CITY OF OLYMPIA
ENGINEERED RESPONSE TO SEA LEVEL RISE

COAST & HARBOR ENGINEERING

Technical Report

CITY OF OLYMPIA
ENGINEERED RESPONSE TO SEA LEVEL RISE

Prepared for:

City of Olympia Public Works Department, Planning & Engineering

This Technical Report is being released for the purpose of documenting hydraulic, civil, hydrogeological, and coastal engineering analyses of potential inundation of downtown Olympia due to precipitation runoff combined with tidal and wave effects in the context of possible future sea level rise. The Technical Report includes a proposed strategy for responding to flooding potential. The report and included files are intended to provide planning information and are not to be used directly for design or for flood insurance risk calculation.

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Executive Summary

The City of Olympia, located on Budd Inlet in southern Puget Sound, experiences occasional flooding in the downtown area due to extreme tides with the current sea level. Because of the relatively low ground level and multiple open stormwater outfalls discharging to the Inlet, flooding will become more of a problem as the mean sea level rises. Flooding also results from high precipitation runoff when combined with a high tide that inundates a major gravity storm drain system. The City has decided to defend its downtown from flooding.

This study established areas of flooding and flooding depths corresponding to 10-, 50-, 100-, and 500-year return periods for increments of sea level rise up to 50 inches. These return periods correspond to average annual exceedance probabilities of 0.1, 0.02, 0.01, and 0.002, respectively. Flooding elevations and areas accounted for storm tides, wave effects on mean water level at the shoreline, and precipitation runoff. Flooding information corresponding to these probabilities is in the form of inundation maps created with a Geographic Information System (GIS). One example of GIS analysis output, the one-percent-annual-chance flood at the existing mean sea level, is shown in Figure ES-1. A small incremental sea rise greatly increases the probability of flooding downtown. The flood elevation currently having a 100-year recurrence interval (11.37 ft) is reached by the flood having an 18-year recurrence interval after sea level rises 0.5 ft.

Study results served as a basis for developing engineering responses to protect against flooding. The study identified infrastructure that could be modified and locations where flood barriers should be installed, evaluated types of flood barriers applicable for each vulnerable area, determined the elevations of the barrier crests to protect against the 100-year overtopping event, evaluated tide gates and pump stations to be installed, and identified at which sea rise amount various responses should be implemented. Conceptual design of flood protection is keyed to the 100-year return period flood. The recommended strategy for flood defense is to plan in the near-term for infrastructure changes and construction needed for the 50-inch rise case and to implement measures that will permit deferring large expenses into the future. Flood barrier locations for protecting downtown Olympia, the Port of Olympia, and parts of West Bay Drive for the case of 0.5 ft sea level rise are shown in Figure ES-2.

Major findings are:

- Parts of downtown Olympia are currently not protected from inundation by the one-percent-annual-chance flood.
- Many catch basins in the vicinity of Water Street to Capitol Way north of 5th Avenue are inundated with backflow of salt water by even the ten-percent-annual-chance flood

elevation under existing conditions. Salt water would then flow to some catch basins that are pumped to LOTT.

- Controlling flooding at the ten-percent-annual-chance level by emergency response (by using sand bags and sealing catch basins) becomes impractical when mean sea level has risen 0.25 ft.
- After the first increment of sea level rise, broad areas of the peninsula are susceptible to inundation. Therefore, downtown and Port of Olympia must be protected together with common infrastructure.
- Barrier types are specific to location and are determined by barrier attributes and site use. Barrier types recommended for the study area include vegetated earthen berm, armored slope earthen berm, sheet pile, and temporary barrier.
- Near-term measures may include raising the shoreline elevation at currently low areas on the west facing shoreline of the peninsula, improving erosion protection on all the peninsula shoreline, and installing more valves on outfalls that are connected to catch basins on Water Street.
- Pipe modification for eventual outfall consolidation can occur when property is redeveloped. This would reduce the number of outfalls and thereby reduce the number of sources of backflow to the upland.
- Flood barriers should be installed first at locations on the west facing shoreline of the peninsula by the time sea level has risen 0.25 ft.
- Flood barriers should be installed at locations on the east facing shoreline of the peninsula by the time sea level has risen 0.5 ft.
- Initially, flood barriers are recommended to protect to one foot of sea level rise.
- Locations of flood barriers installed at the point of 0.5 ft sea level rise are nearly the same as barriers protecting to 50 inches of sea level rise; only the height and footprint are larger.
- Separate consolidated outfalls are recommended for East Bay and for West Bay. This plan should be implemented at the point of 0.25 ft sea level rise in order to protect downtown to the one-percent-annual-chance level.
- Tide gates must be installed on the consolidated outfalls to protect against backflow to the upland.
- Pump stations to discharge stormwater are required to be in operation at the time that tide gates are installed on outfalls.
- By providing a separate, smaller outfall, tide gate, and pump station for catch basins on the eastern half of the peninsula and just south of the East Bay shoreline, and by not combining with the existing Indian and Moxlie Creek drainage system and outfall, the expense of a tide gate and pump station for this larger system can be deferred until sea level has risen 2 ft.
- Implementation costs for this long-term plan are summarized in Table 11.

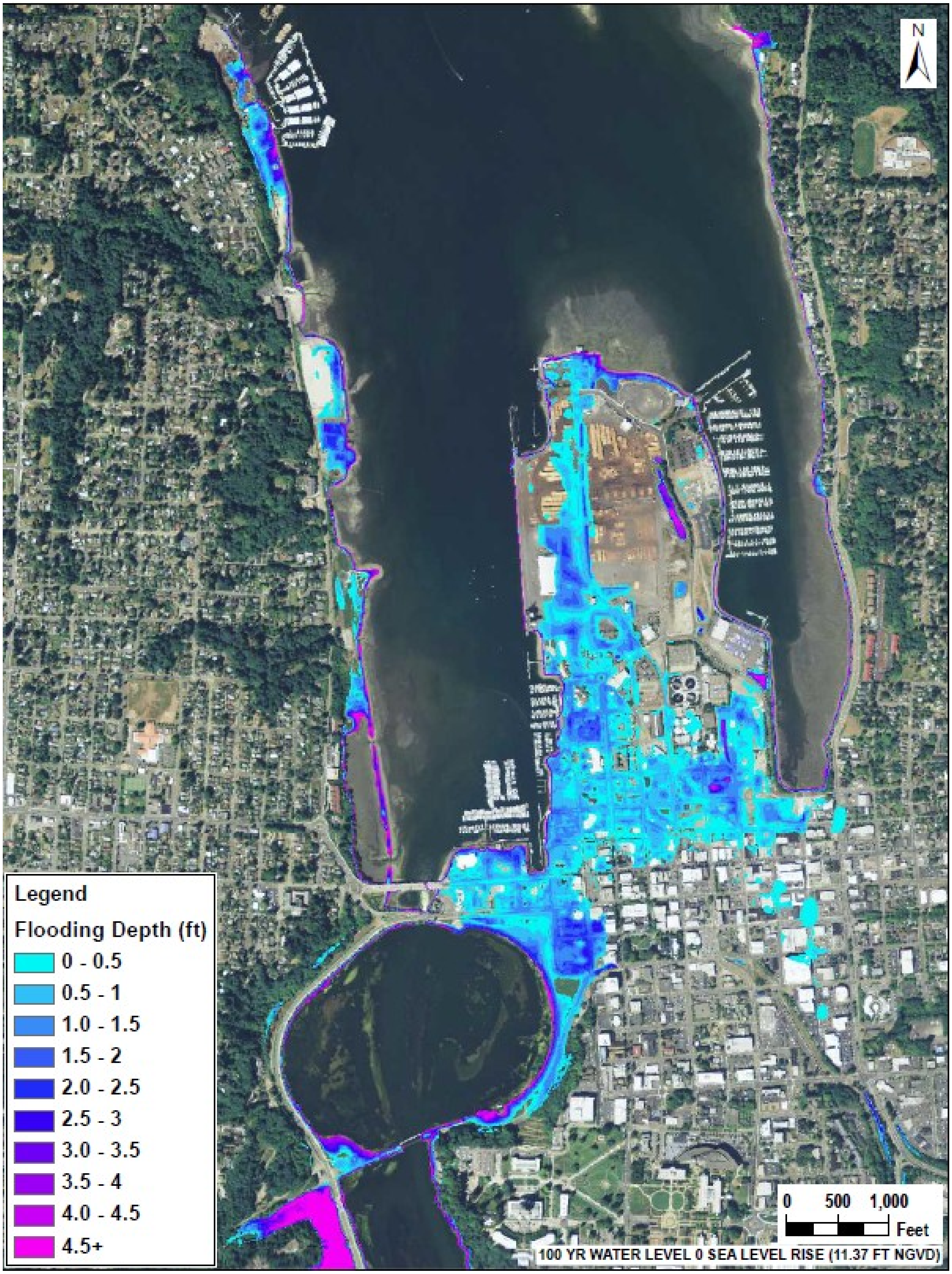

Figure ES-1. Inundation by one percent annual chance flood, existing sea level

Figure ES-2. Flood barrier locations to protect Olympia at 0.5 ft sea level rise

Technical Report

City of Olympia Engineered Response to Sea Level Rise

1. Introduction

The City of Olympia has taken the lead in determining future effects that rising sea level could have on its downtown. Technical work completed for the City in 2008-2010 showed that if a combination of historical precipitation and tide height occurred under the accepted scenarios of sea level rise, several parts of the stormwater drainage system would discharge water onto the surface and Capitol Lake could overtop its bank, causing localized flooding.

The City is developing plans for protecting its downtown in anticipation of a possible increase in sea level of 50 inches, based on conclusions of the Climate Impacts Group at the University of Washington (Mote *et al.* 2008). The current phase of work is to build on the previous studies and develop flood management scenarios and conceptual designs to mitigate the hazards. Parts of downtown Olympia are built on fill and have a relatively low elevation. Figure 1 is a location map showing the relationship of Olympia and Budd Inlet in Puget Sound. LiDAR data displayed as a relief map in Figure 2 illustrate the general vulnerability of part of downtown to inundation by tides in East Bay and West Bay. Color intensity in the figure represents elevation. Additionally, the combined flows of Indian and Moxlie Creeks discharge through a pipe that is routed under the eastern part of downtown and empties into East Bay. Under certain combinations of streamflow, street runoff, and tide level, the storm drain system connected to this pipe is susceptible to being a flooding source.

1.1. Purpose and Objective

Phase 1 of the sea level rise response study, completed in 2010, identified areas that could be vulnerable to flooding with certain rare combinations of creek flows and tide heights and illustrated how the problem areas expanded with rising sea levels. No other coastal processes besides tide levels were incorporated in the Phase 1 study. The purpose of the current phase of study is to better define the conditions of precipitation runoff, tide level, and storm waves that produce surface flooding of specific areas, and to quantify probabilities of occurrence of such flooding. Flooded areas and their probabilities of flooding are to be recomputed with increments of sea level rise. The objective of developing the information is to create strategies to combat the threat of flooding in the near-term and identify plans for guiding major infrastructure changes to eventually accomplish a long-term plan for protecting the downtown.

The scope of the project incorporates storm drain hydraulics of the Indian/Moxlie system downstream (north) from the I-5 crossing, coastal water levels as affected by tides and storm waves, shore erosion and inundation, and water levels in Capitol

Lake. Areas of downtown included in the study are the East Bay shoreline and the developed area south from there, the peninsula, Fiddlehead Basin, Percival Landing, the northeast shoreline of Capitol Lake, and West Bay shoreline north to the marina. Proactive responses are developed to counter rising probabilities of flooding critical transportation corridors, emergency services, and essential upland facilities including government buildings and the Port of Olympia. This study does not establish a timeline for accomplishing parts of the response plan; elements of the plan are tied to amounts of increase in sea level above the current level. No new quantitative field data were collected. Certain simplifying assumptions were made; specifically that future climate change would not affect extreme value statistics that have been developed from precipitation runoff, wind waves, and storm setup data of the past several decades.

Figure 1. Location map of City of Olympia and sea level rise study area

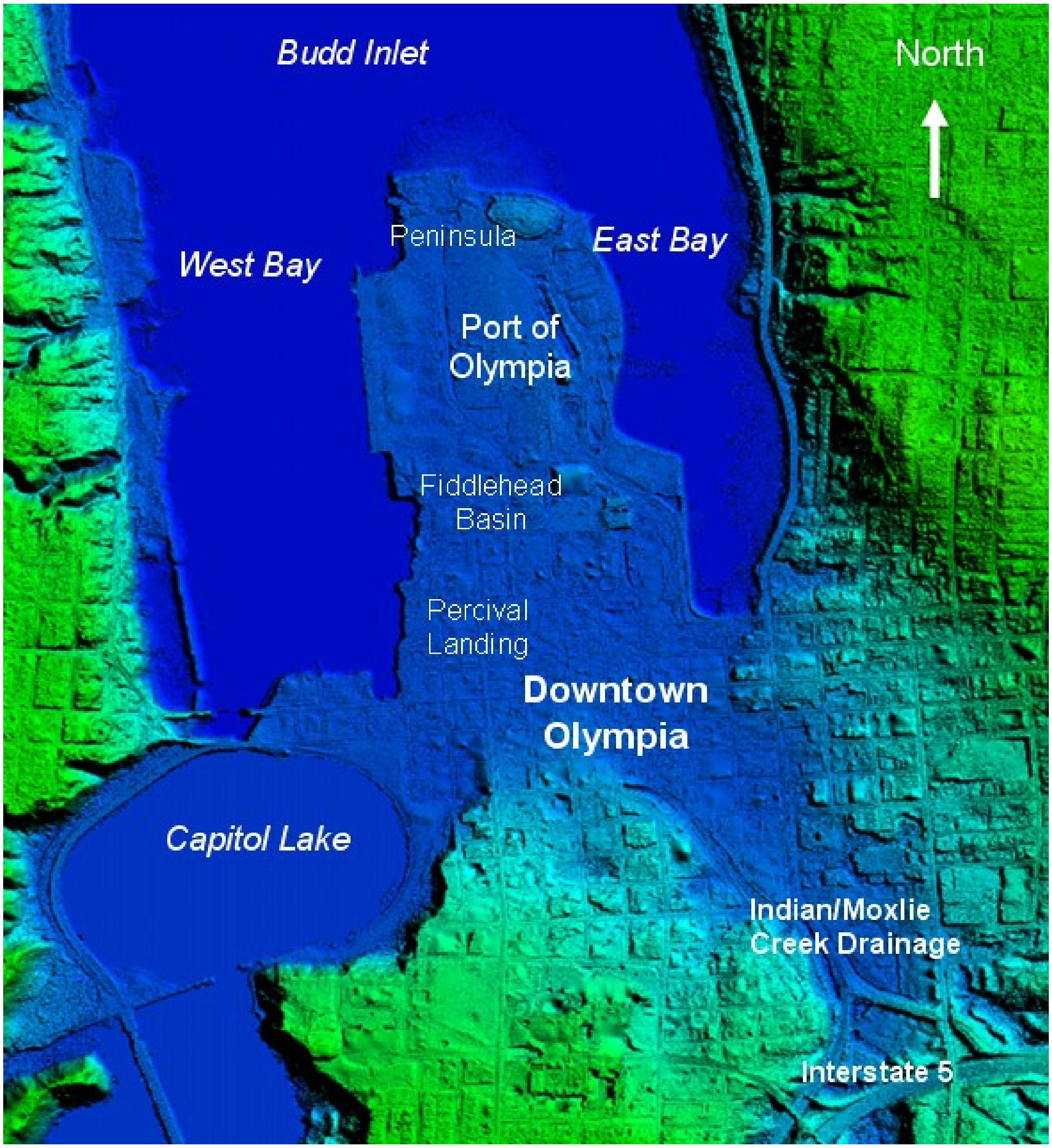

Figure 2. Relief topography showing low elevation parts of study area

1.2. Organization of the Report

Many technical analyses in separate disciplines were conducted to accomplish this study. Team members and their expertise who contributed to the study are listed below:

- Joe Brascher, Clear Creek Solutions, hydrology and hydraulic modeling of storm drain system
- Erik Davido, P.E., Davido Consulting Group, storm drain and combined sewer system performance and modification concepts

- Steve Helvey, L.G., L.E.G., L.G.H., GeoEngineers, groundwater flow, soil mechanics, contaminant assessment
- Bob Richardson, P.E., ABAM Engineers, pump station, tide gate, and flood barrier design
- David Simpson, P.E., Coast & Harbor Engineering, coastal engineering, project management

Analysis begins with review of magnitudes, timing, and statistics of precipitation runoff, routing flows in the storm drain system, and review of the system response as determined from modeling. Tide height statistics are developed for Olympia. Wind statistics are developed and waves are modeled with a numerical model to determine the nearshore wave climate at specific locations.

The factors controlling water surface elevation at the shoreline for various probability events are described and computed. Effects on upland water level by way of connection with Budd Inlet are described qualitatively and quantitatively with GIS images showing locations and depths of inundation and the associated probability of occurrence.

Observation of the sequence of flooding at various areas with rising sea level leads to a strategy of defending against flooding risks in the current condition, in the near-term future, and progressively to the target of 50 inches of sea level rise. Recommendations are made for more accurate monitoring of tides and winds that affect flooding, and for documenting ground surface level and groundwater level at areas vulnerable to increasing flooding probability.

2. Data and Specifications

Data relied upon and developed in this study is mainly in digital format and many data files are large. Data referenced in this section are stored in numbered files contained in the enclosed DVD. The file numbering system is described in the document Technical Memo-Organization of Deliverables-rev 12-13-2011.doc in the root directory of the DVD.

Aerial photographs including downtown Olympia and the southern part of Budd Inlet are contained in file 1.1. The photograph dated 2010 was specified as the base photography for locating project features and presenting study results.

Light Detection And Ranging (LiDAR) data was provided by the City and was the source of all elevation data and topography for the study. LiDAR data collected in 2002 was trimmed to the project area and is contained in file 1.2. Elevations in the file are referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). Horizontal datum is Washington State Plane South, NAD 83.

Bounds of the area included in the study were provided by the City and are shown in Figure 3. The GIS information specifying the study area is contained in file 1.3. Separate GIS files contain information on catch basins, stormwater pipes, and the combined sanitary sewer system, and are located in file 1.4.

Figure 3. Bounds of study area and base photograph for displaying study results

Ground photographs showing water levels at times of notable high tides (2010 and January 23, 2011 tide level of 17 ft MLLW) were provided by the City. Ground photographs were made of the study area on July 6, 2011. Ground photographs of pertinent aspects of the study area, with descriptions, are contained in file 1.5.

Tide data recorded at the National Oceanic and Atmospheric Administration (NOAA) Seattle tide gauge were used for deriving tide statistics for Olympia. Measured and predicted elevations and corresponding dates are listed in file 3.3. Conversion among tidal datums and geodetic datum is necessary for using elevations that are based on the different datums. Using the computer program VDATUM developed by NOAA, elevations of the datums were derived specifically for Olympia. The conversion is shown in Figure 4.

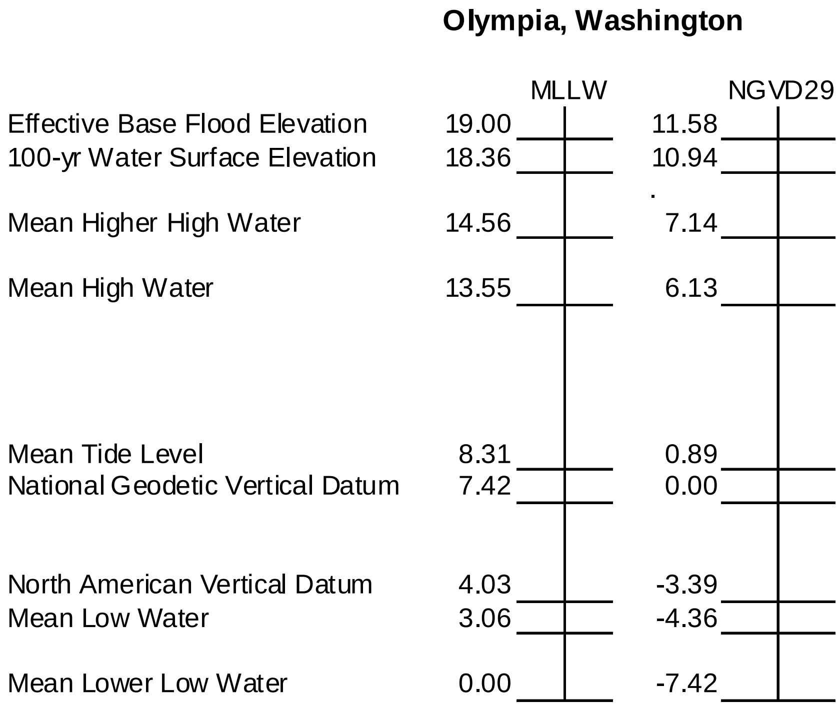

Figure 4. Conversion between tidal and geodetic datum at Olympia

Wind data were collected from recordings at Olympia Airport, Boston Harbor, and Swantown Marina to develop wind speed values from the north direction. These data were adjusted to more accurately represent winds of the wave-generating area for the Budd Inlet shoreline. Wind data were developed for computing extreme value statistics. Statistical wind speeds were the basis of wind input to the wave model for simulating waves reaching the study shoreline. Pertinent wind data are contained in file 3.6.

Precipitation runoff volumes were determined for the 100 largest storms in the 50-year period from 1955 to 2007 for use in modeling of the storm drain hydraulics downstream of the confluence of Indian and Moxlie Creeks. Runoff is the volume of water that flows through a section of pipe or a channel during a length of time that results from precipitation falling in the drainage area. Previous studies showed the magnitude of runoff volume is more important to flooding in this system than is peak discharge of the runoff hydrograph. That is the reason that volumes and not discharge rates were tabulated in file 3.1. Runoff volume is defined as the area under the discharge hydrograph from the point of rise above base level (discharge due to groundwater flow to the stream network) to the point at the post-storm base level at the end of the runoff event.

Soils and groundwater information for downtown Olympia was made available through two reports commissioned by the Lacy Olympia Tumwater Thurston Clean Water Alliance (LOTT) (Robinson Noble 1996, 1999). These data were reviewed as part of the hydrogeological and geotechnical evaluation completed in the present study, which is attached as Appendix A.

Water levels in Capitol Lake corresponding to return periods were previously derived (Moffatt & Nichol 2008). The City Fire Department has developed plans for anticipating and responding to flooding of areas of downtown which are keyed to specific water levels. Information regarding flooding by Capitol Lake levels is contained in files 2.2, 2.3 and 2.4.

Land use information consisting of locations of structures having various categories of uses, essential transportation corridors, and locations of historical structures, was provided by the City. Files containing the data are in file 4.4.

The effective Flood Insurance Rate Map dated 1982 shows the limit of the 100-year floodplain and is contained in file 4.1. The Base Flood Elevation (100-year flood) currently in effect is 11 ft NGVD. The City has converted the tidal elevation to 19 ft MLLW.

