Seattle streets covered under SDOT's Winter Storm Response Plan, showing snow and ice removal routes.	SDOT	9/21/18 (downloaded from Seattle Tools)	*DWW GIS Library (DSA) on SharePoint* SDOT_snowice.zip (SDOT_snowice.shp) *X:\Separated Systems\Business_Areas\Planning\DSA\data\Impacts* SDOT_snowice.shp	major transportation routes and street type
Streets	The City's Street Network Database showing driveable public streets within the Seattle city limits.	SDOT	1/24/2020 (downloaded from Seattle Tools)	*Seattle Tools*, Streets (SDOT.STREETS)	streets

Name	Description	Source	Date	Storage Location	Name of Analysis Data Set Used In
Urban center (Figure 1)	Densest developed areas in the city with the widest range of land uses. (See the Comprehensive Plan 20-year Growth Strategy, http://www.seattle.gov/Documents/Departments/OPCD/OngoingInitiatives/SeattlesComprehensivePlan/CouncilAdopted2016_CitywidePlanning.pdf)	OPCD	Sept 2018	*Seattle Tools*, Urban Centers, Villages, Manufacturing Industrial Centers (CITYPLAN.URBAN_VILLAGE_CENTER_MIC)	high use area

OPCD = Office of Community Planning and Development
City = City of Seattle
ST = Sound Transit
KC = King County
SDOT = Seattle Department of Transportation
OEM = Office of Emergency Management
DWW GIS Library (DSA) on SharePoint = *https://seattlegov.sharepoint.com/:f:/r/sites/spu-D1/Planning/DWW%20GIS%20Library/DSA/Data/SPU?csf=1&web=1&e=UBk4k2*