3. Analysis of Flooding Potential

3.1. Flooding and Probability

Sources of flooding in downtown Olympia are recognized as Budd Inlet, precipitation runoff, and Capitol Lake. Water level in Budd Inlet is controlled by the tide and other processes collectively termed setup. High water level can cause upland flooding by direct inundation of the shoreline as well as backflow through outfalls and street drains. Precipitation runoff is a hydrological process independent of tides, but under certain conditions of tidal inundation of the existing storm drain system the pipes cannot discharge runoff at a sufficient rate to prevent flooding. Currently only one outfall (discharging to Capitol Lake) has a valve, which is operated manually to control flooding of the area of Water Street and 7th Avenue.

Planning decisions and economic analysis are keyed to risk or probability. Risk is the product of a numerical value for consequence of damage or loss of use multiplied by probability of occurrence. The current study presents a map of land use types for each city block in the study area but does not quantify risk. The study does establish areas of flooding and probabilities of occurrence as a planning tool. Risk can be inferred subjectively by overlaying flooding probability on a land use map. A comparison of this type is presented in Section 4.2.

Extreme value analysis is a procedure for establishing the probability that the magnitude of some random event will be equaled or exceeded. The procedure involves fitting observed data to a theoretical distribution and extrapolating or interpolating to probabilities of interest. The Generalized Extreme Value distribution (FEMA 2005) is a group of distributions, each being more or less appropriate for representing different processes. When annual maximum data are used in extreme value distributions, or when values greater than a high threshold are used in the Pareto distribution, the probabilities are expressed as “chance of being equaled or exceeded in any one year." Return period values are calculated as the inverse of probability. Return period and recurrence interval are common terms and it should be understood that the occurrence of a particular flood level in one year does not affect the probability of occurrence in another year. For example, a 50-year flood has a 2 percent chance of being equaled or exceeded in any one year.

3.2. Tidal Elevations

Return period tidal elevations at the Budd Inlet shoreline were calculated using data measured at Seattle and adjusted for Olympia because measurements of sufficient quality and length of record at Olympia do not exist. The adjustment was made by establishing a ratio between astronomical high waters at the two locations and adding the tidal residual. Using the NOAA computer program VDATUM to establish tidal relationships, the MHHW elevation is 14.56 ft above MLLW at Olympia, and 11.36 ft at Seattle (ratio of 1.28). The annual highest measured tides for the Seattle tide gauge was tabulated for the longest period for which times of both measured and predicted tides were available (1983 to 2010). Table 1 lists the annual maximum series of tide heights measured at Seattle and the steps for deriving the residual, and the astronomical and observed tides for Olympia. The term "observed" is applied to Olympia tides in the right-hand column of Table 1 because the tide was not actually measured, but includes the same tidal residual as was observed in Seattle. The meteorological effect causing the residual is assumed to be a large-scale phenomenon, producing a similar residual in Olympia and Seattle. The Olympia observed tidal elevations were fit to a Weibull extreme value distribution for prediction of return period observed tides. Figure 5 is a plot of the values and best-fit distribution. Return period observed tidal elevations are shown in Table 2. Return periods of 10-, 50-, 100-, and 500-years were used in the subsequent analyses, to make results comparable with flood probability calculations in Flood Insurance studies of FEMA.

Table 1. Annual maximum series of Seattle tide heights

Year	Month	Day	UTC (hr)	PST (hr)	Measured Seattle (ft MLLW)	Predicted Seattle (ft MLLW)	Difference (ft)	Predicted Site (ft MLLW)	Total Tide Site (ft MLLW)
1983	1	27			14.48	12.3	2.18	15.77	17.95
1984	1	22	16:12	0812	13.60	13.3	0.30	17.05	17.35
1985	2	11	16:54	0854	12.92	12.3	0.62	15.77	16.39
1986	1	15	16:48	0848	13.03	12.5	0.53	16.02	16.55
1987	2	1	15:24	0724	14.30	13.1	1.20	16.79	17.99
1988	11	22	22:36	1436	13.54	11.9	1.64	15.25	16.89
1989	3	11	14:36	0636	13.18	12.2	0.98	15.64	16.62
1990	12	4	15:00	0700	13.38	13.1	0.28	16.79	17.07
1991	2	2	15:00	0700	13.43	12.8	0.63	16.41	17.04
1992	1	25	16:36	0836	13.70	12.6	1.10	16.15	17.25
1993	12	14	14:12	0612	13.27	13.0	0.27	16.66	16.93
1994	12	20	15:06	0706	13.40	12.4	1.00	15.90	16.90
1995	12	12	16:48	0848	13.70	12.1	1.60	15.51	17.11
1996	2	20	13:48	0548	13.90	12.8	1.10	16.41	17.51

Year	Month	Day	UTC (hr)	PST (hr)	Measured Seattle (ft MLLW)	Predicted Seattle (ft MLLW)	Difference (ft)	Predicted Site (ft MLLW)	Total Tide Site (ft MLLW)
1997	1	1	17:48	0948	14.04	11.6	2.44	14.87	17.31
1998	1	4	17:24	0924	13.84	13.0	0.84	16.66	17.50
1999	1	21	16:00	0800	13.19	12.9	0.29	16.54	16.83
2000	1	9	16:00	0800	12.84	12.4	0.44	15.90	16.34
2001	11	22	19:00	1100	13.10	11.6	1.50	14.87	16.37
2002	12	28	19:36	1136	13.55	12.4	1.15	15.90	17.05
2003	1	3	14:12	0621	14.21	12.9	1.31	16.54	17.85
2004	1	24	15:30	0730	13.23	13.1	0.13	16.79	16.92
2005	12	31	14:06	0606	14.08	12.8	1.28	16.41	17.69
2006	2	4	16:48	0848	13.96	12.3	1.66	15.77	17.43
2007	12	3	20:06	1206	13.70	11.41	2.29	14.63	16.92
2008	1	10	15:00	0700	13.47	12.36	1.11	15.84	16.95
2009	11	17	13:54	0500	13.35	12.01	1.34	15.40	16.74
2010	1	20	16:00	0800	13.90	12.15	1.75	15.57	17.32

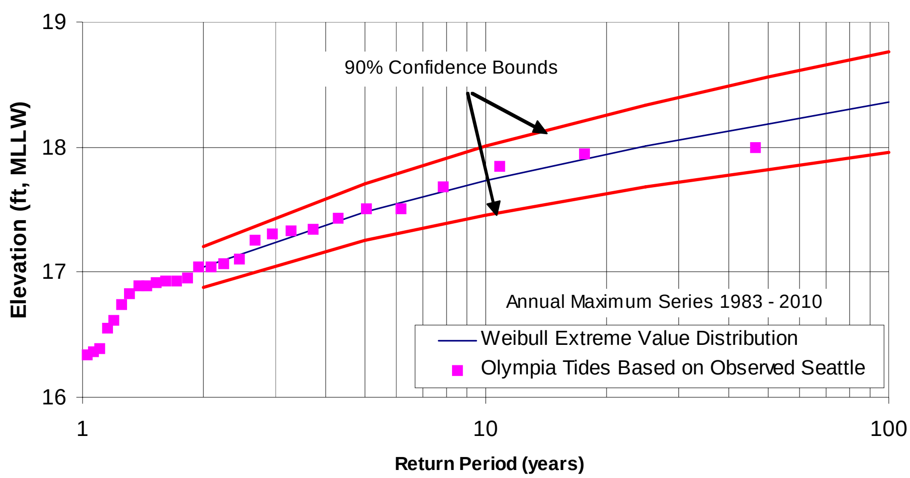

Figure 5. Extreme value distribution of annual maximum tide height at Olympia

Table 2. Return period tidal elevations at Olympia

Return Period (yr)	Tide Height (ft, MLLW)	Tide Height (ft, NGVD)
2	17.05	9.63
5	17.48	10.06
10	17.73	10.31
25	18.01	10.59
50	18.19	10.77
100	18.36	10.94
500	18.70	11.28

Note: Elevations determined from measurements at Seattle 1983 – 2010, adjusted for Olympia

3.3. Waves and Wave Setup

Flooding potential must account for wave effects at the Olympia shoreline. Wave effects include wave runup and overtopping onto the upland and wave setup at the shoreline. The height of wave runup and the inland distance traveled by the overtopping wave are relatively small because waves are not expected to be large. Water contributed to the upland by overtopping would travel to a storm drain, where the water level would equilibrate with the level at the end of the outfall at the shoreline. Water level at the shoreline is increased slightly by wave setup, which is the addition to the mean water level caused by transfer of wave momentum to the water between the point of wave breaking and the limit of runup. Therefore, the storm tide consisting of astronomical tide and large-scale meteorological effects plus wave setup define the total water level. The total water level controls flooding elevation at the shoreline and at upland locations where the ground is lower than the total water level. The description of wave setup calculation follows.

Wave modeling for Budd Inlet required developing wind fields for storms of given return periods. Wind measurements of sufficient record length are not available in the wave generating area. Therefore, short-term measurements at Boston Harbor and Swantown Marina were used to develop corrections to the longer-term data measured at Olympia Airport. The strongest winds are from the southwest, but shorelines of downtown Olympia, East Bay, and West Bay are exposed to waves generated only by wind from the north. Therefore, the wave setup analysis focuses on waves only from the northern quadrant. Return periods and corresponding wind speeds from the north are shown in Table 3.

Table 3. Return period wind speeds for wave modeling in Budd Inlet

Return Period (yr)	Wind Speed From North	
	(miles per hour)	(knots)
10	27.7	24.1
50	35.5	30.9
100	39.2	34.1
500	45.8	39.8
Wind speeds based on data from Olympia Airport adjusted for exposure and over water		

Weather conditions that produce extreme winds are frequently the conditions that also produce large tidal residuals. Therefore, because of the linkage between high tides and strong winds, wave modeling was performed using water levels listed in Table 2 and wind speeds in Table 3 with matching return periods. Waves were modeled using the two-dimensional numerical model SWAN (Holthuijsen 2004). Bathymetry for the large-scale grid was developed from the Puget Sound Digital Elevation Model (Finlayson). Close to the project area shoreline a high resolution grid was created using data merged from other sources, including the Corps of Engineers hydrographic surveys. Figure 6 shows the large grid bathymetry, with depth scaled in color format. Wave height output by SWAN is plotted with color format for 10-, 50-, 100-, and 500-year return period storms in Figures 7 through 10.

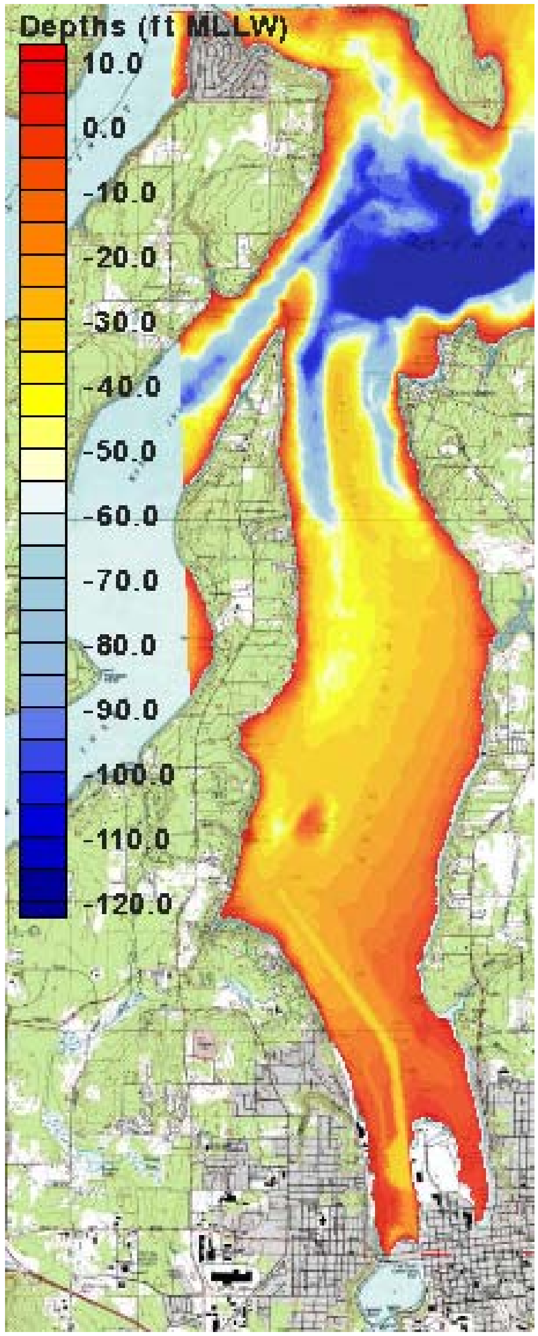

Figure 6. Bathymetry of wave modeling area for Budd Inlet

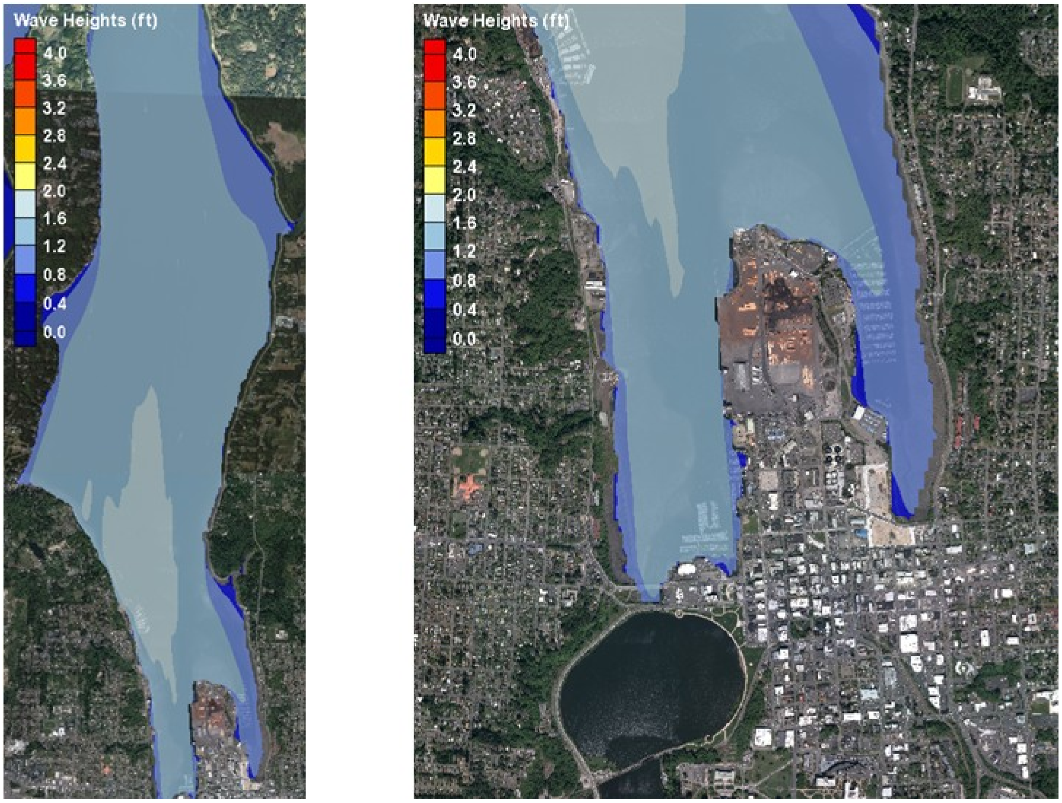

Figure 7. Wave height pattern representing 10-year return period storm

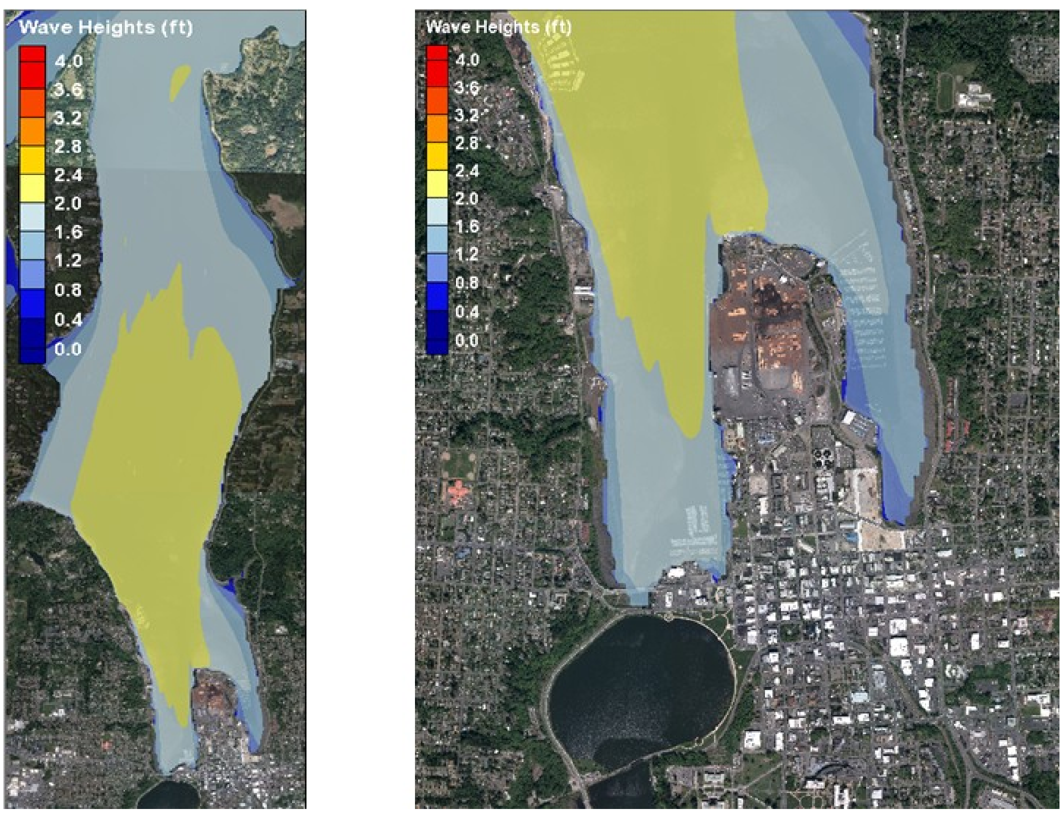

Figure 8. Wave height pattern representing 50-year return period storm

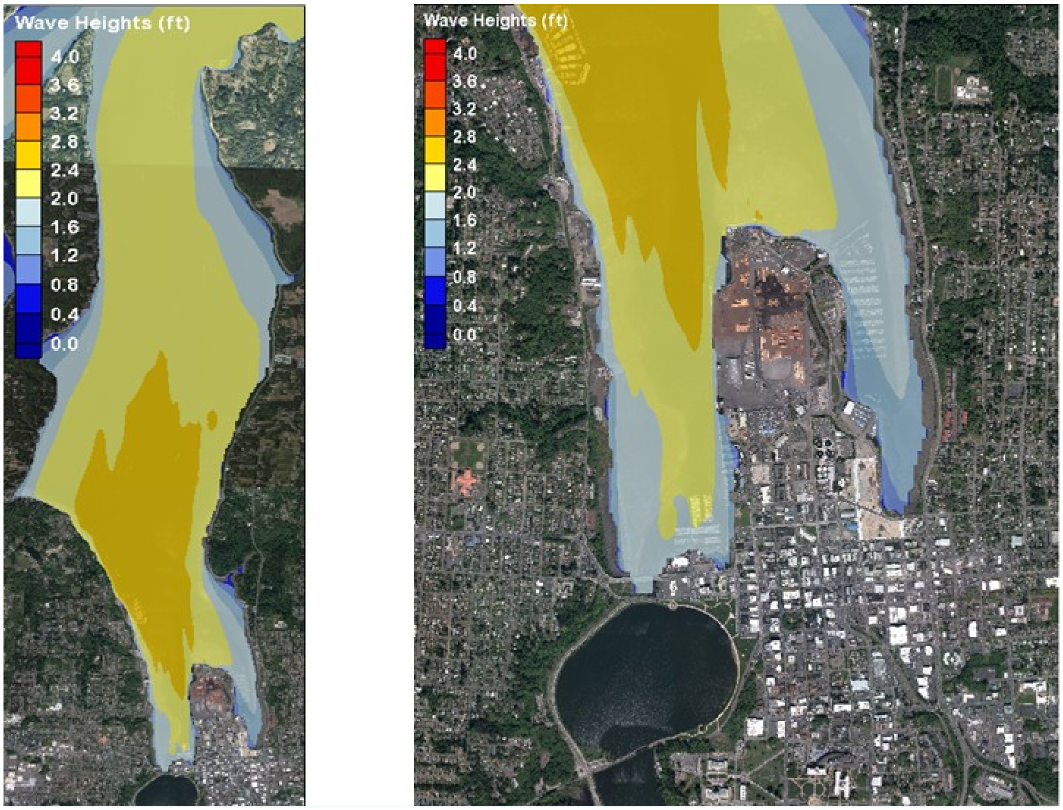

Figure 9. Wave height pattern representing 100-year return period storm

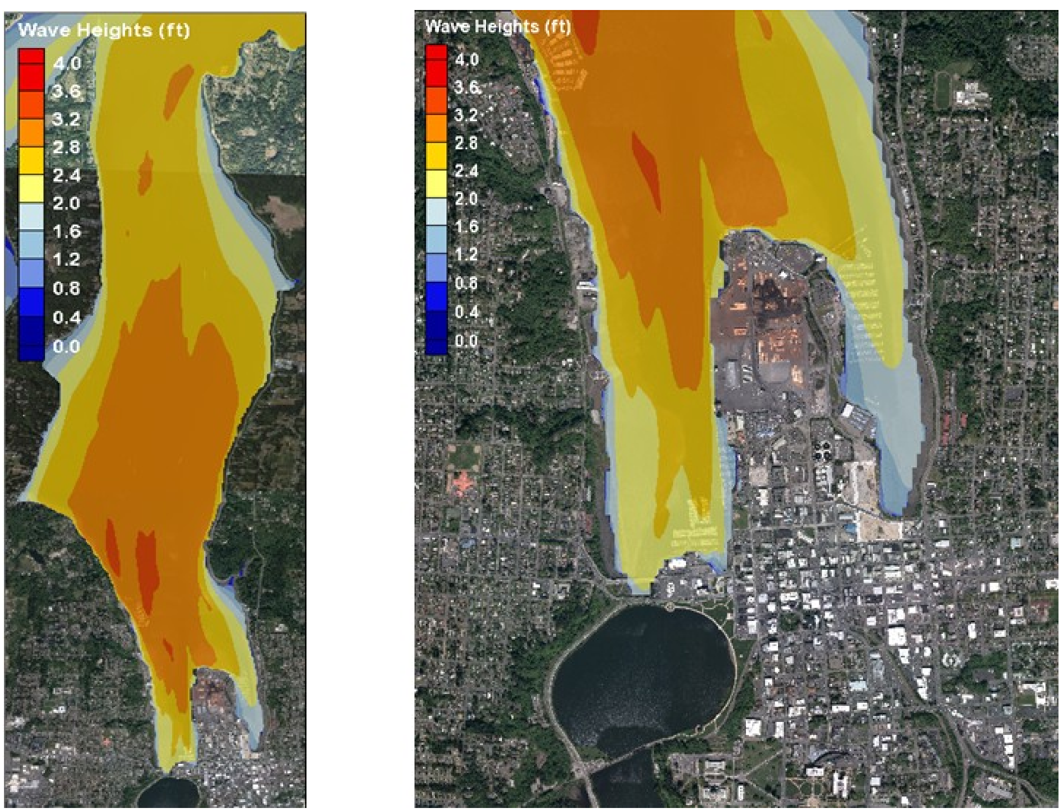

Figure 10. Wave height pattern representing 500-year return period storm

Wave height was extracted at 24 grid locations offshore of the project shoreline for use in calculating wave setup, as well as wave runup and overtopping for wave barrier design. Locations of wave extraction points are at the seaward ends of transects shown in Figure 11. Extracted wave height and period for the modeled cases are shown in Table 4.

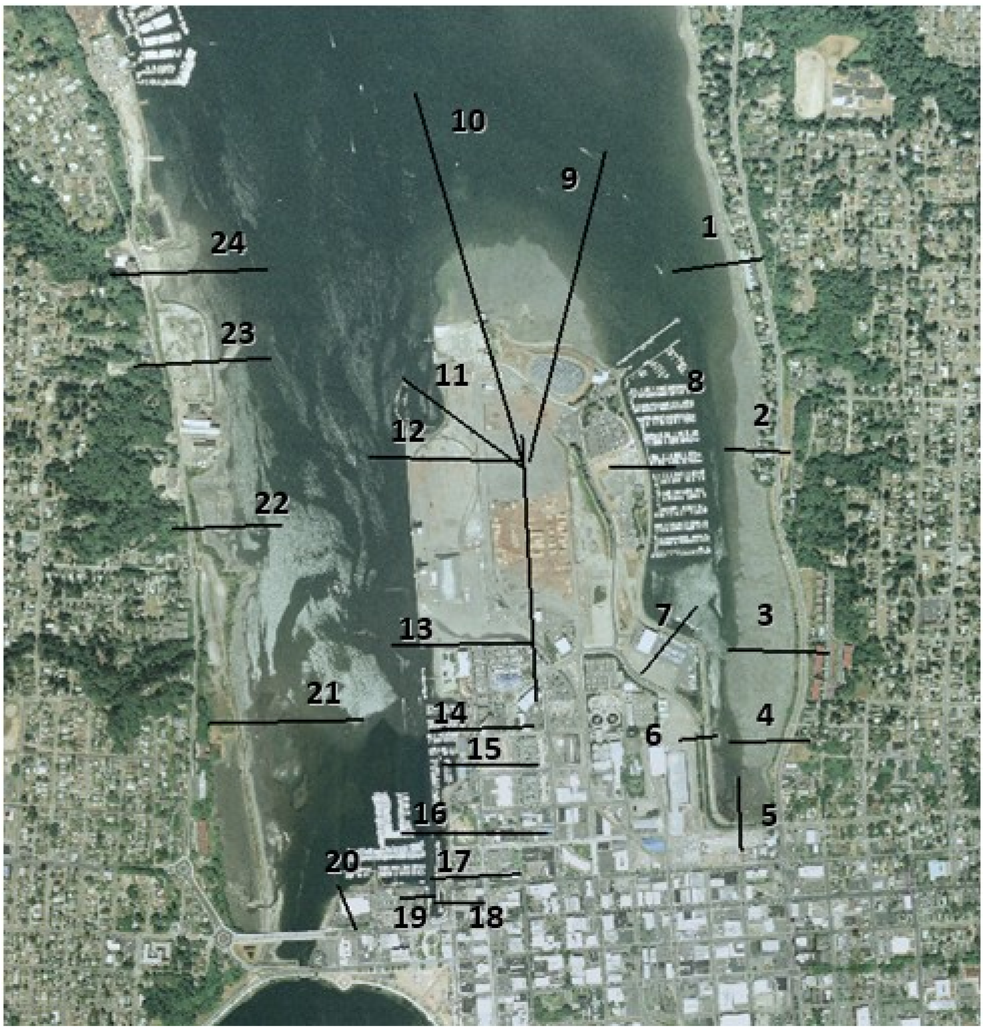

Figure 11. Wave information extraction point locations at analysis transects

Table 4. Wave information at extraction points in Budd Inlet model grid

	10-year Storm			50-year Storm			100-year Storm			500-year Storm		
Node	Wave Height (ft)	Peak Period (sec)	Direction (deg)	Wave Height (ft)	Peak Period (sec)	Direction (deg)	Wave Height (ft)	Peak Period (sec)	Direction (deg)	Wave Height (ft)	Peak Period (sec)	Direction (deg)
1	1.2	2.6	335.0	1.61	3.0	335.0	1.87	3.0	335.0	2.27	3.5	335.0
2	1.1	2.6	335.0	1.50	3.0	335.0	1.74	3.0	335.0	2.05	3.0	335.0
3	1.0	3.0	345.0	1.31	3.5	345.0	1.49	4.1	345.0	1.78	4.1	345.0
4	0.8	2.2	355.0	0.98	2.2	355.0	1.11	2.6	355.0	1.31	2.2	355.0
5	0.8	2.2	345.0	0.98	2.2	345.0	1.15	2.6	345.0	1.32	2.6	345.0
6	0.7	2.2	355.0	0.96	2.6	355.0	1.07	2.6	355.0	1.27	2.2	355.0
10	1.5	3.0	355.0	2.13	3.0	355.0	2.42	3.5	355.0	2.98	3.5	355.0
13	1.4	3.5	355.0	1.92	4.1	355.0	2.10	4.1	355.0	2.53	4.1	355.0
14	1.1	3.0	345.0	1.39	3.5	345.0	1.54	3.5	345.0	1.85	4.1	345.0
15	1.0	3.0	345.0	1.27	2.6	345.0	1.40	3.5	345.0	1.69	3.0	335.0
16	1.2	3.5	355.0	1.67	4.1	355.0	1.82	4.1	355.0	2.14	4.1	355.0
17	1.2	3.0	355.0	1.64	3.5	355.0	1.77	3.5	355.0	2.10	3.5	345.0
18	1.1	3.0	345.0	1.46	3.5	345.0	1.58	3.5	345.0	1.86	3.5	345.0
19	1.0	3.0	355.0	1.29	3.0	355.0	1.41	3.5	355.0	1.65	3.5	355.0
20	1.3	3.0	355.0	1.59	3.0	355.0	1.75	3.5	355.0	2.06	3.5	355.0
21	1.3	3.0	5.0	1.66	3.0	5.0	1.81	3.5	5.0	2.12	3.5	5.0
22	1.4	2.6	5.0	1.86	3.0	15.0	2.05	3.0	15.0	2.44	3.5	15.0
23	1.5	2.6	5.0	2.05	3.0	5.0	2.26	3.5	5.0	2.75	3.5	5.0
24	1.6	3.0	355.0	2.17	3.0	5.0	2.40	3.5	355.0	2.96	4.1	5.0

3.4. Total Water Level for Tidal Flooding

To determine a total water level, average wave setup values corresponding to each of the four return period storms were added to the tide elevations. Average wave setup calculated for a return period is the average of individual wave setup values calculated at the peninsula shoreline, Transects 5 through 19. Wave setup was calculated using equation D.4.5-3 of FEMA's Pacific Coast Guidelines (FEMA 2005).

$$\overline{\eta_o} = \left(-\frac{\kappa}{16} + \frac{(3/8)\kappa}{1+(3/8)\kappa^2}\right)H_b$$

Where

$\overline{\eta_o}$ = static setup at the shoreline
κ = wave breaker index
H_b = breaking wave height

Average wave setup values range from 0.40 ft to 0.44 ft for return periods of 10 through 500 years. Total water level at the shoreline for return periods and increments of sea level rise are shown in Table 5.

Table 5. Total water level for return periods and sea level rise amounts at shoreline

Return Period (yr)	TOTAL WATER LEVEL (ft, NGVD)					
	Sea Level Rise Amount					
	0	0.25 ft	0.50 ft	1 ft	2 ft	50 inches
10	10.71	10.96	11.21	11.71	12.71	14.88
50	11.19	11.44	11.69	12.19	13.19	15.36
100	11.37	11.62	11.87	12.37	13.37	15.54
500	11.72	11.97	12.22	12.72	13.72	15.89

Graphics were prepared to map precisely where the calculated flood elevations exceeded ground surface elevation, and the depth of flooding in those areas. Flooded areas determined only by tide and wave effects do not illustrate all the flooded areas caused by overflow of the gravity drain system, although there is much overlap. Drain system flooding is added to the graphics of total water level flooding in Section 3.6 Mapping of Return Period Flooding. Development of flooding depths and areas resulting from combining tide and runoff is presented below.

3.5. Flood Potential of Combined Tides and Precipitation

Previous analysis of the storm drain hydraulics (Clear Creek Solutions 2009) demonstrated that the simultaneous occurrence of extremely high tides with large precipitation runoff was the cause of flooding by the Indian/Moxlie Creek system. The 72-inch-diameter outfall at East Bay has no tide gate. High tide levels cause water from the bay to inundate the pipe network. Capacity of the system to discharge precipitation runoff entering catch basins and the pipe at and downstream from the Indian/Moxlie confluence is much reduced by the tidal water filling the system. Determining the probability of joint occurrence of high tides and large runoff was therefore required.

Joint probability can be calculated by multiplying events' individual probabilities together if the events are independent. The observed tide level is the sum of the astronomical component, which is predictable and repeating, and tidal residual, which includes low barometric pressure. The tidal residual is often significant during periods of winter rain storms because precipitation and low barometric pressure are usually linked. Tidal residual is illustrated in Figure 12. The astronomical tide and precipitation are independent.

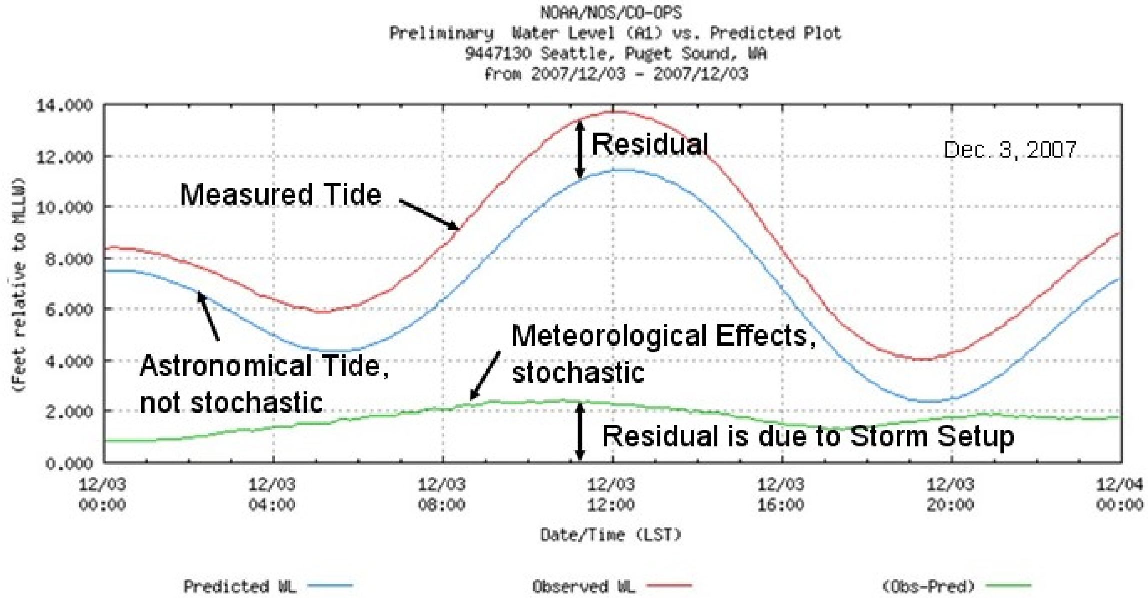

Figure 12. Example of astronomical tide and tidal residual

Return period statistics of runoff volume were computed using the Log Pearson Type III distribution. Return period and runoff volume are plotted in Figure 13. Data points for two notable rain storms, in 2007 and 1996, are identified. Table 6 lists the date, runoff volume, and corresponding return period for the largest 20 runoff events in order of decreasing volume in columns 1, 2, and 3.

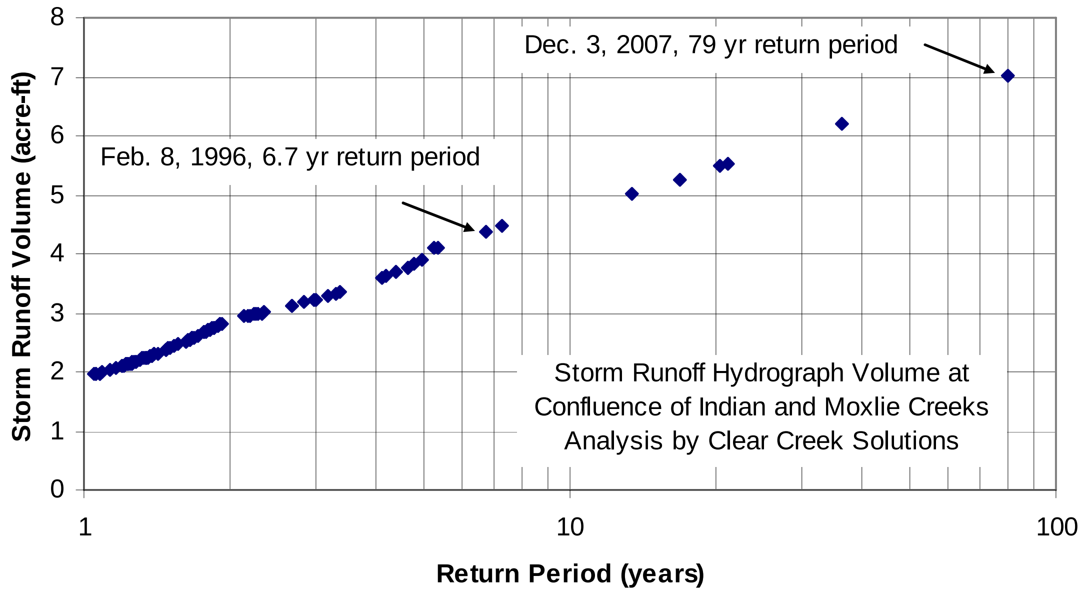

Figure 13. Extreme value distribution of runoff volumes, Indian/Moxlie Creek drainage

Table 6. Precipitation runoff volumes, coincident tide heights, and exceedance frequency

Precipitation Runoff				Predicted Tide Height			
	Runoff	Return	Runoff	Higher		Tide	Combined
	Volume	Period	Exceed.	High Water	Rank in	Exceed.	Exceed.
Date	(acre-ft)	(Yr)	Frequency	(ft MLLW)	Epoch	Frequency	Frequency
12/3/2007	**7.02**	79.3	0.0126	**14.70**	3935	0.4989	**0.00629**
11/24/1990	6.19	36.3	0.0275	14.80	3369	0.4271	0.01176
11/6/2006	5.53	21.1	0.0475	15.60	1211	0.1535	0.00729
1/9/1990	5.49	20.4	0.0489	15.60	1211	0.1535	0.00751
11/14/2001	5.25	16.9	0.0592	15.60	1211	0.1535	0.00909
10/20/2003	5.02	13.4	0.0744	13.90	6232	0.7902	0.05881
1/18/1986	4.49	7.2	0.1380	14.70	3677	0.4662	0.06434
2/8/1996	**4.38**	6.7	0.1489	**15.60**	1333	0.1690	**0.02516**
4/4/1991	4.11	5.3	0.1876	13.30	8035	1.0187	0.19108
11/23/1986	4.09	5.3	0.1897	14.60	3990	0.5059	0.09596
12/16/2001	3.88	5.0	0.2010	16.20	297	0.0377	0.00757
10/6/1981	3.82	4.8	0.2087	12.80	9278	1.1764	0.24546
12/3/1982	3.78	4.7	0.2145	16.40	196	0.0249	0.00533
11/25/1998	3.77	4.6	0.2152	15.10	2485	0.3151	0.06780
10/21/2003	3.68	4.4	0.2284	14.30	4948	0.6274	0.14328
10/31/1994	3.61	4.2	0.2400	14.80	3369	0.4271	0.10253
12/15/1999	3.60	4.1	0.2426	15.40	1684	0.2136	0.05180
11/30/1994	3.35	3.4	0.2970	15.70	995	0.1261	0.03746
1/7/2007	3.32	3.3	0.3040	15.80	795	0.1007	0.03063
4/23/1996	3.28	3.2	0.3141	13.60	7163	0.9082	0.28525

Higher high tide elevations predicted for the date of each runoff event are listed in column 5 of Table 6 (in ft MLLW) for the 20 largest runoff volumes. (Tabulation of the full data set is in file 3.1.) Predicted tides were selected for combined probability analysis because predicted tide is independent of precipitation. Joint occurrences of predicted tide height and runoff volume are plotted in Figure 14. Large runoff events are assumed to have a duration that includes a higher high tidal phase. The implication is that the peak of the tide would occur during a time that would have the most effect on flood discharge in the system. The tidal residual is related through meteorology, at least partially, to the rain storm itself. Therefore, some of the observed tide height is related to the phenomenon that produced the runoff. The exceedance probability of predicted tides was determined by ranking the higher high tides occurring in a tidal epoch. A tidal epoch is the length of the cycle in which tidal elevations repeat approximately 19 years. A plot of the ranked predicted higher high tides is shown in Figure 15. The higher high tide predicted for December 3, 2007 was 14.70 ft, ranked 3935 of 7887 higher high tides in the epoch, and has a probability of occurrence of 0.4989. (Data are in file 3.10.) Taking the 2007 storm as an example, the chance of a runoff volume having the probability of 0.0126 in any one year occurring on the same day of a 14.7-ft predicted high tide is 0.00629. Similarly for 1996, the chance of coincidence of the observed runoff and predicted tide is 0.02516.

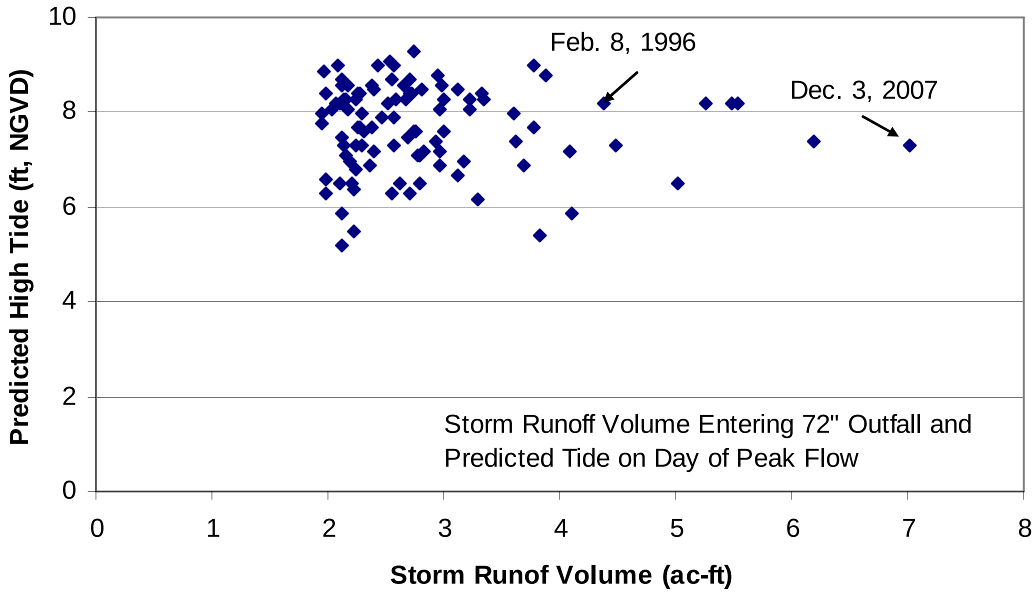

Figure 14. Joint occurrence of runoff volume and predicted tide height

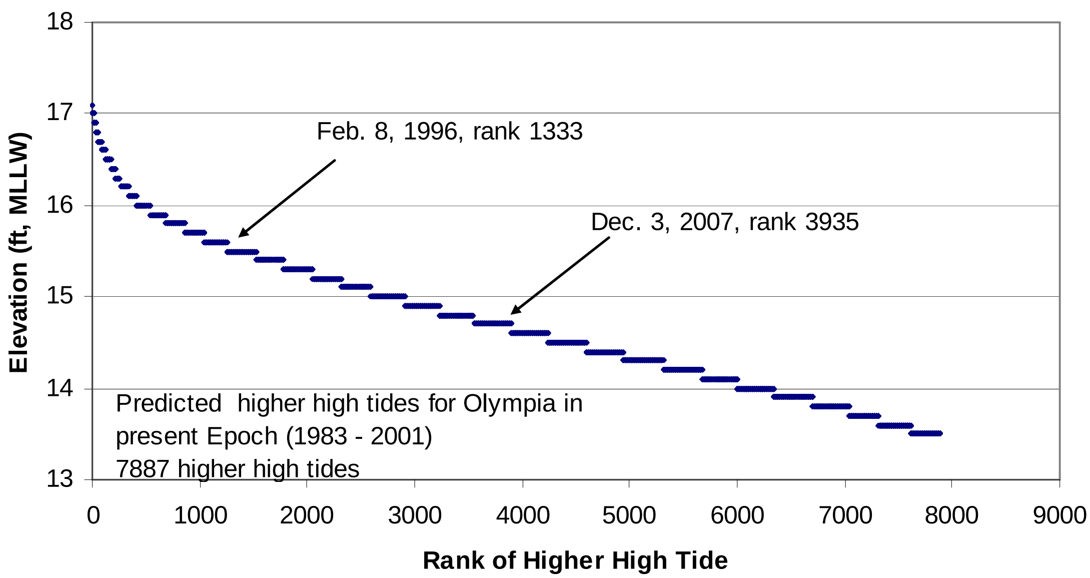

Figure 15. Predicted higher high tides in 1983–2001 tidal epoch, ranked by height

Two historical flooding events and one "maximum" event were modeled for simulating flooding. The events are December 3, 2007 (largest runoff of record, moderate tide level), February 8, 1996 (moderate runoff, high predicted tide), and the theoretical 100-year runoff volume with the 100-year tide elevation). The occurrence probabilities corresponding to these events of combined runoff and tide are 0.00629, 0.02516, and 0.0001, respectively.

The gravity storm drain system is illustrated in Figure 16. Numerical modeling of the 72-inch diameter pipe and associated pipe network of the Indian/Moxlie gravity drain system was performed with the model XPSWMM. The model simulates unsteady flow in pipes and accounts for inflow and outflow at numerous points called nodes, representing catch basins and pipe intersections. Pipe elevations, tailwater elevation, catch basin elevations, and numerous other parameters are input along with inflow rates at given nodes. Figure 17 shows hundreds of model node locations representing catch basins that are part of the 72-inch pipe system. Water surface elevations are calculated at each node. Where calculated water surface elevation exceeds that of the ground surface, flooding occurs. The aerial extent of flooding is calculated from the discharged volume and topographic data. Twenty-six nodes were selected for analyzing flooding depth and to represent flooding extent in the study area (Figure 18) because of the amount of manual analysis required. One example of plotted output for the representative nodes is the case of the February 1996 event with 2 ft of sea level rise, shown in Figure 19.