Seattle Public Utilities
Drainage System Analysis
Figure 1. High Use Areas
LEGEND
Neighborhood Greenway
Residential Urban Village
Hub Urban Village
Urban center
Hospital campus
Colleges and universities
Link light rail stops (with 0.25 mile buffer)
Public and private schools
High frequency bus stop (with 500 foot buffer)
Puget Sound
Lake Washington
Elliott Bay
Lake Union
Green Lake
Union Bay
Miles
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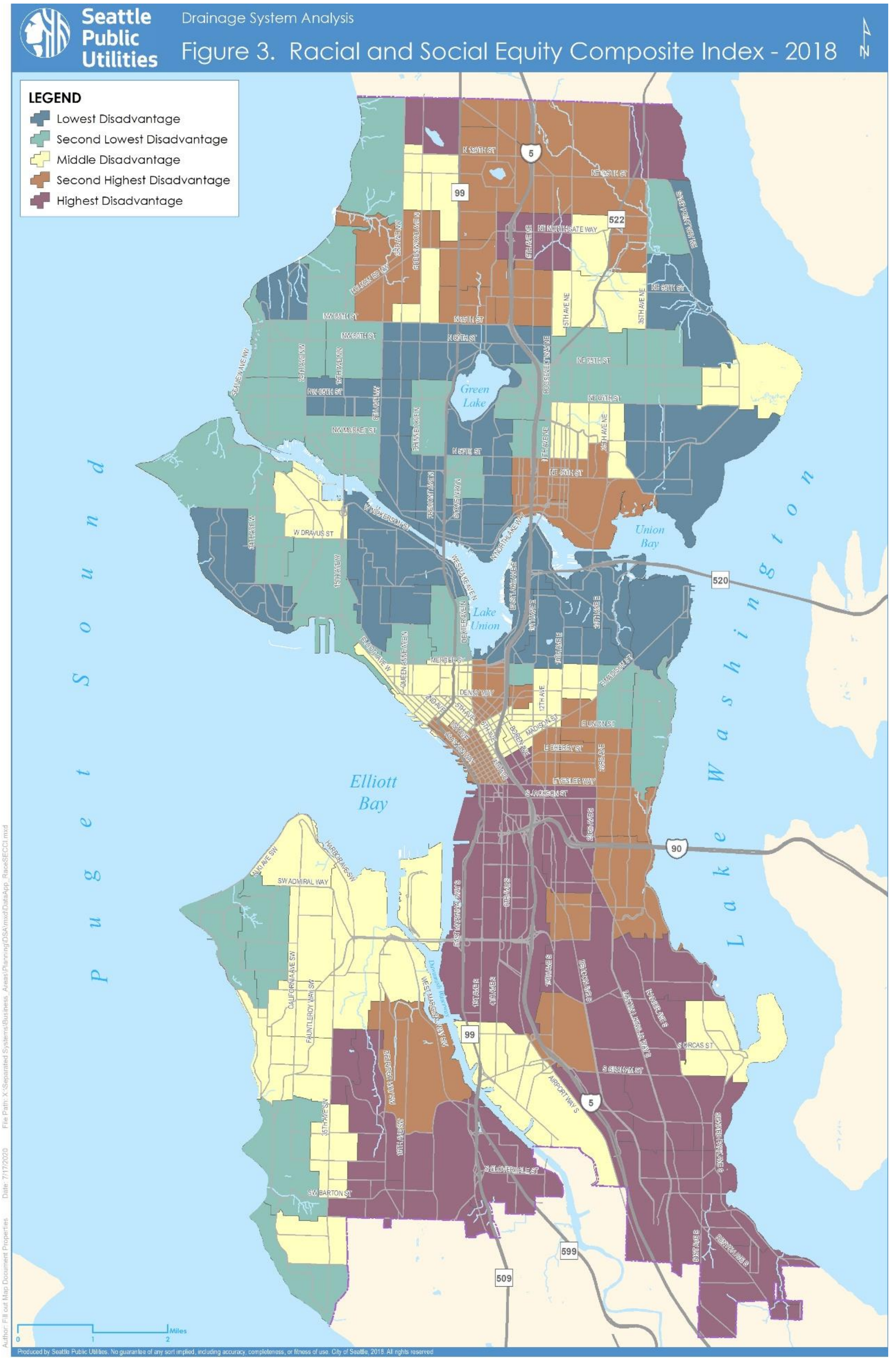
Seattle Public Utilities
Drainage System Analysis
Figure 2. Critical Facilities
LEGEND
Emergency Services
High Population
Human Services
Medical
Protective
Support
Transportation
Vulnerable Population
Puget Sound
Elliott Bay
Green Lake
Lake Union
Union Bay
Lake Washington
Miles
0
1
2


Seattle Public Utilities
Drainage System Analysis
Figure 3. Racial and Social Equity Composite Index - 2018
LEGEND
Lowest Disadvantage
Second Lowest Disadvantage
Middle Disadvantage
Second Highest Disadvantage
Highest Disadvantage
Puget Sound
Elliott Bay
Lake Washington
Lake Union
Green Lake
Union Bay
Miles
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Seattle Public Utilities

Drainage System Analysis

Figure 4. Snow and Ice Routes

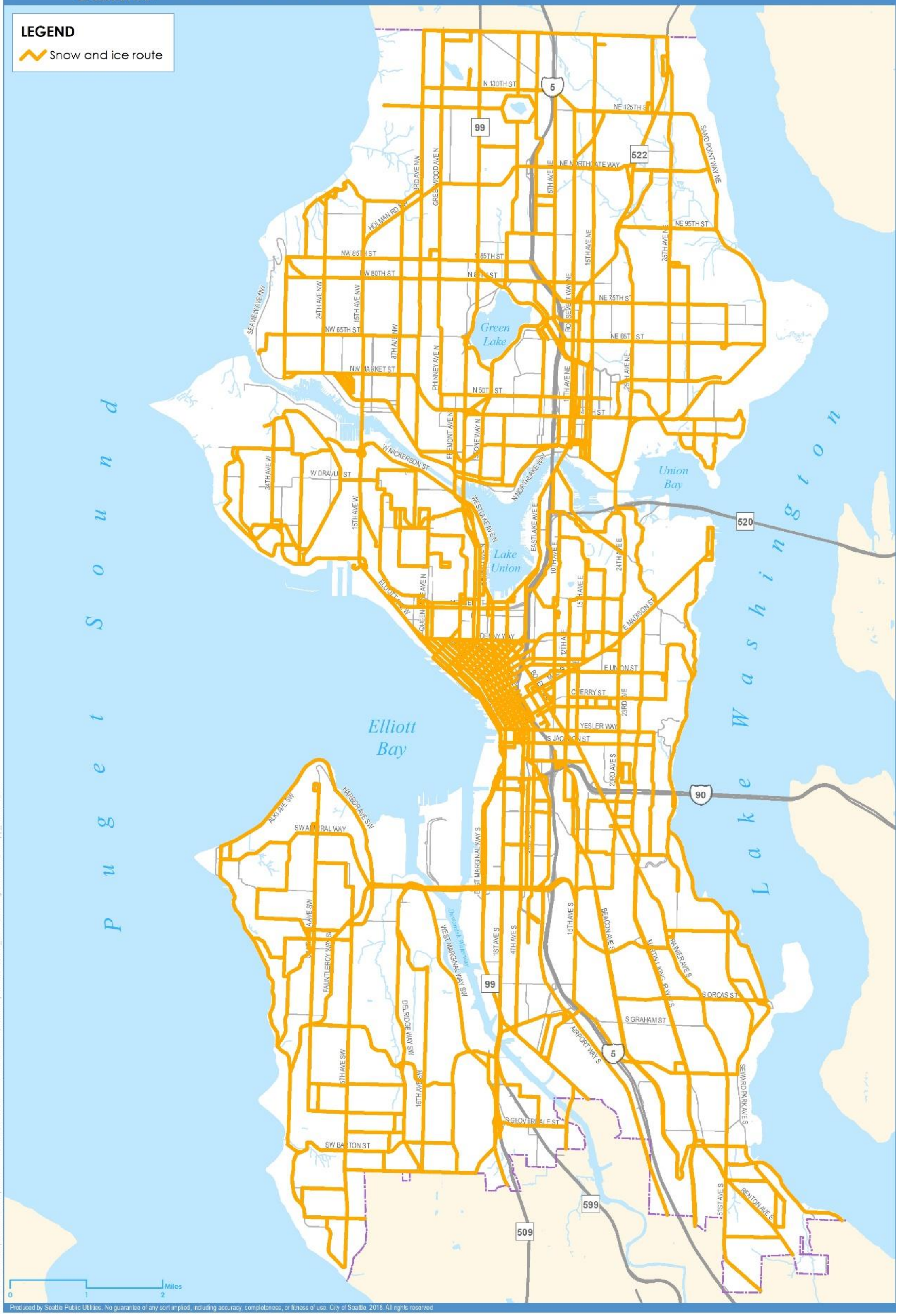

Table 2. Processed Data used in the Systems Analyses Projects

Name	Description	Storage Location(s)	File Name	Data Type	File Date	Analysis in Which the Data were Used: Wastewater system capacity risk areas	Drainage system capacity risk areas	Sea level rise risk map	Creek flooding risk map	Extreme storm event risk map
critical facilities	Point data of the following types of critical facilities: • emergency serviced • high population • human services • medical • protective • support • vulnerable populations The raw data were mapped by lat/long. Sites that mapped outside a parcel, were moved to the parcel based on the address and mapping review. The list was paired down to reflect facilities related to human health and safety for people at that location. See additional information below, after the tables. Exact duplicates were removed. List consists of 746 facilities on 612 unique parcels.	*DWW GIS Library on SharePoint* *Project files*	CriticalFac_rev.zip/.shp	point	12/21/18	✓				
critical facilities	King County parcel data developed from the critical facilities point data. Consists of parcels with at least one critical facility point within it.	*Project files*	CriticalFacility_parcels.shp	polygon	5/5/20		✓			
critical facilities	Raster data developed from critical facilities polygon data. A binary grid (4 foot by 4 foot) was developed by giving grid cells falling within the parcel polygons a value of 1 and all other cells were given a value of 0.	*Project files \rasterdata.gdb*	CritFacility	raster	7/17/20			✓	✓	✓
high use area	An area likely to have a large number of pedestrians traveling in or through it relative to other areas of the city. It consists of the following land uses and right-of-way (ROW) buffers: • Residential and Hub Urban Villages, including a 50-foot ROW buffer • Urban Center, including a 50-foot ROW buffer • Hospital campuses, including a 50-foot ROW buffer • Colleges and universities, including a 50-foot ROW buffer • Public and private schools, including a 50-foot ROW buffer • Link light rail stops, including a quarter mile ROW buffer • High frequency bus stops, including a 50-foot ROW buffer • Neighborhood greenways After each polygon data were buffered, they were merged into one data set.	*DWW GIS Library on SharePoint*	Pedestrian_Areas_for_Prioritization.mpk	polygon and polyline	1/7/19	✓ If at least 50% of a risk area included a high use area, the risk score was increased.				
high use area	Neighborhood greenways were buffered by the ½ of right-of-way width with the attribute "ROWWIDTH", equating to an area equal to the right-of-way width centered on the street polyline. The resulting polygon data were merged with the polygon data set of the other high use areas.	*Project files*	HighUseAreas.shp	polygon	7/15/20		✓			