Figure 16. Gravity drain system for stormwater in downtown Olympia

Figure 17. Hydraulic model nodes at catch basin locations of 72-inch pipe system

Figure 18. Representative hydraulic model nodes at 26 locations in the 72-inch pipe system

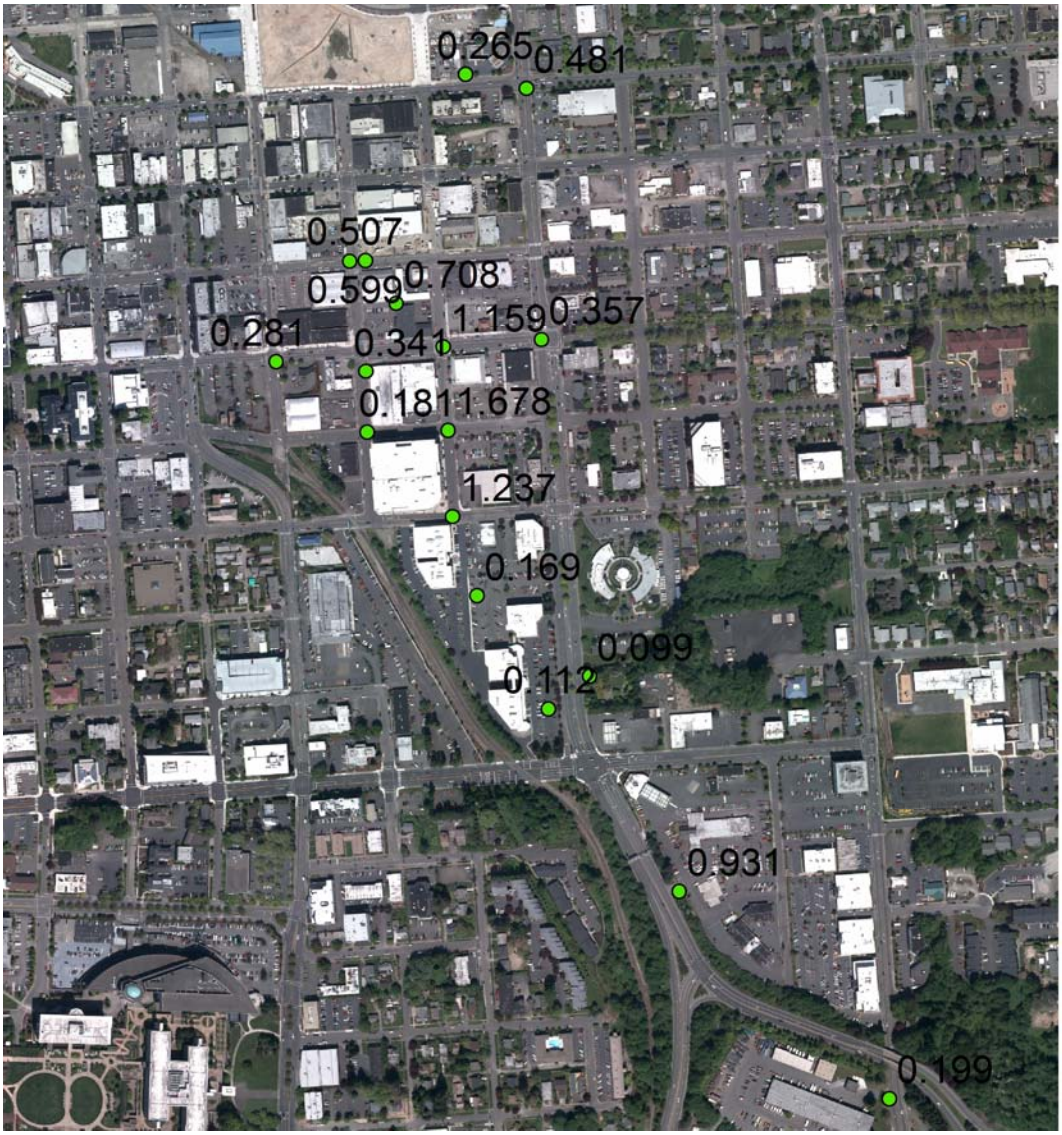

Figure 19. Example model output displayed with nodes for 1996 flood with 2 ft sea level rise

Modeling was performed for tides relative to current sea level, and repeated for sea level rise amounts of 1 ft, 2 ft, and 50 inches. Flooding depths were tabulated for each node for each flooding event and for each assumed sea level. Those flooding depths were plotted according to occurrence probability for each node. Flooding depths are plotted separately for the four sea levels in Figures 20 through 23.

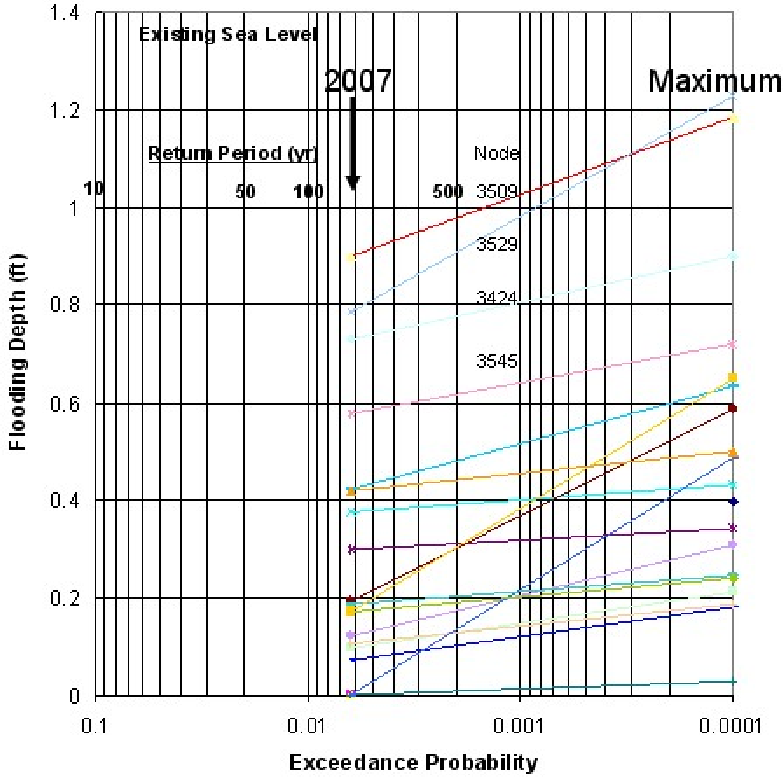

Figure 20. Flooding depths and occurrence probabilities for 26 nodes, existing sea level

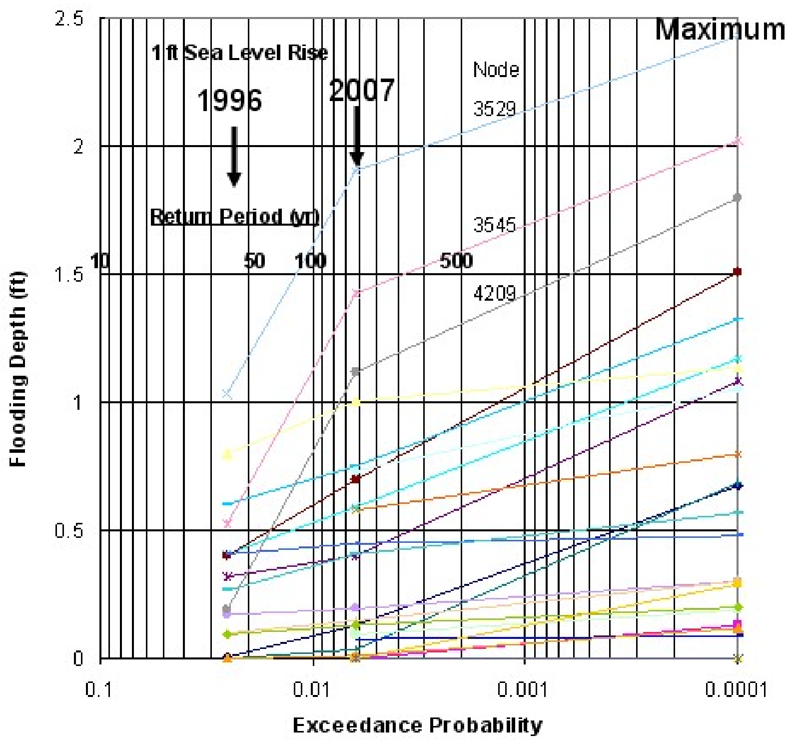

Figure 21. Flooding depths and occurrence probabilities for 26 nodes, 1 ft sea level rise

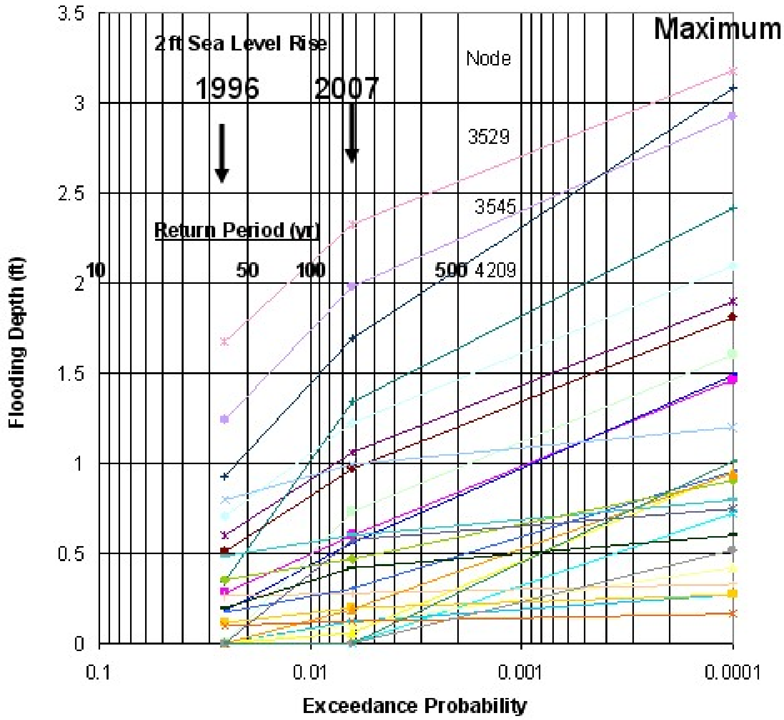

Figure 22. Flooding depths and occurrence probabilities for 26 nodes, 2 ft sea level rise

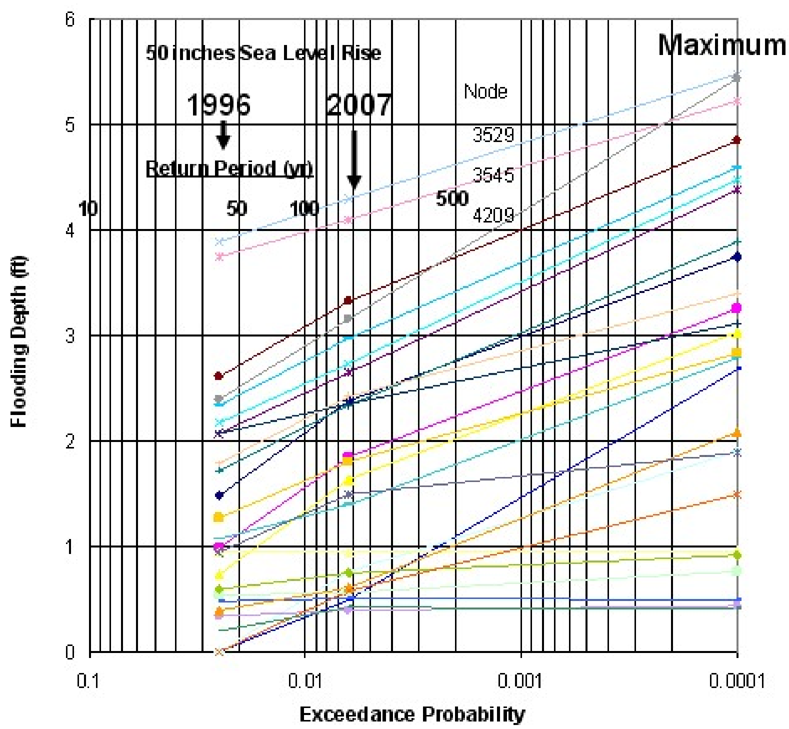

Figure 23. Flooding depths and occurrence probabilities for 26 nodes, 50 inches sea level rise

3.6. Mapping of Return Period Flooding

These plots were used to interpolate flooding depths corresponding to return periods of 10, 50, 100, and 500 years for each node separately for each sea level case. Table 7 provides those flooding depth values. Listed flooding depths were converted to flooded surface areas by way of regression relationships developed between modeled depth and calculated area representing each selected node. Flooded surface area values corresponding to nodes for the modeled cases are listed in Table 8.

Table 7. Return period flooding depth at nodes for cases of sea level rise

FLOODING DEPTH IN FEET ABOVE GROUND LEVEL																
Node No.	Existing Sea Level Return Period Combined Tide and Runoff				1 ft Sea Level Rise Return Period Tide and Runoff (yr)				2 ft Sea Level Rise Return Period Tide and Runoff (yr)				50 inches Sea Level Rise Return Period Tide and Runoff (yr)			
	10	50	100	500	10	50	100	500	10	50	100	500	10	50	100	500
2933						0.03	0.1	0.25		0.35	0.5	0.8	1	1.6	2.1	2.8
3024							0.1	0.1			0.1	0.35		1.1	1.6	2.2
3047												0.2		0.9	1.3	2
3229				0.38		0.4	0.6	0.65	0.3	0.65	0.9	1.3	1.7	2.3	2.5	3.2
3287			0.3	0.32		0.3	0.4	0.6		0.6	0.8	1.2	1.5	2.2	2.5	3.2
3292				0.3		0.4	0.6	0.9		0.5	1	1.6	2	2.7	3.1	3.8
3293				0.03				0.25		0.25	0.46	0.8	1.3	1.8	2.1	2.8
3300				0.1				0.11			0.1	0.18		0.1	0.3	1.1
3391				0.5		0.6	0.75	0.9	0.4	0.78	1.04	1.5	1.8	2.4	2.7	3.4
3424				0.75				0.8		0.2	0.5	0.9			0.25	1.05
3489				0.1				0.1			0.1	0.2	0.3	0.5	0.5	0.6
3509		0.5	0.88	1		0.7	0.9	1	0.3	0.7	0.9	1	0.5	0.9	0.9	1
3529				0.9		1.0	1.6	2	1	1.8	2.1	2.55	3.5	3.9	4.2	4.6
3545				0.62		0.5	1.1	1.55	0.8	1.4	1.75	2.25	3.3	3.8	4	4.5
3573				0.18		0.18	0.2	0.25		0.15	0.23	0.23	0.2	0.3	0.4	0.4
3604			0.1	0.15			0.1	0.2		0.2	0.3	0.5	1.3	1.8	2.1	2.6
3700			0.1	0.2		0.3	0.4	0.45	0.2	0.4	0.6	0.7		0.4	0.7	0.8
3757				0.21		0.2	0.3	0.45		0.2	0.4	0.6	0.7	1.1	1.3	1.7
3779								0.1		0.1	0.1	0.2	0.2	0.5	0.6	0.8
3780								0.1			0.2	0.4	1.1	1.3	1.5	2
3934								0.1		0.1	0.1	0.15		0.1	0.2	1.0
4006				0.2			0.3	0.65		0.1	0.35	0.7		0.1	0.4	0.8
4029								1.0				0.15	0.7	1	1.1	1.3
4209				0.3		0.2	0.8	1.3	0.2	1.05	1.48	2.05	1.5	2.3	2.9	3.8
4455												0.3	1.7	2.1	2.3	2.5
4863				0.42		0.2	0.4	0.45		0.2	0.4	0.45		0.2	0.4	0.5

Table 8. Return period flooded surface area at nodes for cases of sea level rise

FLOODING AREA IN SQUARE FEET																
Node No.	Existing Sea Level Return Period Combined Tide and Runoff				1 ft Sea Level Rise Return Period Tide and Runoff (yr)				2 ft Sea Level Rise Return Period Tide and Runoff (yr)				50 inches Sea Level Rise Return Period Tide and Runoff (yr)			
	10	**50**	**100**	**500**	**10**	**50**	**100**	**500**	**10**	**50**	**100**	**500**	**10**	**50**	**100**	**500**
2933						22037	22165	22440		22623	22898	23448	23815	24914	25830	27113
3024							4868	4868			4868	5526		7500	8816	10395
3047												5131		6974	8027	9869
3229				5605		5658	6184	6316	5395	6316	6974	8027	9079	10659	11185	13027
3287			5395	5447		5395	5658	6184		6184	6711	7763	8553	10395	11185	13027
3292				22532		22715	23082	23631		22898	23815	24914	25647	26930	27663	28946
3293				4684				5263		5263	5816	6711	8027	9343	10132	11975
3300				4868				4895			4868	5079		4868	5395	7500
3391				5921		6184	6579	6974	5658	6658	7342	8553	9343	10922	11711	13554
3424				6579				6711		5131	5921	6974			5263	7369
3489				4868				4868			4868	5131	5395	5921	5921	6184
3509		22898	23595	23815		23265	23631	23815	22532	23265	23631	23815	22898	23631	23631	23815
3529				23631		23815	24914	25647	23815	25281	25830	26655	28396	29129	29679	30412
3545				23118		22898	23998	24822	23448	24548	25189	26105	28029	28946	29312	30229
3573				22312		22312	22349	22440		22257	22403	22403	22349	22532	22715	22715
3604			4868	5000			4868	5131		5131	5395	5921	8027	9343	10132	11448
3700			22165	22349		22532	22715	22807	22349	22715	23082	23265		22715	23265	23448
3757				5158		5131	5395	5789		5131	5658	6184	6447	7500	8027	9079
3779								4868		4868	4868	5131	5131	5921	6184	6711
3780								4868			5131	5658	7500	8027	8553	9869
3934								4868		4868	4868	5000		4868	5131	7237
4006				22349			22532	23173		22165	22623	23265		22165	22715	23448
4029								7237				5000	6447	7237	7500	8027
4209				22532		22349	23448	24364	22349	23906	24694	25739	24731	26197	27296	28946
4455												5395	9079	10132	10659	11185
4863				22752		22349	22715	22807		22349	22715	22807		22349	22715	22898

A contour map showing node locations was prepared for each flooding case. The flooded surface area corresponding to each node was drawn on the map to match the scaled area and topographic configuration in the vicinity of the node. One example of mapped flooded area is the 100-year flooding event with 2 feet of sea level rise, showing merged areas of several nodes in Figure 24. The drawn area was digitized and combined with flooded area determined with the total water level (Section 3.4). An image of the GIS file for this example is shown in Figure 25. It is accurate to display total water level and combined flooded areas having the same occurrence probability on the same figure because they represent processes having the same probability, although they are derived from statistics of different populations. GIS files, including graphics of flooded areas corresponding to the four return periods and six amounts of sea level rise are contained in file 3.19. Graphics of all cases are contained in Appendix B.

4. Evaluation of Flood Damage Vulnerability

4.1. Inundation Zones

Delineated floodplains and flood hazard zones are information found on Flood Insurance Rate Maps (FIRM) of the Federal Emergency Management Agency (FEMA). The maps are a basis for developing and enforcing land use regulations at the local level. The FIRM currently in effect for Olympia is shown in Figure 26. The map was published in 1982 and lists a Base Flood Elevation (100-year return period water level) of 11 ft (NGVD) for Budd Inlet. Minor changes have been made to the FIRM in the years since. A Letter of Map Revision approved in 2003 changed the Base Flood Elevation (BFE) of Capitol Lake from 11 ft to 12 ft NGVD.

The Flood Insurance Rate Map shows parts of the peninsula within the floodplain. The BFE is shown rounded to the nearest foot on the FIRM. A more precise elevation is not known because engineering details of the Flood Insurance Study (FIS) are not available. The amount of sea level rise in the 30 years since the FIS was completed would indicate that a larger portion of downtown is subject to inundation by the 100-year flood. Updating the flood hazard area for current and future conditions is needed for effective planning.

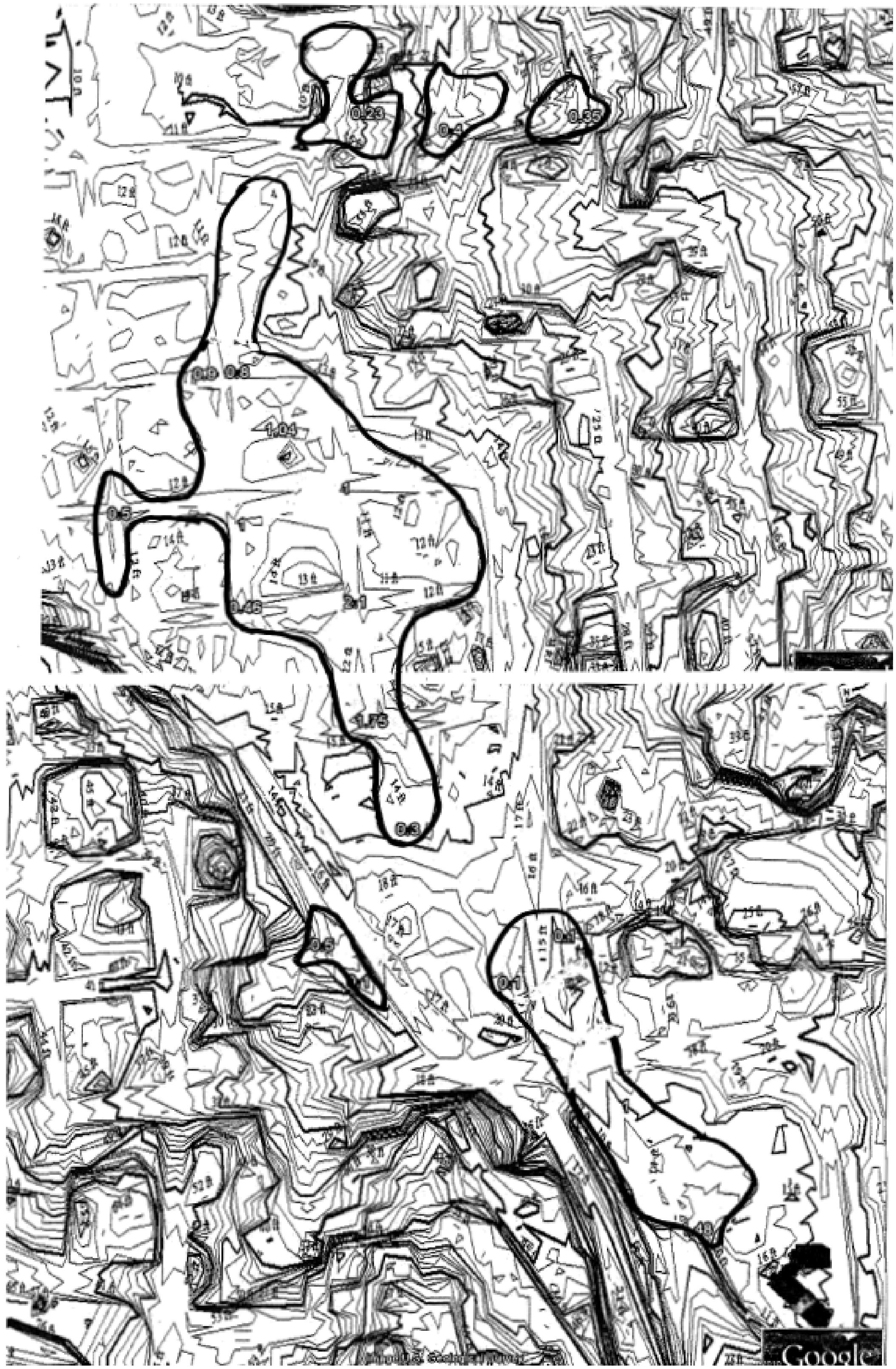

Figure 24. Flooded area mapped from flooding depth and area for modeled nodes, 100-year return period, 2 ft sea level rise