Name	Description	Storage Location(s)	File Name	Data Type	File Date	Analysis in Which the Data were Used				
						Wastewater system capacity risk areas	Drainage system capacity risk areas	Sea level rise risk map	Creek flooding risk map	Extreme storm event risk map
high use area	Raster data developed from high use area polygon data. A binary grid (4 foot by 4 foot) was developed by giving grid cells falling within the high use area polygons a value of 1 and all other cells were given a value of 0.	*Project files* \rasterdata.gdb	HighUse	raster	7/17/20			✓	✓	✓
land area	Land within the city, and, except for Green Lake, no inland water bodies.	*DWW GIS Library (DSA) on SharePoint* *Project files*	CityofSeattle_DSA.zip/shp	polygon	3/25/20			✓	✓	✓
major transportation routes	From the streets data (Streets_DSA.shp), (1) Snow and ice routes were identified through a spatial join, and (2) interstates/freeways were identified based on attribute "OWNER" = "WSDOT". Identified features were merged into one dataset. Right-of-way widths (attribute "ROWWIDTH") of 60 feet were added to interstates/freeways. The polyline data were buffered by the ½ of right-of-way width equating to an area equal to the right-of-way width centered on the street polyline. A binary grid (4 foot by 4 foot) was developed by giving grid cells falling within the major transportation route polygons a value of 1 and all other cells were given a value of 0. (The dataset available has a grid cell value of 1.5 for major transportation routes.)	*Project files* \rasterdata.gdb	MajorTrans	raster	7/17/20			✓	✓	✓
Racial and Social Equity Composite Index	Polygon data were dissolved on the composite index. A binary grid (4 foot by 4 foot) was developed by giving grid cells falling within each disadvantage category the following value: • highest = 5 • second highest = 4 • middle = 3 • second lowest = 2 • lowest = 1	*Project files* \rasterdata.gdb	Equity	raster	7/17/20			✓	✓	✓
street type	Streets_DSA polyline data were buffered by the ½ of right-of-way width (attribute "ROWWIDTH") equating to an area equal to the right-of-way width centered on the street polyline. Snow and ice routes were identified through a spatial join. Major transportations are the routes with attribute "Type" = "SnowIceRoute". Non-arterial streets have the attribute "Type" = "Non-arterial".	*Project files*	StreetType_DSA.shp	polygon	5/5/20		✓			
streets	Street with right-of-way widths added to attribute "ROWWIDTH", where missing, when near a risk area. ROWWIDTHs added were based on aerial photo review.	*DWW GIS Library on SharePoint* *Project files*	Streets_DSA.zip/.shp	polyline	1/24/20		✓ (intermediate data set)			

DWW GIS Library on SharePoint = *https://seattlegov.sharepoint.com/sites/spu-D1/Planning/DWW%20GIS%20Library/Forms/AllItems.aspx*
DWW GIS Library (DSA) on SharePoint = *https://seattlegov.sharepoint.com/:f:/r/sites/spu-D1/Planning/DWW%20GIS%20Library/DSA/Data/SPU?csf=1&web=1&e=UBk4k2*
Project files = X:\Separated Systems\Business_Areas\Planning\DSA\data\Impacts

Table 3. Critical Facilities Included in Analyses

Category	Primary Use	Count
Emergency Services	Emergency Cache	4
Emergency Services	Fire - Support	1
Emergency Services	Government Function	2
Emergency Services	Medical	1
Emergency Services	Parking Garage	1
Emergency Services	Police Station	3
High Population	Conference Center	2
High Population	Landmark	1
High Population	Stadium	6
Human Services	Community Center	31
Human Services	Customer Service	4
Human Services	Family Center	7
Human Services	Food Bank	30
Human Services	Food Distribution Center	1
Human Services	Library	26
Human Services	Meal Program	17
Human Services	Non-Profit	10
Human Services	Shelter	22
Human Services	Support	4
Human Services	Teen Center	1
Medical	Blood Center	5
Medical	Dialysis Center	7
Medical	Hospital	12
Medical	Medical	1
Medical	Public Health	2
Medical	Urgent Care Clinic	17
Protective	Coast Guard Station	1
Protective	Fire - Support	1
Protective	Fire Headquarters	1
Protective	Fire Station	34
Protective	Joint: Fire Station / EOC	1
Protective	Joint: Fire Station / Senior Center	1
Protective	Joint: Police and Courts	1
Protective	Offices	1
Protective	Parking Garage	2
Protective	Police - Support	6
Protective	Police Harbor Patrol	2
Protective	Police Station	6

Category	Primary Use	Count
Support	Backup EOC	5
Transportation	Ferry Terminal	1
Vulnerable Population	Child Care Center	252
Vulnerable Population	Nursing Home	25
Vulnerable Population	School	90
Vulnerable Population	School - 6-12	2
Vulnerable Population	School - 6-8	10
Vulnerable Population	School - 9-12	13
Vulnerable Population	School - Gym	1
Vulnerable Population	School - K-5	59
Vulnerable Population	School - K-8	11
Vulnerable Population	School - Service School	2

Appendix D: SLR Risk Maps

Figure D-1. Sea Level Rise Risk Area, Southwest

Figure D-2. Sea Level Rise Risk Area, Southeast

Figure D-3. Sea Level Rise Risk Area, Northwest

Northeast quadrant not included because there is no risk mapped within that area.

ArcGIS map package for these figures provided in digital format.