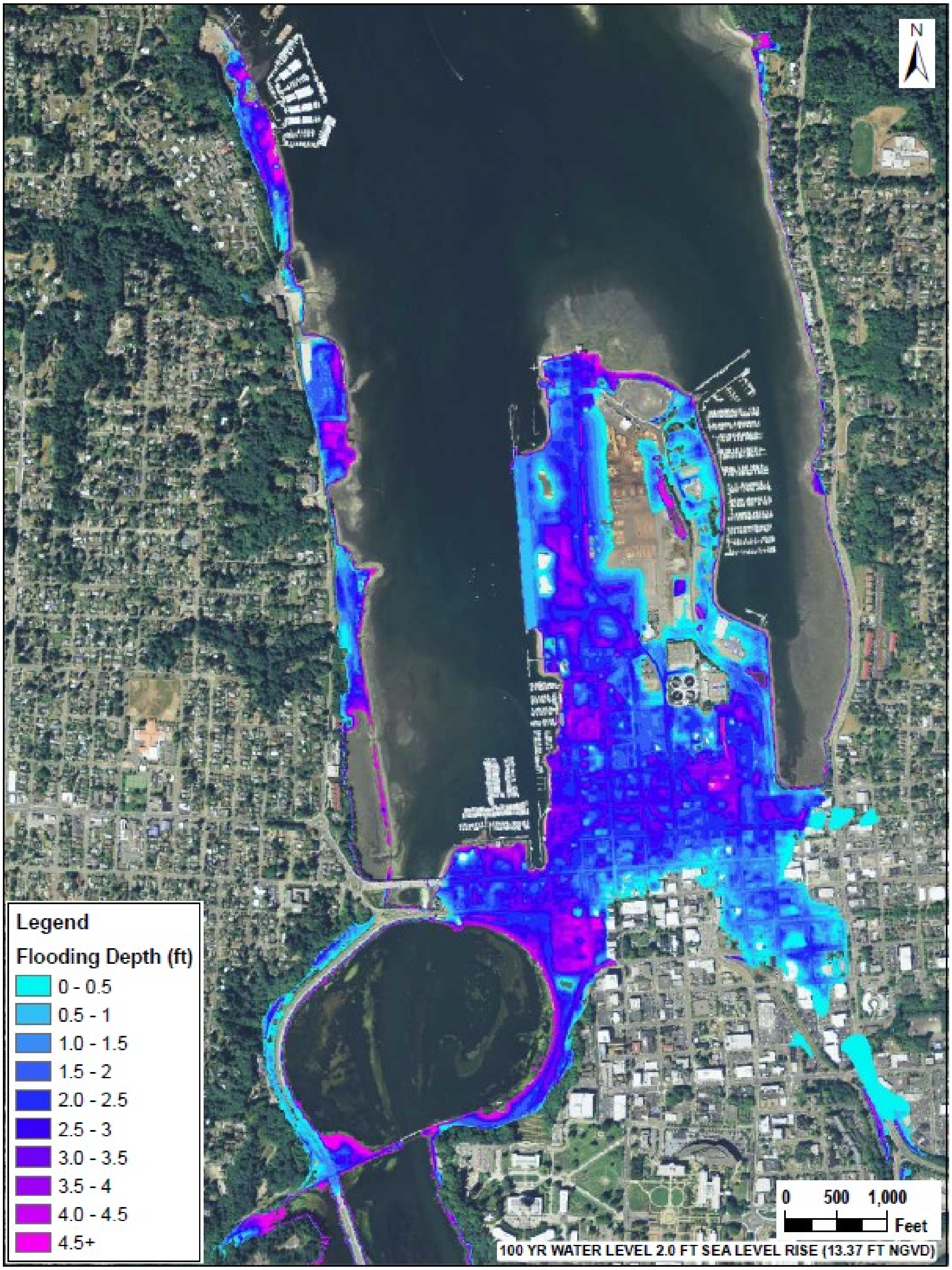

Figure 25. Flooded area and depths of 100-year return period, 2 ft sea level rise

Figure 26. Effective Flood Insurance Rate Map for Olympia shoreline, published in 1982

Areas inundated by the 100-year total water level (11.37 ft NGVD) calculated in the present study are shown in Figure 27 as a comparison with the FIRM. Figure 28 shows inundation by a 17.5-ft tidal elevation (10.08 ft NGVD) and illustrates the potential vulnerability of parts of downtown to flooding from a water level more frequently occurring than the BFE. This elevation corresponds to the 5-year return period tide only, without wave effects. The figure shows locations where water from Budd Inlet overflows the shoreline as well as flows to low parts of the upland through the storm drain system. Catch basin locations are marked with red dots in the figure.

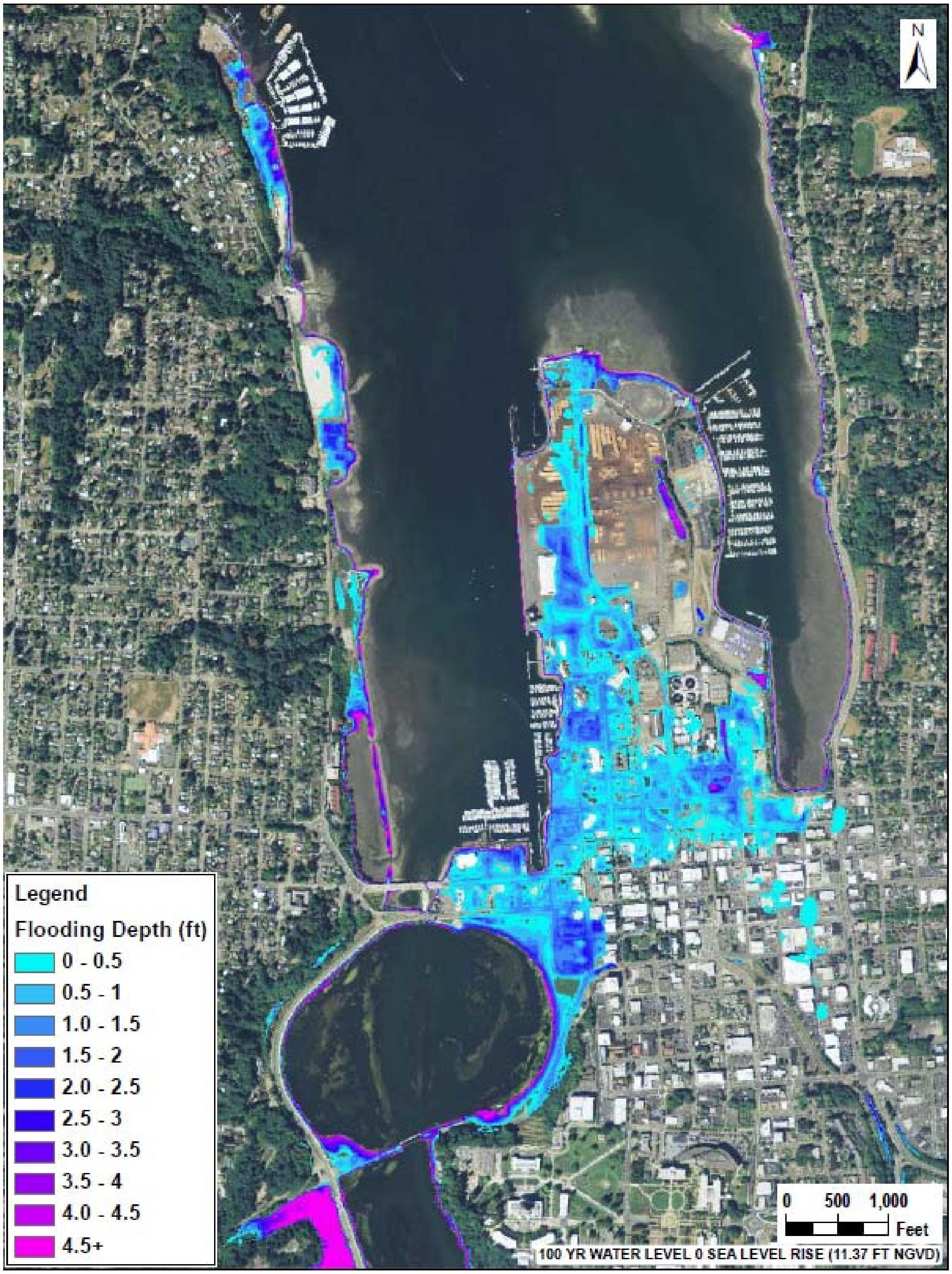

Figure 27. Inundation area due to 100-year flooding event (11.37 ft NGVD)

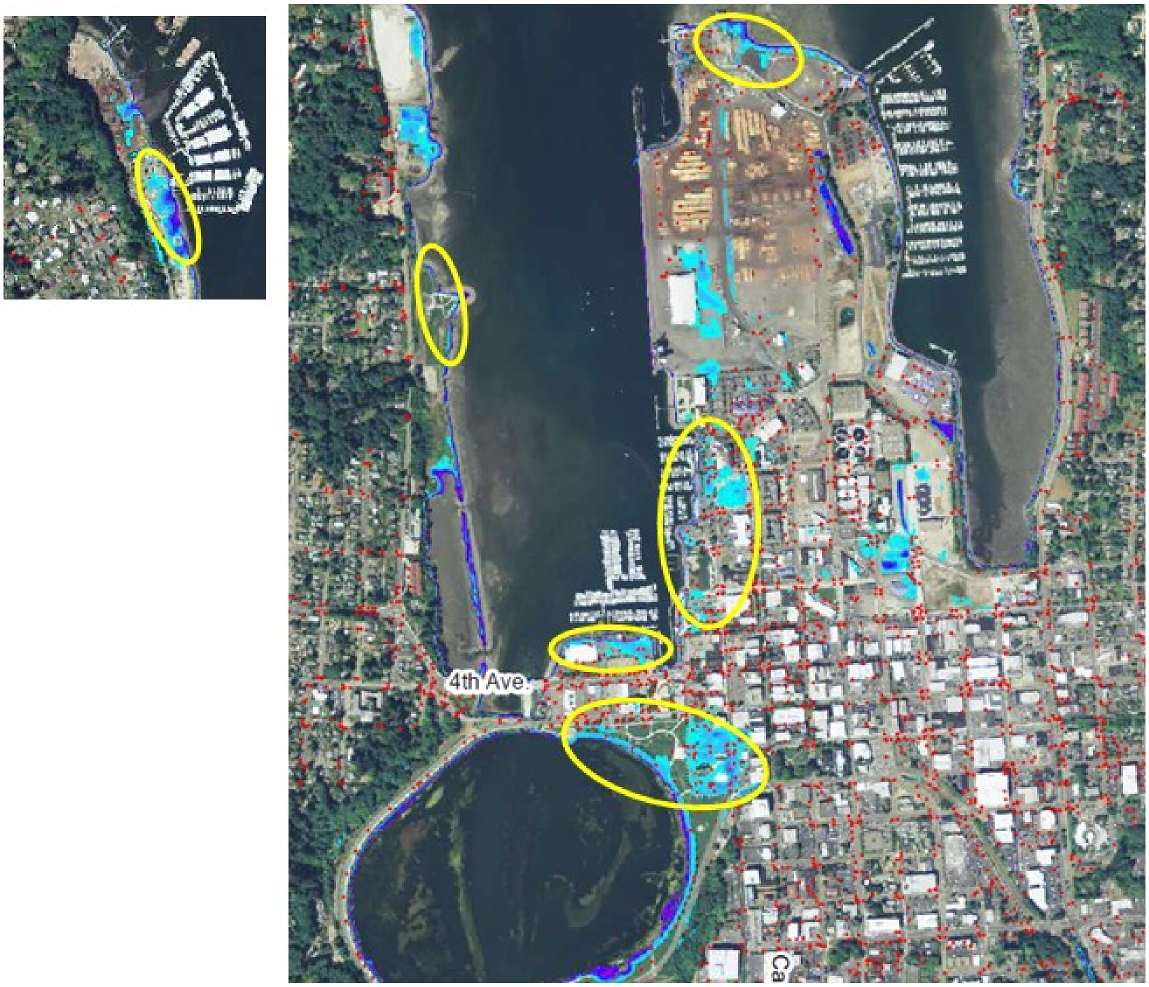

Figure 28. Inundated shoreline due to 17.5-ft tidal water level (10.08 ft NGVD)

4.2. Potential Facilities Damage

Blocks of downtown are colored in Figure 29 to indicate six categories of land uses. Essential transportation corridors are shown with red lines in the figure. The use categories are Critical Facilities, Government and Public Services, Housing, Commercial-Professional, Public-Open Space, and Undeveloped. Inundation by the 100-year total water level, also shown in Figure 27, would cover the location of the pump station at Water Street (Critical Facility) and many locations of the other categories.

A shallow water table appears to exist within the study area. An overall rise in sea level will result in a corresponding rise in groundwater levels within geologic materials which underlie the study area. These materials, within the site area, comprise Vashon recessional outwash and man-placed fill. Much of the low-lying part of the study area is underlain by man-placed fill. A rise in groundwater levels within these materials, from sea level rise, can be expected. The magnitude of groundwater rise caused by sea level rise, and seepage rates through soils below flood protection barriers is presently unknown. These elements are more thoroughly discussed in the preliminary hydrogeological and geotechnical assessment completed for the present study and which is contained in Appendix A.

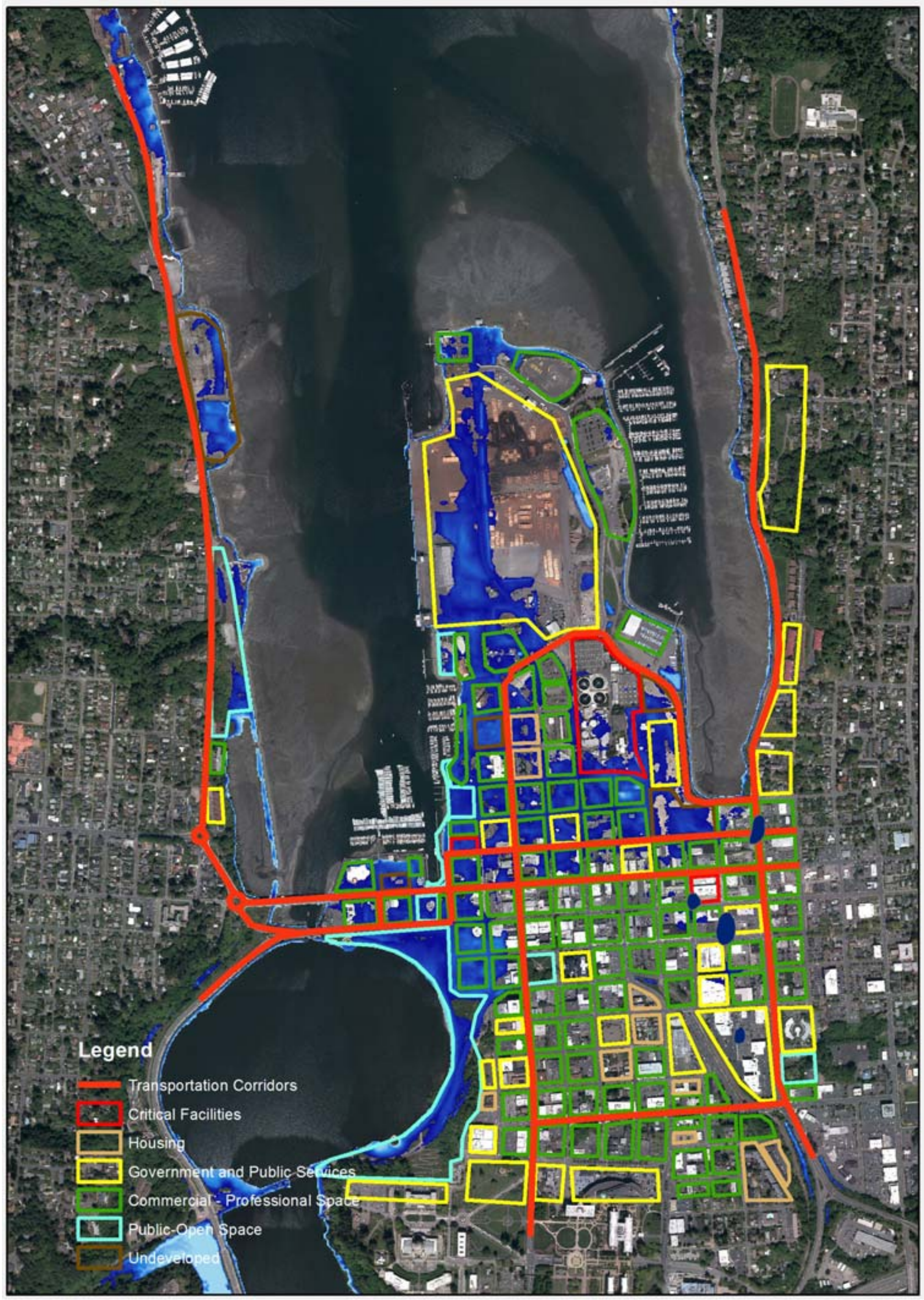

Figure 29. Land use categories and essential transportation corridors with inundation limits of 100-year total water level, existing sea level

Rising sea level can be a factor in increased shoreline damage. Several areas were identified where erosion and damage to existing shore protection is likely to occur, particularly with higher future water levels. Shore structures are also vulnerable to frequency of water levels that might not have been considered during original design.

Besides water level effects on floating structures and shore-connected ramps, wave uplift forces on fixed overwater structures become greater, as do horizontal wave forces and moments on inwater structures. Figures 30 through 35 show examples of areas of potential erosion and shore damage, and potential structural damage if no actions are taken to protect or upgrade the features.

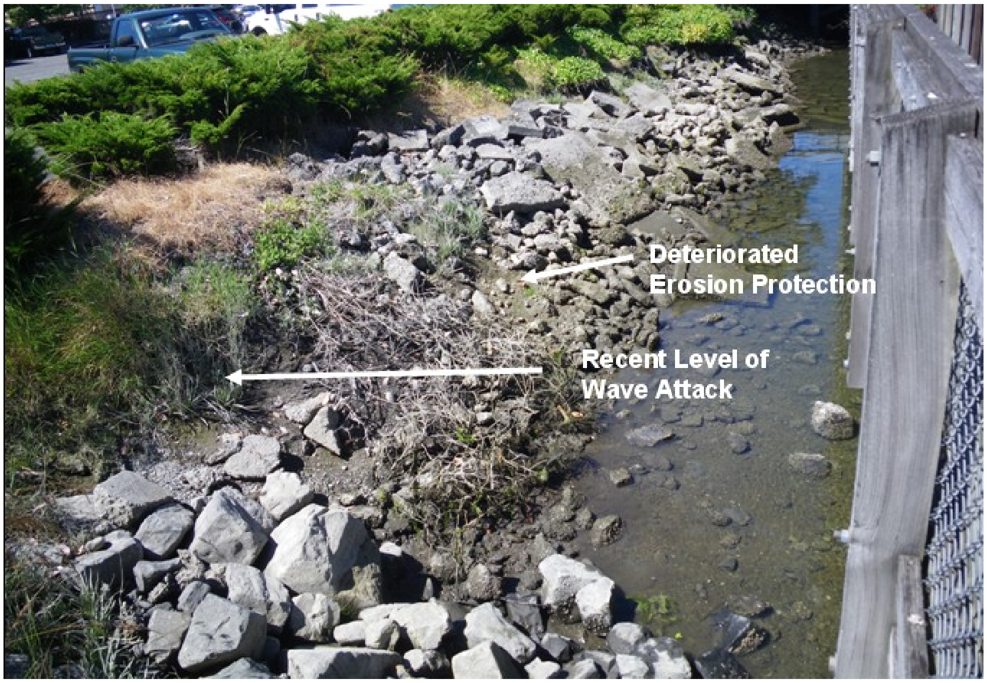

Figure 30. Bankline at Percival Landing vulnerable to increasing wave damage

Figure 31. Bankline at East Bay vulnerable to increasing loss rate

Figure 32. Fixed shore structure vulnerable to more frequent inundation

Figure 33. Overwater structure vulnerable to inundation and wave damage

Figure 34. Exposed structural supports vulnerable to wave and debris impact at higher elevation

Figure 35. Shore protection and habitat enhancement features vulnerable to increasing level of wave damage

Some catch basins in downtown are connected to the gravity stormwater system and drain through outfalls to East Bay and West Bay, and some are connected to the combined sewer system that is pumped to the LOTT treatment plant. At high water levels in Budd Inlet the open outfalls allow saltwater to inundate the gravity system and become sources of flooding for low areas. This potential flooding is due to stormwater that cannot exit the inundated outfalls and saltwater that backflows out the storm drain system. When flooding by saltwater is so extensive that flood water flows to catch basins that are pumped to LOTT, the water to be pumped could then become unlimited, a situation to be protected against. Figure 36 shows catch basins of the two systems that could be inundated by the 10-year return period total water level with existing sea level and with 0.25 ft and 0.5 ft sea level rise (10.71, 10.96, and 11.21 ft NGVD, respectively). The figure shows that the combined sewer system could receive surface water flowing over low shorelines of West Bay, even with the existing sea level.