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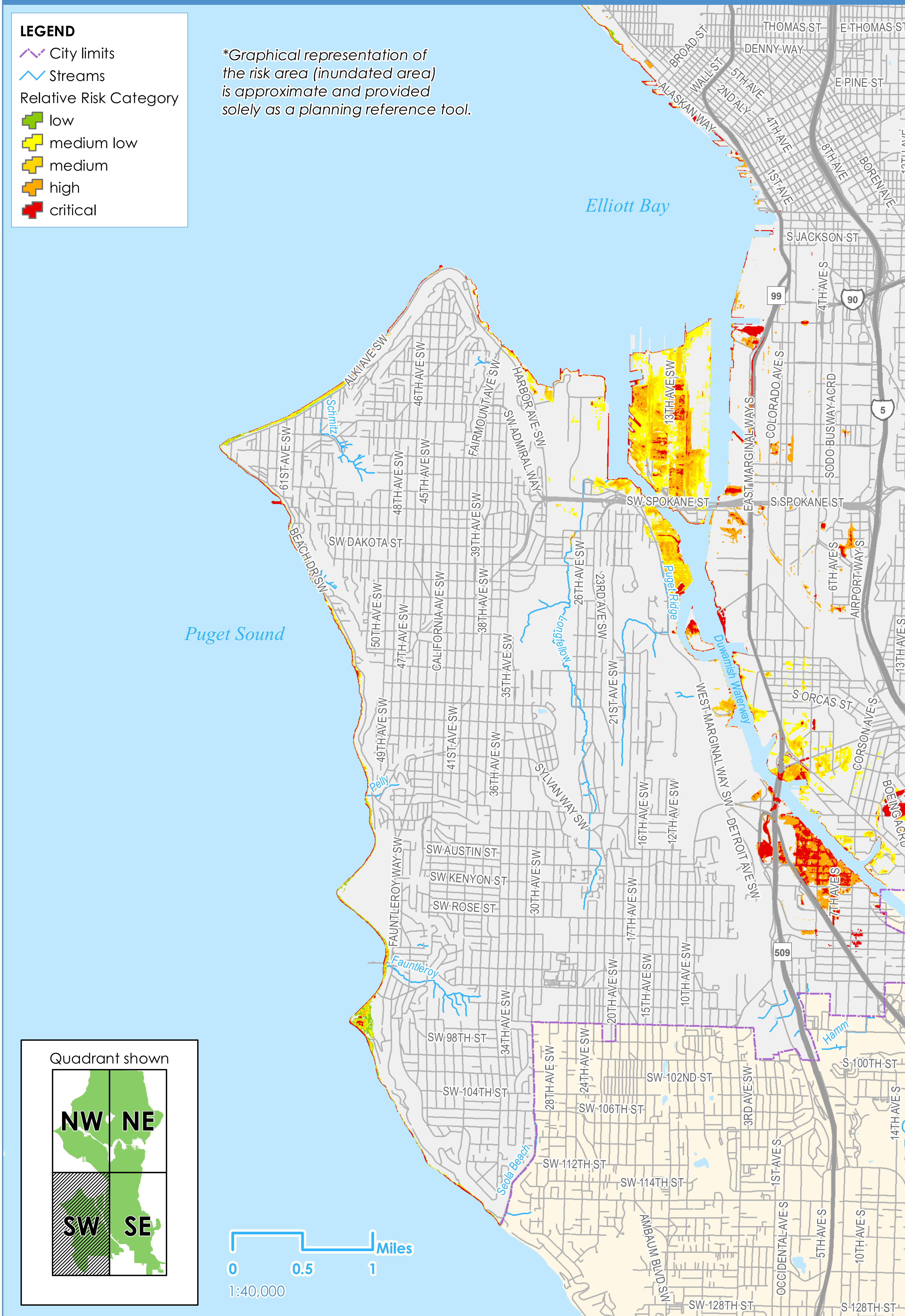
Figure D-1. Sea Level Rise Risk Area, SW



Author: BC Date: 10/6/2020 File Path: C:_BC\DSAGIS\SPU_DSA_T2_SLR_AppD1_20201006.mxd

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Figure D-2. Sea Level Rise Risk Area, SE

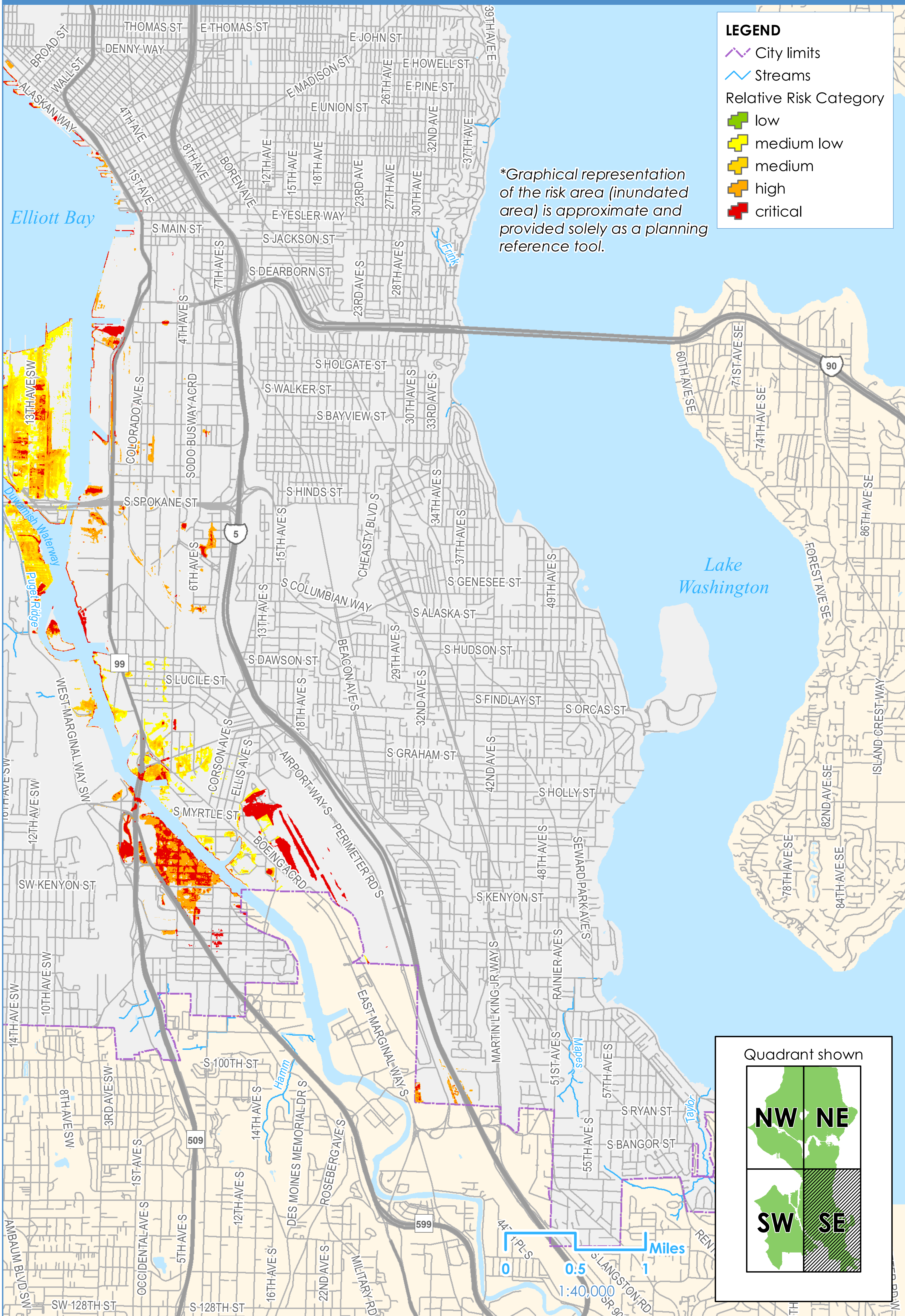

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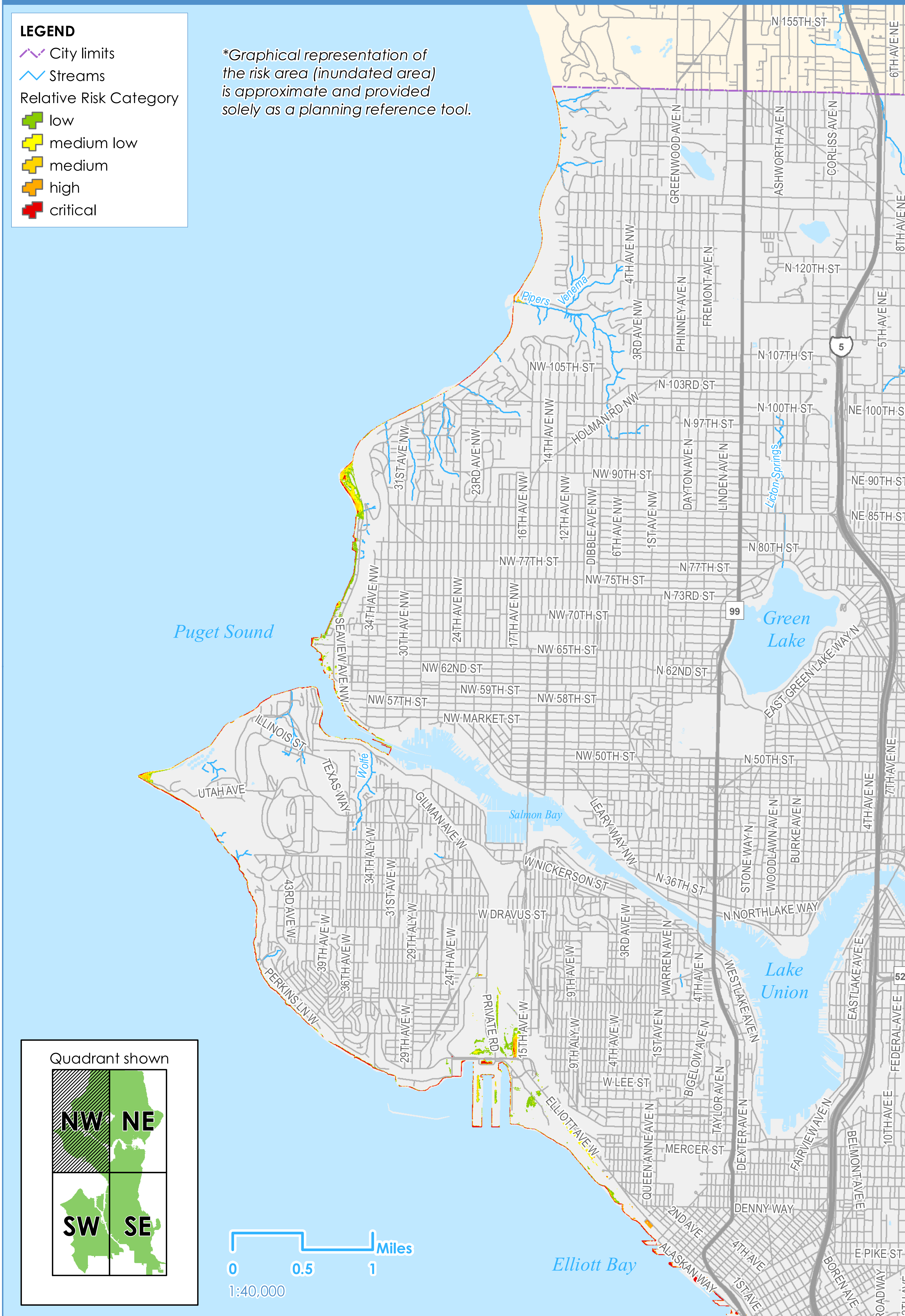
Figure D-3. Sea Level Rise Risk Area, NW



Author: BC
Date: 10/6/2020
File Path: C:_BC\DSAGIS\SPU_DSA_T2_SLR_AppD3_20201006.mxd

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