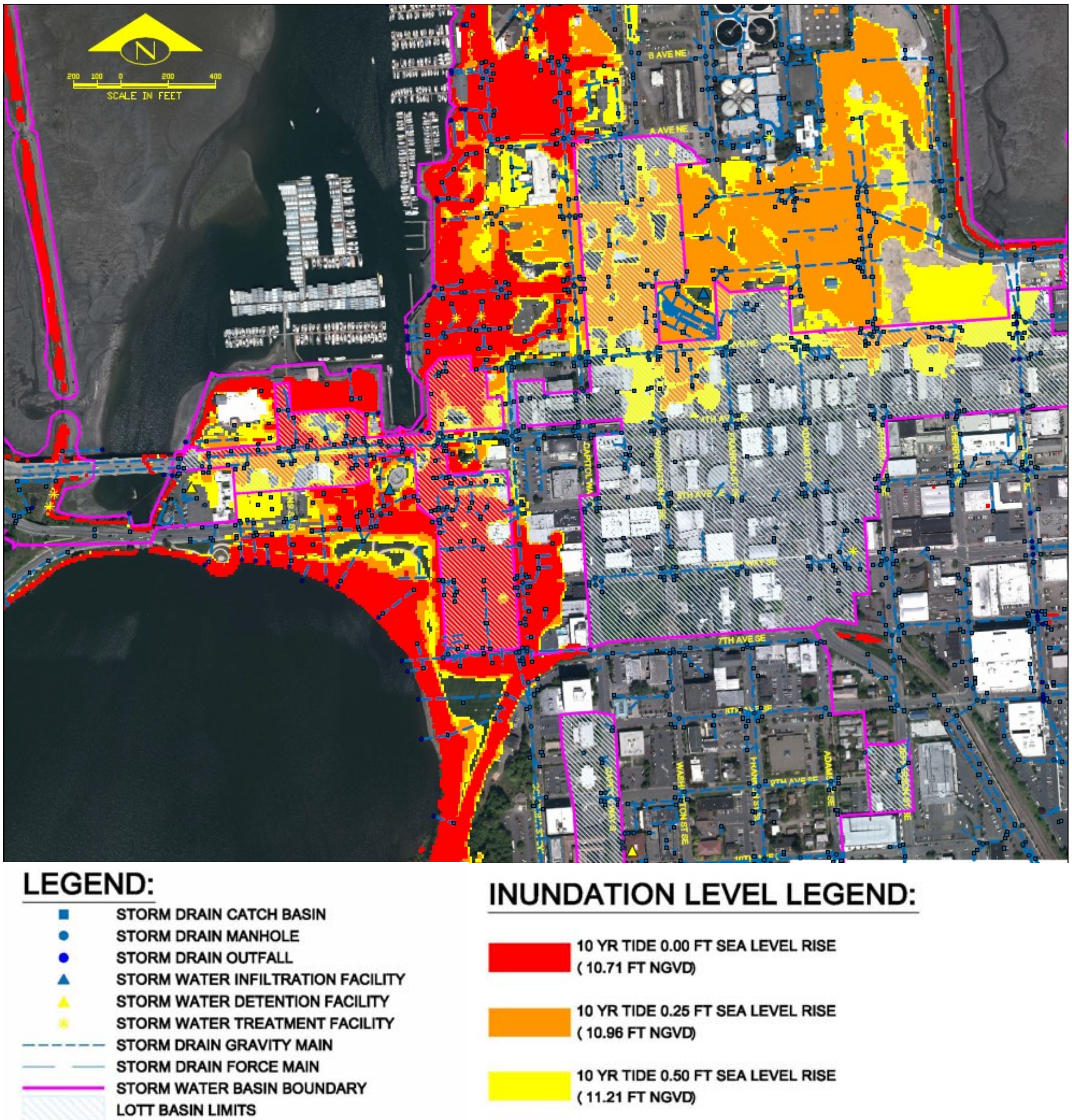

Figure 36. Inundation of catch basins for 10-year return period flood with existing sea level and sea level rise of 0.25 ft and 0.5 ft

4.3. Increasing Risks as Sea Level Rises

The elevation of the 100-year total water level is 11.37 ft. With existing sea level there is a 0.01 chance in any year of that water level occurring or being exceeded. As sea level rises the probability increases for inundation to that elevation. Figure 37 contains plots of return period water levels for six sea levels and compares them with the fixed 11.37-ft elevation. The figure shows the reduced return period (or increased probability) of reaching elevation 11.37 even with a small rise in sea level. For example, with 0.5 ft sea level rise, the elevation now corresponding to the 100-year return period water level will be the 18-year return period water level. Table 9 summarizes the plots by listing return periods corresponding to 11.37 ft for increments of sea level rise.

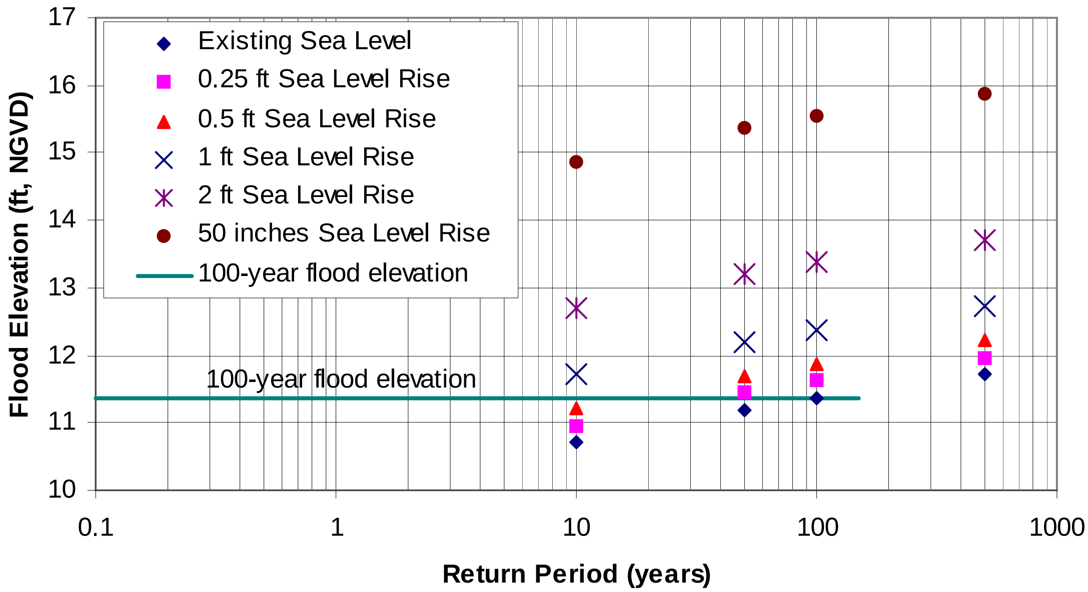

Figure 37. Return period flood elevations for cases of sea level rise

Table 9. Return period flood matching current 100-year water level for given sea level rise increments

Sea Level Rise Amount (ft)	0	0.25	0.5	1	2	50-inches
Return Period Storm Tide Reaching Current 100-year Flood Level	100	40	18	2	<1	<<1

5. Engineering Response to Flooding Risk

5.1. Emergency Response

The City currently responds to the threat of flooding due to extreme tides by having identified Budd Inlet and Capitol Lake levels that cause backflow in outfalls and where flooding results. City staff responds to identified flooding hotspots by sealing specific catch basins and, where needed, deploying portable pumps to pump accumulated water to a location where it can discharge to the Inlet. A map of hot spots developed by the City is shown in Figure 38. Areas flooded by high levels in Capitol Lake are shown in a drawing produced by the City in Figure 39. One response to high lake levels is to manually close a valve on an outfall that connects the catch basins in the area around 7th Avenue and Water Street to the lake. Standing water caused by the closed outfall is pumped to the lake with a portable pump.

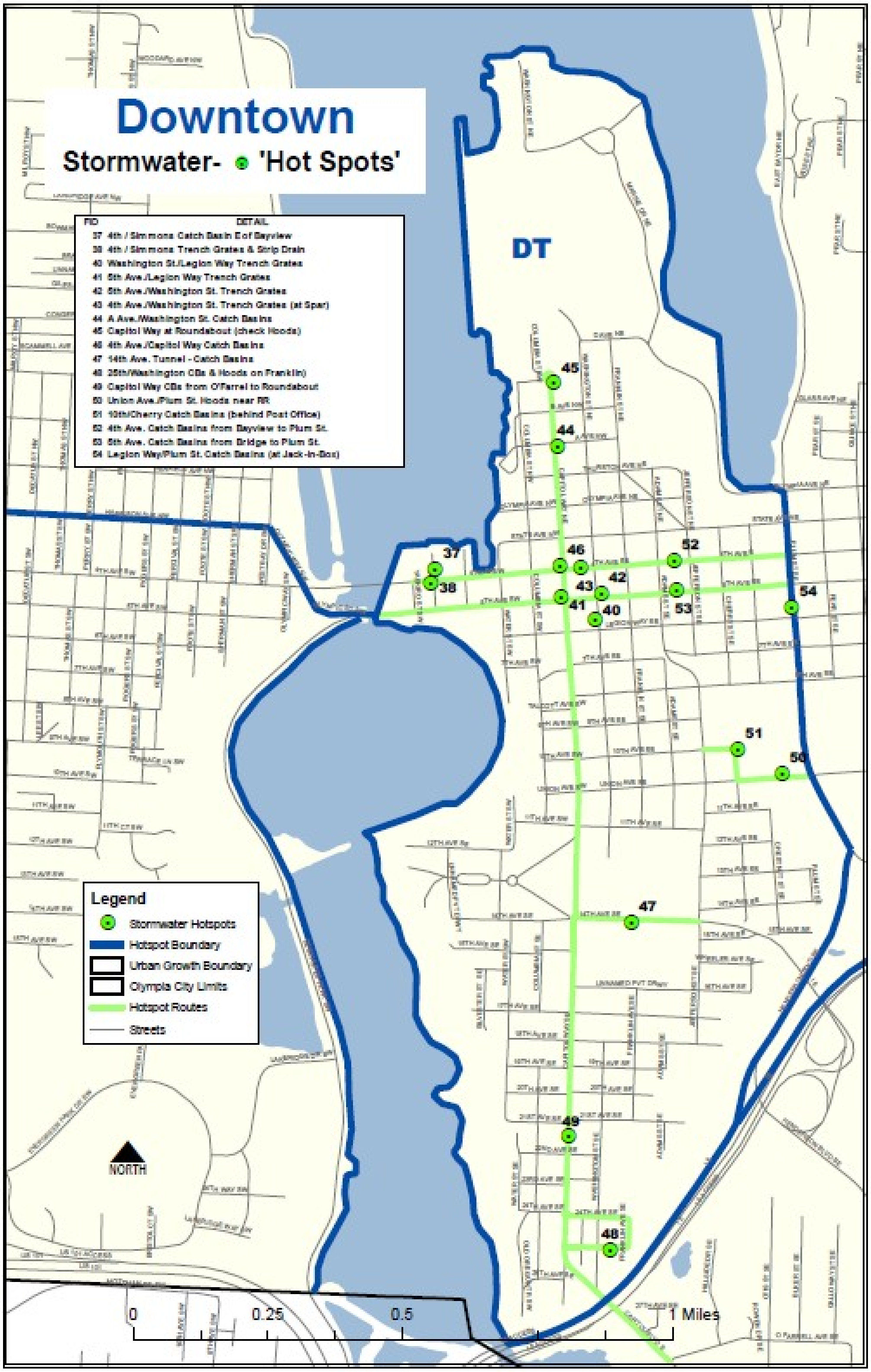

Figure 38. Flooding hot spots identified by the City of Olympia

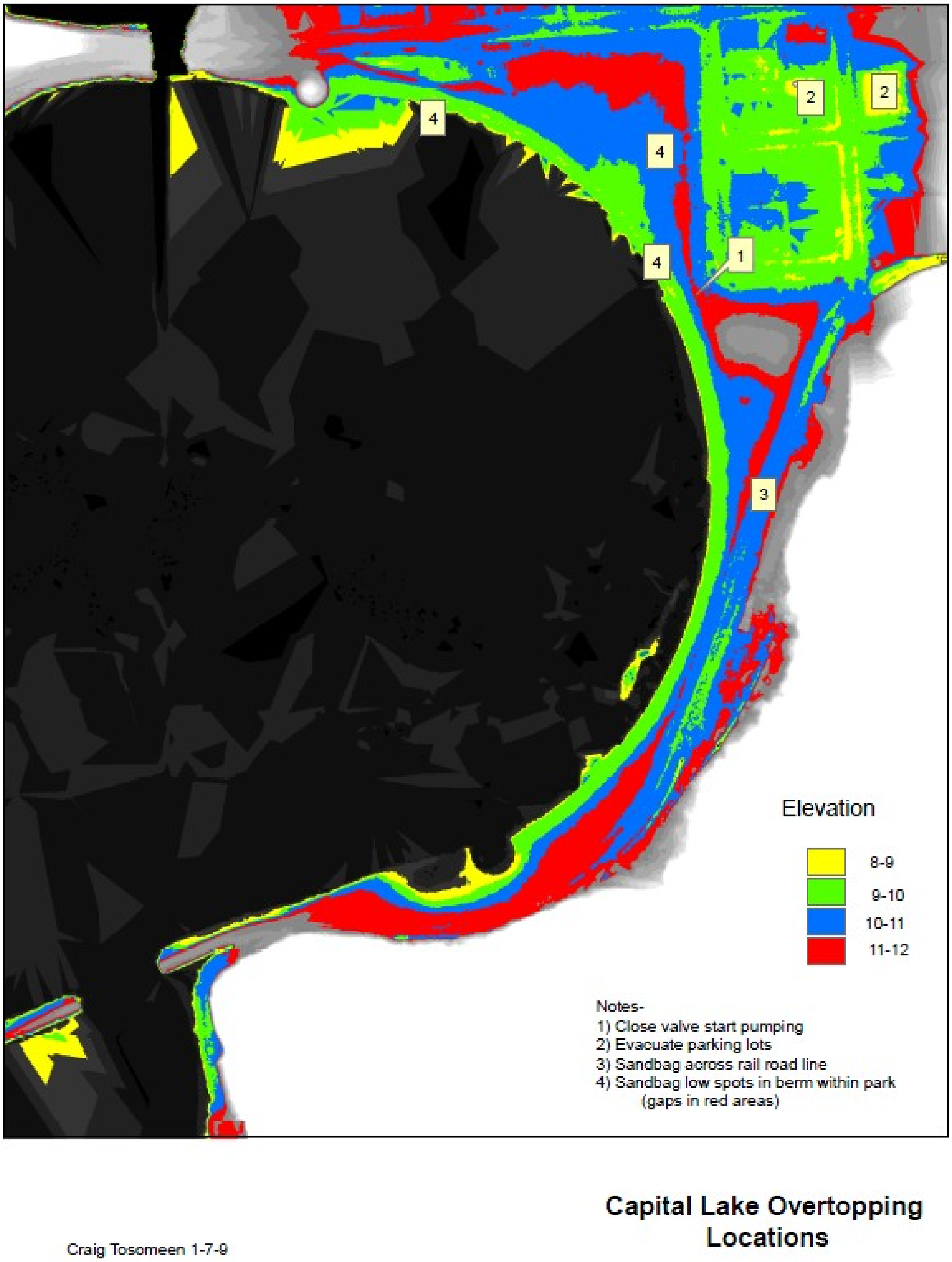

Figure 39. Areas adjacent to Capitol Lake flooded by high lake level with plans for responding to high water

With increasing sea level emergency response could be more frequent and sealing catch basins could be required at more locations. Inundation extent in Figure 27 shows that a large part of downtown Olympia is currently not protected from the 100-year flood. A flood elevation of 10.71 ft NGVD (10-year flood at existing sea level) would inundate a large number of catch basins, including those that are pumped to LOTT. Modeled inundation of the stormwater system on the west side of downtown by the 10-year flood is shown in Figure 40 and illustrates the large number of catch basins that are potentially affected. The figure also shows the increase in number of affected catch basins by a 0.25-ft increase in sea level.

Figure 40. Possible inundation of stormwater system on west side of downtown by 10-year flood

5.2. Infrastructure Planning for Sea Level Rise

Conceptually, four options are possible for controlling flooding: divert, confine, store, or pump the stormwater. Practically, the options for Olympia are narrowed to diverting and pumping stormwater, and combinations of those two. Diverting includes consolidating outfalls, installing tide gates on the remaining outfalls, and constructing barriers to tide and wave overtopping at the shoreline. Pumping stormwater that drains from the upland is required when outfall tide gates are closed.

The large number of outfalls that currently connect the storm drain system to Budd Inlet and Capitol Lake makes it difficult to control backflow to the upland when the tide is high. The City's GIS mapping shows at least 19 outfalls crossing the shoreline into West Bay. Better control can be achieved by rerouting flow to a limited number of outfalls, closing the remaining ones, and installing tide gates on the few operational outfalls. This also limits the number of pump stations required. A conceptual plan was developed for reconfiguring stormwater pipes by combining outfalls separately on eastern and western parts of downtown, to better control backflow. A diagram of the pipe connections to achieve the plan for downtown is shown in Figure 41. Contributing basins are shown in magenta borders and new consolidated pipes are shown in dark blue. One possible consolidated outfall is located in East Bay, one in West Bay on the west side of the peninsula, one is located at Capitol Lake, and two are located along the western shoreline of West Bay, although the western shoreline locations are not shown in the figure due to scale. Consolidated outfalls consist of a new tide gate to prevent saltwater backflow and pumps to pump stormwater around the tide gate when the gate is closed.

A stormwater interceptor is shown for the upper Capitol basin that would bypass the upper basin flow through the lower area at 7th Avenue and Water Street into Capitol Lake to alleviate the amount of stormwater that is pumped from the area at 7th Avenue and Water Street.

The outfall to West Bay, collecting stormwater runoff from up to 50 acres of the western side of the downtown area (assumed to be 85 percent effective impervious surface) must discharge up to 40 cubic feet per second (cfs) for the 100-year return period. The consolidated outfall discharging to West Bay requires a pipe diameter of approximately 36 inches. Reconfigured pipes in the eastern part of downtown may connect to the existing 72-inch-diameter pipe that discharges to East Bay. The 100-year peak flow in the 72-inch pipe is 500 cfs. When a tide gate on an outfall is closed, the statistics of combined tide and runoff flooding no longer apply. Only the runoff exceedance probabilities govern the discharge capacity when the gate is closed.

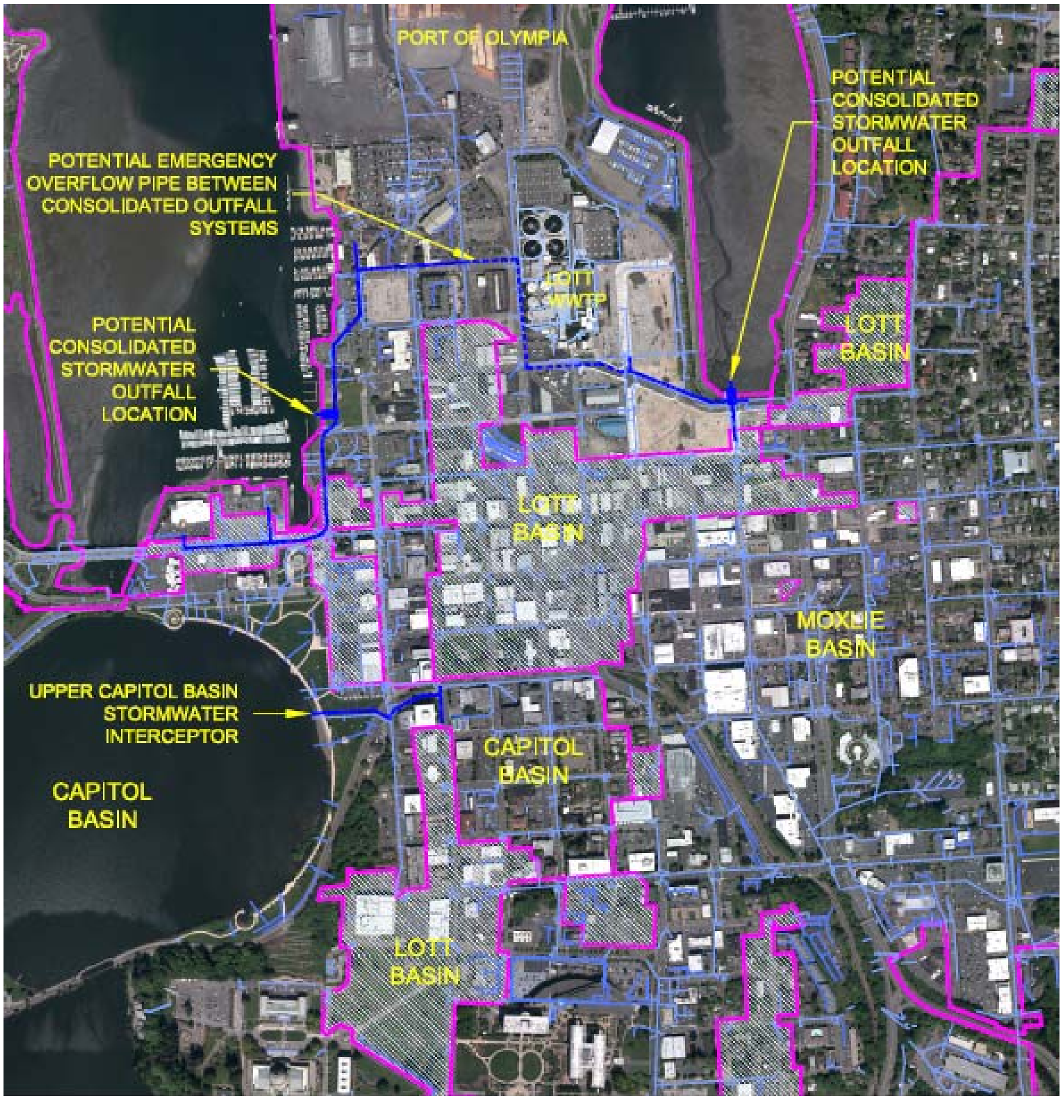

Figure 41. Contributing basins and new consolidated outfalls as component of flood control concept

Pump stations for meeting the discharge requirements were researched. A wet well is required for efficient operation of a pump, but due to the typically long-duration of potential runoff a practically-sized well cannot help reduce the peak of the runoff that the pump must handle. Therefore, the two larger pump stations must have capacity of 500 cfs for the East Bay location and 40 cfs for the West Bay location. For illustration purposes, a facility the size of the larger pump station is pictured in Figure 42. Pumps the size of the smaller station are shown in Figure 43. Pump capacity could be provided by a number of smaller capacity pumps, to efficiently handle a base flow and moderate flows. If smaller areas and outfalls along West Bay could not be intercepted and routed to the consolidated outfall system, then localized smaller pump stations and tide gates could be installed in a similar manner to the larger consolidated outfalls.

Figure 42. Example pump station having 500 cfs capacity

Figure 43. Example pump station having 40 cfs capacity

Flood barriers of various types were analyzed for protecting vulnerable areas of downtown and the West Bay shoreline. Potential inundation of the Port of Olympia, shown to occur with similar probabilities as inundation of downtown (Figure 27, for example), was the basis for including the Port area in the flood protection for the City. Examination of flooding areas corresponding to lower flooding elevations was the basis of siting barriers to control the first stage of inundation. It was determined that the first phase of barriers should be constructed by the time that sea level rose 0.25 ft above existing level. Crest height for the first phase barriers is recommended to protect up to 1 ft of sea level rise above the level at the time of installation. Using these criteria and a close examination of topography, the first phase of flood barriers were located as shown in Figure 44. At the point of 0.5 ft of sea level rise above the existing level, flood barrier locations should be expanded as shown in Figure 45. For sea level rise amounts greater than 0.5 ft the barriers only increase in height. Their locations and tie-in to higher topography are fixed by their installation at the 0.5-ft sea level rise amount. The flood barrier locations for 50 inches of sea level rise are the same as shown in Figure 45.

Flood barrier types were analyzed relative to their performance and attributes of their locations. Barrier types initially considered were earth berm, concrete wall, concrete step barrier, sheet pile wall, removable timber barrier, and temporary barriers. Evaluations of each are summarized in Table 10. Recommendations for barrier types at specific locations are based on evaluation of information in Table 10 and knowledge of site uses. Barrier types for each area are indicated by the graphical key in Figures 44 and 45.

Figure 44. Barrier location for flood protection at 0.25 ft and 50 inches sea level rise

Figure 45. Barrier location for flood protection at 0.5 ft and 50 inches sea level rise

Table 10. Flood barrier types and attributes

BARRIER TYPE	RELIABILITY	FIRST COST	ABILITY FOR HEIGHT ADJUSTMENT	PERMANENCE	ADAPTABILITY FOR CHANGED LAND USE	POTENTIAL FOR MULTIPLE USE	ASTHETICS	ADVANTAGES
Earth Berm	High	Low	Good	Medium	High	High	Good	Low Maintenance Would Not Create a Barrier to Shoreline
Concrete Wall	Very High	High	Poor	High	Low	Low	Good	Low Maintenance Narrow Footprint
Concrte Step Barrier	Very High	Medium	Good	High	Medium	Medium	Good	Low Maintenance Would Not Create a Barrier to Shoreline
Sheet Pile Wall	Very High	Very High	Poor	Medium	Lowest	Lowest	Poor	Narrow Footprint Can Be Installed Over Water
Removable Timber Barrier	High	High	Good	Low	High	Low	Poor	Removable When Not In Use
Temporary Barriers	High	Low	Depends on System Selected	Low	High	Low	Poor	Removable When Not In Use Can be Deployed on Uneven Ground

See map for areas in which barrier types are suitable

Analysis of wave overtopping at flood barriers was performed to determine the barrier crest elevation using criteria of allowable overtopping. At the concept design stage, the objective was to provide the minimum barrier height that would limit the volume discharge rate from wave overtopping to an amount deemed acceptable by standard criteria. The criterion selected was 1 liter per second water discharge per meter of barrier length for the 100-year coastal storm. The criterion was developed by international laboratories and has been adopted as policy by many entities, including recently the British Columbia Ministry of Environment in its publication *Sea Dike Guidelines* (January 2011).

Wave overtopping discharge rate was calculated for barrier concepts at Olympia using formulas recommended in FEMA's Pacific Coast Guidelines (FEMA 2005). Wave runup elevation at structures was calculated using equation D.4.5-19. Wave overtopping discharge rates were calculated using equations D.4.5-30 through 33. All these equations account for water level, elevation of the barrier toe and crest, and slope and roughness of the barrier face. Although equations of the two processes are not computationally connected, runup elevation was calculated at each barrier as a check of discharge results. After reasonable discharge result was assured, the barrier crest elevation was adjusted to provide the overtopping rate that matched the criterion. Barrier crest elevations were calculated to represent separately the east facing shoreline, north facing shoreline, and west facing shoreline of the peninsula and the West Bay Marina area. A spreadsheet used for calculating overtopping is contained in file 5.6. Conceptual cross-sectional views of barrier types applicable for particular locations and stages of sea level rise are shown in Figures 46 through 49.

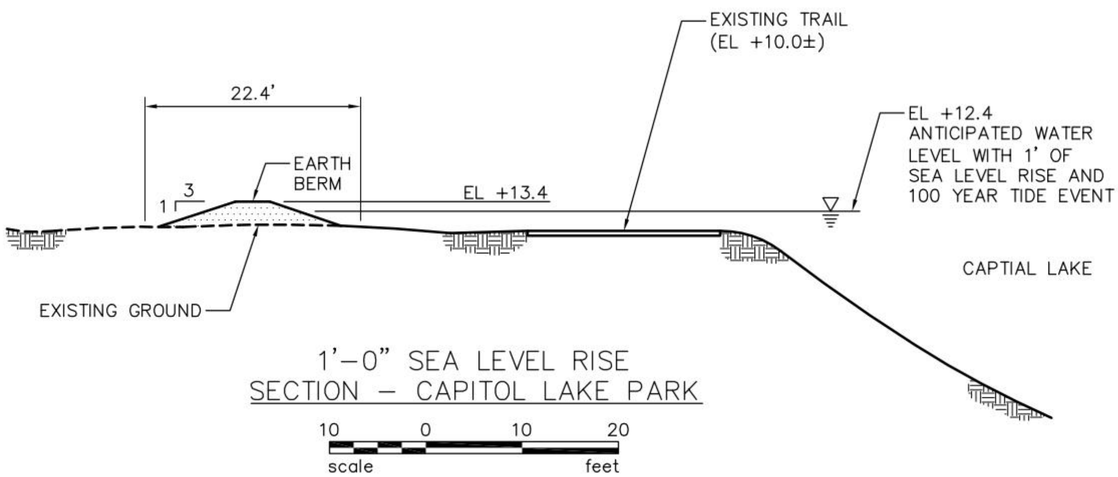

Figure 46. Earthen berm concept applicable to Capitol Lake shoreline

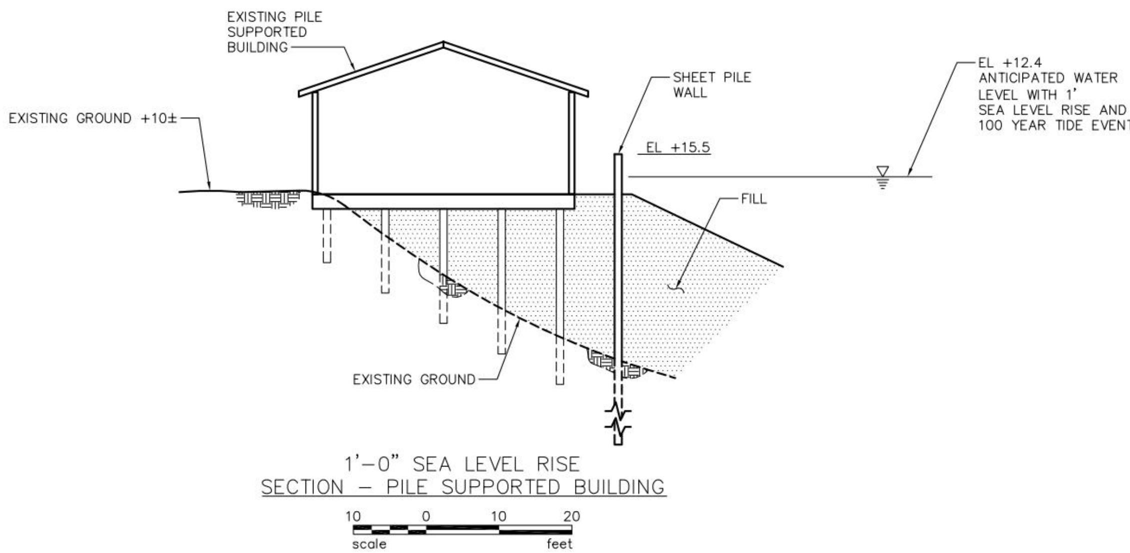

Figure 47. Sheet pile barrier concept applicable to pile supported building

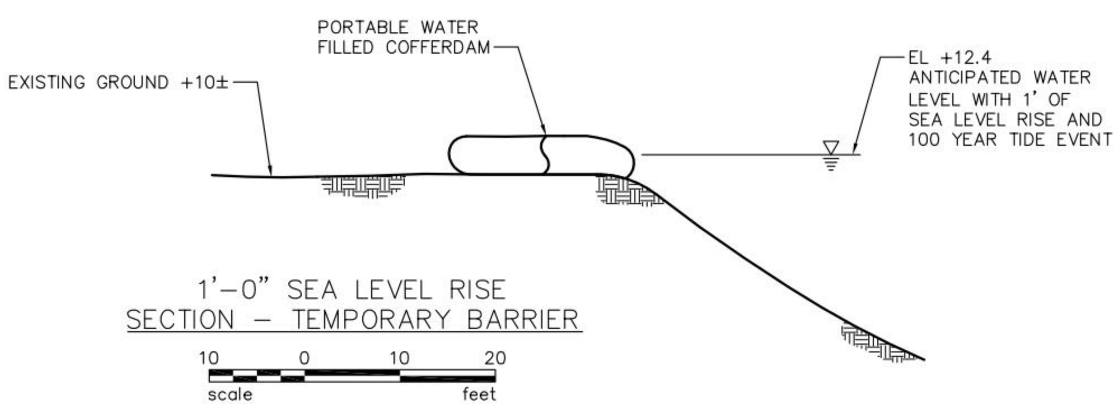

Figure 48. Temporary barrier concept applicable to Port docks

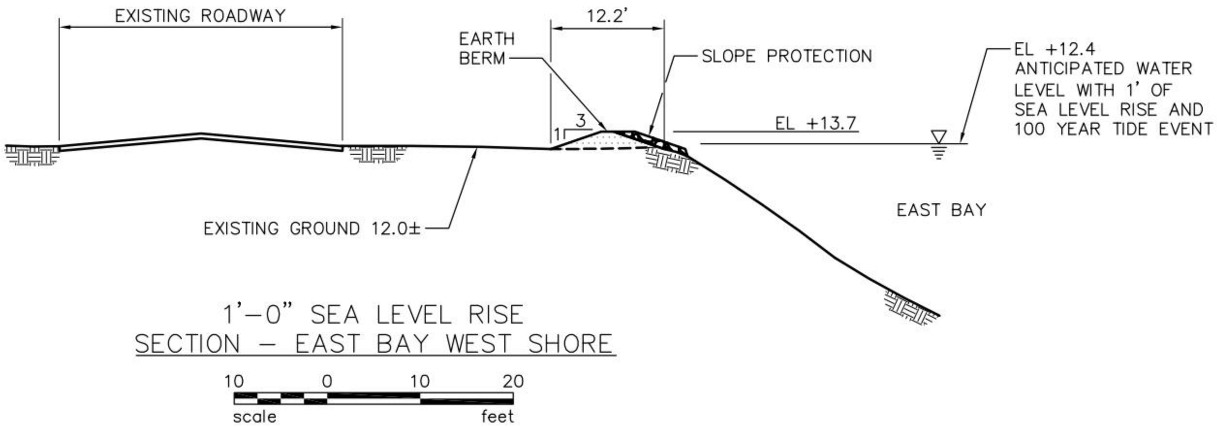

Figure 49. Armored slope earthen berm concept applicable to East Bay area

Final determination of actual locations and types of barriers will require a detailed survey of the shoreline and a detailed evaluation of space available for barriers and may require geotechnical analyses to design the barriers. Flood protection for buildings located at the shoreline or over the water is assumed to require a sheet pile wall. Floor elevations for the buildings were not available for this study and were assumed to be approximately the same as the surrounding area. Final determination of the method of protection for each structure will have to be made on a case-by-case basis. The cost to protect these structures from flooding versus the cost of relocation or raising the floor level should be considered when making the final selection. Earth berm and temporary barriers could be unsuitable for some areas due to underlying soil conditions. Highly permeable soils could allow water to pass under the barrier causing flooding. This condition would be exaggerated at higher levels of sea level rise. A geotechnical investigation of the underlying soils along the barrier alignment will be required prior to selecting a final barrier location and barrier type.

When planning for future flood protection, design opportunities should be sought to develop protection that conforms as far as practical with shoreline designations or existing use. Enhancing habitat value and public access should also be design goals. One example is shown in Figure 50, in which adding steps at the top of the existing structure could be done incrementally and without changing the shoreline use. Figure 51 is an example taken from the Fiddlehead Basin area of enhancing shoreline aesthetics and environment while making the shoreline more resilient to flood impacts.

Figure 50. Flood protection by increasing steps of existing structure

Figure 51. Flood protection and shoreline enhancement through habitat design

5.3. Costs

Costs of the components of the flood protection system were estimated at the concept level. Table 11 summarizes costs. Costs are at the planning level and do not include design engineering, permitting, contract administration, land acquisition, contingency for unforeseen conditions, and cost escalation through time. Information in the table is based on recent experience with similar types of construction, vendor data, and standard cost estimating guides. Barrier costs for 1 ft sea rise and 50 inch sea rise are treated as separate cases and independent of each other.

Table 11. Conceptual cost estimate of flood protection components

ITEM NO.	DESCRIPTION	UNIT	QUANTITY	UNIT COST	TOTAL COST
BASE PROJECT - BARRIER CONSTRUCTION					
	1-FOOT SEA LEVEL RISE				
1	Earth Berm with Grass	LF	3600	$139	$500,400
2	Earth Berm with Grass & Slope Protection	LF	12,425	$145	$1,801,625
3	Temporary Barrier	LF	2,555	$100	$255,500
4	Sheet Pile Wall	LF	2,680	$2,000	$5,360,000
5	Fill	CY	14,200	$40	$568,000
6	**Total for 1-Foot Sea Level Rise**				**$8,486,000**
7					
8	**4-FOOT 2-INCHES SEA LEVEL RISE**				
9	Earth Berm with Grass	LF	3600	$367	$1,321,200
10	Earth Berm with Grass & Slope Protection	LF	12,425	$420	$5,218,500
11	Temporary Barrier	LF	2,555	$250	$638,750
12	Sheet Pile Wall	LF	2,680	$2,200	$5,896,000
13	Fill	CY	14,200	$40	$568,000
14	**Total for 4-Foot 2-Inches Sea Level Rise**				**$13,643,000**
15					
16	**500 cfs Pump Station**	**LS**			**$30,000,000**
17	**50 cfs Pump Station**	**LS**			**$7,000,000**
18	**Small Pump Station**	**EA**	**3**	**$150,000**	**$450,000**
19	**72" Tideflex Valve**	**EA**	**1**	**65,200**	**$65,200**
20	**36" Tideflex Valve**	**EA**	**1**	**19,300**	**$19,300**
21					
22					
23					
OUTFALL CONSOLIDATION - WEST BAY PIPE SEGMENT					
1	North Trunk Line	LF	1,066	$1,200	$1,279,200
2	North Trunk Line Laterals	LF	636	$900	$572,400
3	South Trunk Line	LF	1,651	$1,200	$1,981,200
4	South Trunk Line Laterals	LF	221	$900	$198,900
5	Outfall Pipe from Structure to Bay	LF	48	$1,500	$72,000
6	**Total for West Bay Outfall Consolidation**				**4,103,700**

6. Flood Protection Strategy and Implementation Sequence

The recommended strategy for providing and improving flood protection has near-term and long-term aspects. In the near-term the current practice of responding to high water with temporary measures should continue, while planning for implementing a long-term plan. This includes continuing operating the manual valve in the pipe near 7th Ave and Water Street and deploying a portable pump when the valve is closed. The City should anticipate evacuating low areas or sand bagging low shorelines. Photographs of high tide events indicate that high waves in Budd Inlet have not accompanied historically high tides yet. When strong north winds occur with extreme predicted tides, a more involved emergency response should be planned for. Planning should incorporate new knowledge of flooded areas and depth corresponding to return periods. The process would be to select a return period to which emergency response should protect, then prepare staff and acquire materials to provide that level of protection.

6.1. Near-Term Approach to Flood Protection

This analysis showed that backflow to catch basins on Water Street from State Avenue to 7th Avenue could be a source of flooding of basins in the zone that flows to LOTT. Those problem basins on the gravity system should be temporarily sealed if the water elevation exceeds 10.71 ft NGVD. To protect against rare high water events, plans for temporarily sealing catch basins on Capitol Way from the roundabout to A Avenue should be made. Portable pumps may be required to remove stormwater where catch basins are sealed. Additional crews may be needed to deal with larger inundation area. For a 10-year flood with 0.25 ft sea level rise (elevation 10.96 ft NGVD), 702 catch basins are affected in the study area.

Hydraulic modeling shows that early increases in water level in Budd Inlet with historically large runoff will flood catch basins at 5th and Cherry, 7th and Chestnut, 8th and Cherry, 9th and Chestnut, and 11th and Plum. Flooding of catch basins at a 50-year return period in the vicinity of State Avenue and Cherry Street from tidal water inundating the 72-inch pipe system will cause flooding of basins in the zone that drains to LOTT. Sealing those catch basins on the gravity system or installing a valve at a strategic location on the affected pipe and pumping just the accumulated surface water is a strategy to prevent tidal water from flowing (indirectly) to LOTT in the near-term stages of sea level rise.

Controlling flooding by this type of emergency response may become impractical before reaching the point of overflow to the LOTT basins on a 10-year recurrence interval. More permanent infrastructure changes are needed to defend against flooding having a 10 percent annual chance occurrence by the time sea level has risen 0.25 ft. Parts of downtown Olympia are vulnerable to flooding by the 100-year flood with existing sea level. A large amount of infrastructure change will be required to defend against 50 inches of sea level rise. The strategy presented here is to plan for the changes and flood defense needed for the 50-inch rise case, but to implement measures in the shorter time frame that will permit deferring large expenses.

An effective measure would be to raise the shoreline elevation at currently low areas on the west facing shoreline of the peninsula from the Port boundary south to 4th

Avenue and improve erosion protection there. Slope protection should also be improved at the north end of the peninsula and southward in East Bay. Results of this study indicate that more valves on pipes in the vicinity of Water Street will be needed to prevent back flow from Capitol Lake and from West Bay until outfall consolidation can be accomplished. With an overall plan developed for outfall consolidation, it can be completed piecemeal by taking advantage of redevelopments to excavate and reroute portions of the pipe network.

A practical means of protecting the Port may be purchasing a temporary barrier to protect area that should not be inundated and deploying the barrier ahead of the occurrence of high water. Study results show that catch basins in the Port area can flood due to high water in Budd Inlet with the current outfall configuration. If the Port has not yet observed flooding by way of backflow in catch basins on Port property it should be recognized that that can be a flooding source in addition to flooding over the shoreline.

Owners of marinas and docks in Budd Inlet should raise utility lines and deck elevation of docks as part of a maintenance program and raise abutments of gangways. Condition inspection of marinas and over water structures should be made with the awareness that the design lateral load can produce larger moments in the future as water level rises. Strength of structures to resist loading by vessels, debris or other objects may be insufficient with higher water levels in the future. Maintenance and repair programs should be used to upgrade components as required.

6.2. Long-Term Approach to Flood Protection

Flood protection elements designed for sea level rise include permanent structures, consolidated outfalls, tide gates on outfalls, and pump stations. Tentative pump station locations are near Columbia Street and Olympia Avenue, near Chestnut Street and Olympia Avenue, and smaller permanent pump stations at Water Street and 7th Avenue, and near West Bay Marina. Land requirements for a pump station must include space for a wet well, which is sized to the pumping rate. Pumps must have maximum capacities to discharge 40 cfs to West Bay and 500 cfs to East Bay (including Indian/Moxley Creek flow).

The first permanent barriers and associated systems for West Bay are needed by the time of 0.25 ft of sea rise above existing level. The first increment of barrier should have the crest elevation to be effective in the 100-year flood up to the sea level 1 ft above existing sea level. The barrier crest elevation is 13.4 ft NGVD for the earth berm barrier. This barrier would prevent inundation of most of the peninsula catch basins. At that time a barrier of similar height will be needed for the vicinity of West Bay Marina. Transportation corridors on 4th and 5th Avenues can be protected by connecting the barrier to the bridge abutment.

Most of the peninsula shoreline along East Bay is 0.5 ft higher than on West Bay. The higher shoreline allows a permanent barrier on East Bay to be deferred until the sea level has risen 0.5 ft.

Except for flooding in a localized area in the vicinity of Chestnut Street and Cherry Street that starts after 0.5 ft of sea level rise, flooding on the 72-inch pipe system is not problematic at the 100-year return period until sea level has risen 2 ft. Without piping changes, at 0.5 ft sea level rise, backflow water from the bay could flood the Chestnut and Cherry area up through the catch basins and overflow northward on the surface to the basins that flow to LOTT. To defer constructing the large pump station and tide gates until the point of 2 ft of sea rise, the recommendation is made to handle the localized flooding by separating the part of the system containing the problem catch basins from the 72-inch system and pumping just the localized area. Accumulated surface water in the now isolated area could be pumped with a small pump or could be routed to the LOTT basins located just to the north. After the 72-inch outfall is tide gated, the catch basins that had been disconnected from this system can be connected again and any separate pumping for the localized area can cease.

7. Recommendations

Flood protection infrastructure described above is costly, which increases the importance of accurate projections of flood hazards. Installing an official recording tide station and a meteorological station at Olympia will improve quality of tide data and wind speed and direction data for developing better statistics for predicting future total water level at the Budd Inlet shoreline.

Survey monuments should be installed and resurveyed periodically at several points in downtown to provide data on changes in ground level. Monitoring wells should also be installed to document groundwater elevation changes. Pressure-transducers in the wells could document long-term groundwater level information within shallow aquifers at the site.

Elevation of all stormwater elements should be surveyed and entered in the City's GIS database. Accurate elevation information will facilitate hydraulic modeling that better predicts flood depths and areas.

8. References

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APPENDIX A

Hydrogeological and Geotechnical Evaluation

Preliminary Hydrogeologic and Geotechnical Services

Sea Level Rise Response Study - Downtown Area
Olympia, Washington

for
Coast and Harbor Engineering

August 4, 2011

GeoEngineers
Earth Science + Technology

Preliminary Hydrogeologic and Geotechnical Services

Sea Level Rise Response Study – Downtown Area
Olympia, Washington

for
Coast and Harbor Engineering

August 4, 2011

GeoEngineers

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30 YEARS 2010

Preliminary Hydrogeologic and Geotechnical Services

Sea Level Rise Response Study – Downtown Area Olympia, Washington

File No. 0415-062-00

August 4, 2011

Prepared for:

Coast and Harbor Engineering
110 Main Street, #103
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512
Licensed Geologist
STEPHEN WAYNE HELVEY

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INTRODUCTION

This report summarizes our preliminary hydrogeologic and geotechnical evaluation concerning the potential impacts of long-term sea level rise on the downtown Olympia area. The focus of our study was to qualitatively identify the potential effects of rising sea levels on groundwater within the study area, with respect to specific hydrogeologic and geotechnical issues. These issues include:

- Seepage beneath structures (walls/berms) that may be built to limit future inundation of the downtown area from rising seawater.
- Potential effects of rising groundwater on existing or potential areas of contaminated soil/groundwater within the downtown area.

The area of our study is generally shown in the Vicinity Map, Figure 1 and comprises a portion of a peninsula of land which is bounded to the north by Port of Olympia property, to the west by the West Bay of Budd Inlet, to the east by the East Bay of Budd Inlet and upland areas, and to the south by upland areas.

We understand that walls and/or berm systems to prevent or limit sea water inundation of the downtown area are being considered. The approximate proposed locations of these features is shown in Figures 1 and 2. We understand that the walls and/or berms may comprise one or more of the following:

- Low earthen berms with vegetated side slopes.
- Architectural king piles with removable panels.
- Stepped architectural concrete walls.

We understand that the type and location of the proposed wall systems is in the preliminary design stage and may change in the future.

SCOPE OF SERVICES

The purpose of our services is to complete a preliminary hydrogeologic and geotechnical evaluation of the potential effects of sea level rise on the downtown Olympia area. The specific scope of services completed for this project includes the following tasks:

1. Meet with the design team and perform a brief site visit to observe areas where sea water flooding can currently occur during high tide conditions.
2. Meet with City of Olympia officials regarding hydrogeologic reports completed within the downtown area.
3. Review select published and unpublished documents regarding geologic and hydrogeologic conditions within the downtown portion of the site.
4. Review City of Olympia maps which show known contaminated sites within the downtown Olympia area.

5. Discuss the geologic/hydrogeologic framework of the site area, based on the results of our research.
6. Discuss the relative magnitude of potential groundwater flow under the proposed flood control structures, if built. Discuss the potential for contaminant mobilization by rising groundwater.
7. Summarize the locations of known contaminated sites within the subject area, based on data provided by the City of Olympia.
8. Discuss the range of potential seepage flow rates, as appropriate based on the available data, beneath proposed flood protection systems along the Budd Inlet shoreline.
9. Discuss gaps in the data and the steps necessary to close the gaps as they relate to future design-level studies.

SITE CONDITIONS

Surface Conditions

The project area is presently developed with commercial businesses and roadways. Topographically the site area is relatively flat; the southern portion of the site has a slight downward slope to the northwest. We understand that the elevation of most of the site area within the study area is about 20 feet above mean sea level.

We understand that commercial/industrial development within the downtown area began in about the 1850s based on information obtained from the City of Olympia. Development and re-development within the downtown area has continued through to the present day. We understand that fills were placed within the downtown area to extend the shoreline and to fill embayments. The information reviewed suggests that most of this filling activity was completed by the mid 1920s. The composition of the fill material was undocumented and likely comprised whatever materials (soil, debris) were readily available at the time filling occurred.

We understand that gravity and force-main storm sewers exist throughout the downtown area. These features daylight to the West Bay and East Bay at various locations. We understand that, during high tide conditions, seawater flows into one of the storm sewers in the West Bay area and flows out of a nearby storm sewer grate into a parking lot area.

Published Geology

Surface geologic conditions at the site were evaluated by reviewing the "Geologic Map of the Tumwater 7.5-minute Quadrangle, Washington" U.S. Geological Survey Miscellaneous Field Investigation, scale 1:24,000, Walsh, T.J., Logan, R.L., Schasse, H.W., and Polenz, M. (2003). The distribution of surficial geologic units within the site area is shown in Figure 2.

Materials mapped within the study area at the site and in the site area consist of man-deposited fill (map symbol Q_f) and Latest Vashon recessional sand and minor silt (map unit Qgos). Fill is mapped on the margins of the peninsula and within a filled embayment on the east side of the site. Based on our experience, fill, within the site area, can comprise an extremely variable mixture of numerous materials types, including clay, silt, sand, gravel, wood, sawdust, concrete metal debris and rip rap.

Vashon recessional outwash at the site typically consists of fine sand with some silt. This material also likely underlies the man-placed fill material mapped at the margins of the site. The recessional outwash was deposited by rivers and streams flowing into glacial lakes and as such is a relatively low-energy deposit.

Published Subsurface Conditions

Subsurface conditions within the site area were evaluated by reviewing Technical Memoranda 1200 (1996) and 1204 (1999) for the LOTT Wastewater Management Plan. We also reviewed published boring log data at the Department of Ecology website for the downtown Olympia area. Relatively few well logs were found for the downtown area during our evaluation.

The data suggests that the Vashon recessional outwash deposit can extend to depths of at least 30 feet below ground surface (bgs) in the site area. Maps contained in "Hydrology and Quality of Ground Water in Northern Thurston County, Washington (1998)" indicate a layer thickness of between 20-25 feet in the site area.

The thickness of fill material within the site area is unknown and is likely highly variable, based on the information reviewed and our experience in the site area.

Interpreted Hydrogeologic Conditions

A shallow water table aquifer appears to exist within the recessional outwash sand (map unit Qgos) and the man-deposited fill (map symbol Q_f) materials at the site. The outwash and fill materials appear to be in direct contact and groundwater likely readily flows between the two material types. The recessional outwash and fill materials are recharged by direct infiltration of rain water and from lateral flow within the recessional outwash material from nearby upland areas. Groundwater within the outwash and fill materials also likely discharges to Budd Inlet, and to the West and East Bays.

Groundwater levels within the shallow aquifer are also likely tidally influenced, because the aquifer is in direct contact with salt water to the north, east and west. The magnitude of tidal influence is presently unknown however. We expect that water levels within the shallow aquifer, across much of the project site, vary to some extent due to tidal fluctuations, particularly at locations near the shoreline.

The gradient and direction of groundwater flow within the shallow aquifer is presently unknown. Based on topography, we expect that the groundwater flow direction to be generally to the north with more pronounced easterly and westerly directions to the gradient near the east and west shoreline areas. The flow gradient is likely steeper in the south part of the subject site area and flatter in the central to northern parts of the site area.

DISCUSSION

Groundwater and Sea Level Rise

The project area is underlain by a shallow, water table aquifer within recessional outwash and man-placed fill materials. The aquifer likely discharges fresh water to salt water into the East Bay, West Bay and Budd Inlet which are located east, west and north of the project area. Therefore, an overall rise in sea level should result in a rise in groundwater levels within the shallow aquifer.

The magnitude of the potential rise in the shallow aquifer due to sea level rise is currently unknown. It does not appear that groundwater levels within the shallow aquifer have been adequately defined, based on our limited research, to estimate the range of expected groundwater levels that could result from sea level rise. This represents a data gap for purposes of this study. A network of shallow wells, completed within the shallow aquifer, and measurements of groundwater within those wells over time would be required.

Flood Walls

General

We reviewed preliminary plans provided by Coast and Harbor Engineering regarding potential locations for low, flood prevention walls within the City. The location of these proposed features is shown in Figure 2. As previously stated, we understand that the walls could comprise one or more of the following:

- Low earthen berms with vegetated side slopes.
- Architectural king piles with removable panels.
- Stepped architectural concrete walls.

Most of the proposed flood prevention walls are located in areas where fill soils are mapped at the ground surface (Figure 2).

Seepage

Some seepage beneath the proposed wall structures should be expected, particularly during high tide conditions. The potential amount of seepage however, is difficult to quantify at present because the composition of the material underlying the walls (man-placed fill) is likely highly variable across the site. In addition, the amount of seepage beneath a typical wall may also vary with the head difference between groundwater behind the wall and sea water in front of the wall, and the gradient of that head difference. The gradient will generally be more gradual through an earthen wall than either a concrete or king pile wall.

We reviewed data contained in “Hydrogeologic Framework of the Puget Sound Aquifer System, Washington and British Columbia (1998)” regarding typical hydraulic conductivity values for geologic materials. The document indicates that an average horizontal hydraulic conductivity value for recessional outwash material at the site (fine sand) is about 4 feet per day. A similar hydraulic conductivity value could be expected within the fill material if the fill is composed of fine to medium sand. A much lower horizontal hydraulic conductivity value (and much lower potential for seepage) should be expected if the fill contains a high percentage of silt. Higher seepage rates could be expected if the fill has a high percentage of gravel and/or debris that result in large void spaces within the material.

Because the potential seepage rates will be highly dependent on the hydraulic properties of the soil at the wall locations, the lack of geotechnical data in the proposed wall areas represents a data gap. A program of drilled explorations, soil samples, slug tests and/or long term measurements of groundwater within the fill material at the proposed wall locations would be required to close this data gap.

Contamination

A summary of known or suspected contaminated sites within the project area is shown on the map titled "Toxic Sites in Zone 226", which is presented in Appendix A. The map was produced by the City of Olympia in 2009 and appears to comprise a summary of publically available lists of potentially contaminated or known contaminated sites.

The project site is in an area that has been developed for commercial/industrial purposes since the mid to late 1800s. Considering the prior and existing land uses over an extended period the potential for shallow soil and groundwater contamination within the site area is high. A comprehensive environmental site assessment of the project area would be required to fully identify all potential contaminated sites within the study area.

We anticipate that expect that a rise in groundwater levels within the shallow aquifer, due to sea level rise, has the potential to mobilize some contaminants in soils that are not currently saturated by groundwater. Contaminants that are lighter than water, such as petroleum hydrocarbons, would be most susceptible to mobilization due to inundation.

CONCLUSIONS AND RECOMMENDATIONS

General

Based on our review of the existing data, we conclude that most of the proposed wall locations appear to all be underlain by fill of unknown composition and quantity. Some seepage of water beneath the structures should be expected, however the magnitude of expected seepage is presently unknown because since geotechnical data for the shallow soils in the immediate vicinity of the walls is not presently available. Hydraulic conductivities within the fill may be similar to that of the underlying recessional outwash aquifer (about 4 feet per day) if the fill is of a similar composition to the outwash.

The shallow water table aquifer within the site area will be affected by a rise in sea level. Some rise in groundwater levels within the shallow water table aquifer should be expected. However, the magnitude of rise is unknown, mostly because the character of the shallow aquifer is not well understood.

A rise of water levels in the shallow aquifer could impact known and unknown contaminated sites. Mobilization of contaminants, for example petroleum hydrocarbons, could occur due to a rise in water levels in the shallow aquifer.

Data Gaps

The character and composition of the shallow soil geologic materials at the potential wall locations is not adequately known and represents a data gap with respect to the study. This data gaps can be filled by performing geotechnical explorations in the proposed wall areas.

Groundwater elevations and flow gradients of the shallow water-table aquifer at the site have not been adequately defined and this represents a data gap. The shallow water table aquifer could be better defined by measuring water levels, over a full season, in either a series of existing shallow monitoring wells which are completed within the aquifer, by drilling new wells or a combination of the two. The water levels would be measured by using dedicated pressure transducers/data loggers installed in the wells.

The resulting data will help define the existing condition of the aquifer, and will provide a basis for evaluating the potential ranges of groundwater elevations that could result from sea level rise.

LIMITATIONS

We have prepared this report for use by Coast and Harbor Engineers and their agents on this portion of the project. The interpretations made in this report should not be construed as a warranty of subsurface conditions. Actual subsurface conditions may vary with location and time.

Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices in this area at the time the report was prepared. No warranty, express or implied, should be understood.

Please refer to Appendix B titled "Report Limitations and Guidelines for Use" for additional information pertaining to use of this report.

REFERENCES

Robinson and Noble, April 11, 1996, Technical Memorandum 1200, LOTT Wastewater Resource Management Plan, Prepared for LOTT.

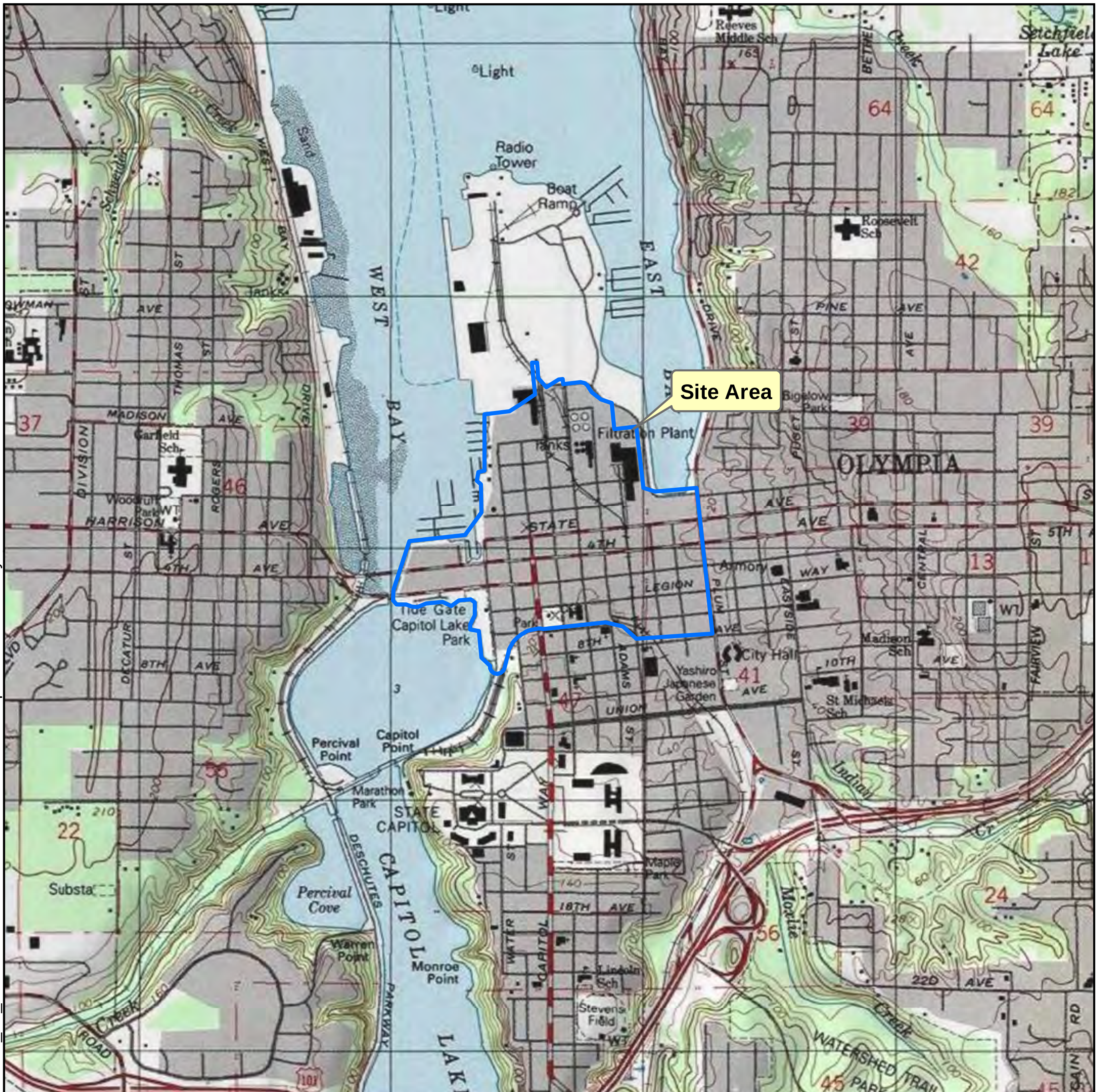
Robinson and Noble., March 26, 1999, Technical Memorandum 1204, LOTT Wastewater Resource Management Plan, Prepared for LOTT.

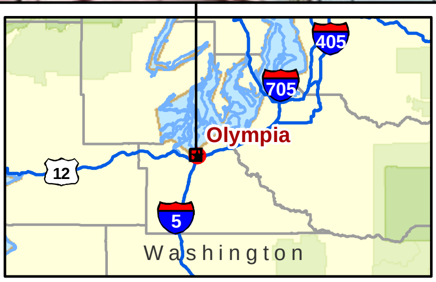
U.S. Department of the Interior, Hydrology and Quality of Ground Water in Northern Thurston County, Washington, 1998.

U.S. Department of the Interior, Hydrogeologic Framework of the Puget Sound Aquifer System, Washington and British Columbia, 1998.

Walsh, T. J., R. L. Logan, H. W. Schasse, and M. Polenz, Geologic Map of the Tumwater 7.5-minute Quadrangle, Thurston County, Washington, 2003.

FIGURES





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2,000 0 2,000
Feet

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
3. It is unlawful to copy or reproduce all or any part thereof, whether for personal use or resale, without permission.

Data Sources: ESRI Data & Maps, USA Topo Maps

Projection: NAD 1983 UTM Zone 10N

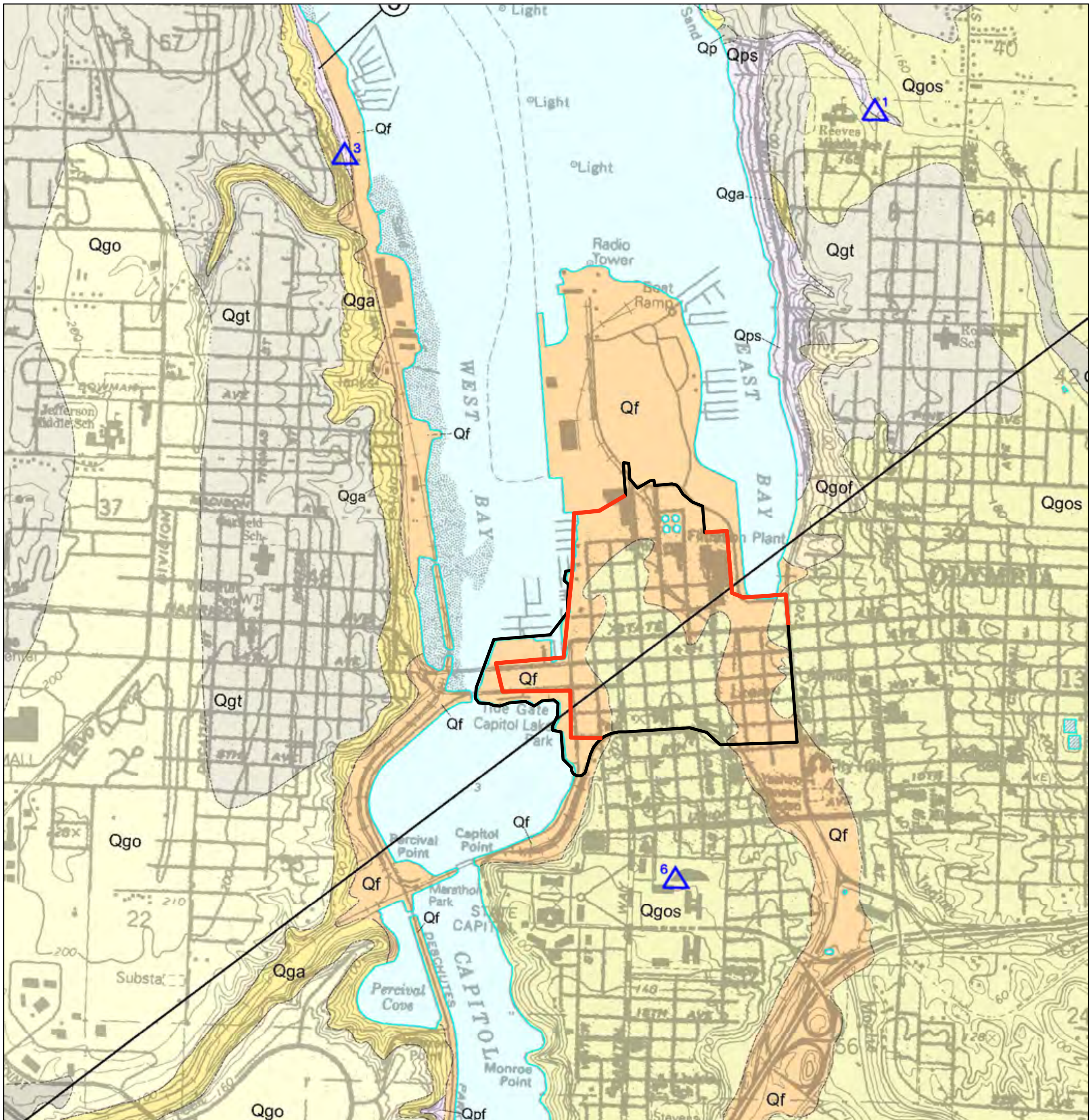
Vicinity Map

City of Olympia - Sea Level Rise Response
Olympia, Washington

GeoEngineers

Figure 1

Office: TAC Path: \\tac\Projects\0\0415062\00\GIS\041506200_F1_VM.mxd Map Revised: 26 July 2011 amanza



Proposed Wall
Site Boundary
Waterbody
Qf: Fill
Qga: Vashon Advance Outwash
Qgo: Vashon Recessional Outwash
Qgof: Fine-grained Sediments
Qgos: Vashon Recessional Sand and Minor Silt
Qgt: Vashon Till
Qps: Pre-Vashon Sandy Deposits

N W E S

0 2,000
Feet

Data Source: USA Topo Maps,
Geologic Map from Washington Department of Natural Resources.

Projection: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Geologic Map

City of Olympia - Sea Level Rise Response
Olympia, Washington

GEOENGINEERS

Figure 2

Office: TAC Path: \\tac\projects\0\0415062\00\GIS\041506200_F2_Geologic.mxd Map Revised: 03 August 2011 amanza

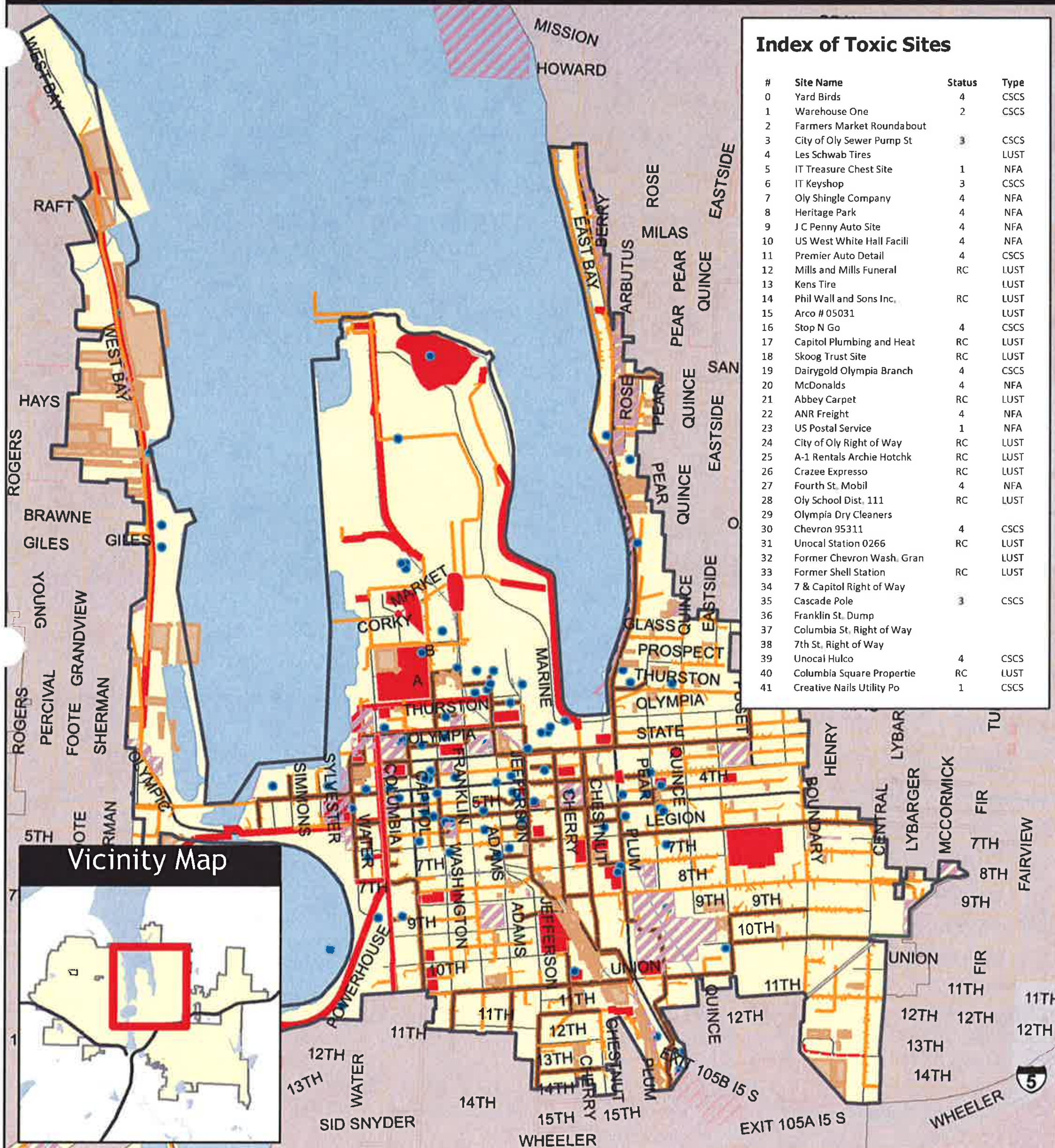
APPENDICES

APPENDIX A
City of Olympia Toxic Sites Map

Toxic Sites in Zone 226

Artesian Well Relocation

City of OLYMPIA



Index of Toxic Sites

#	Site Name	Status	Type
0	Yard Birds	4	CSCS
1	Warehouse One	2	CSCS
2	Farmers Market Roundabout		
3	City of Oly Sewer Pump St	3	CSCS
4	Les Schwab Tires		LUST
5	IT Treasure Chest Site	1	NFA
6	IT Keyshop	3	CSCS
7	Oly Shingle Company	4	NFA
8	Heritage Park	4	NFA
9	J C Penny Auto Site	4	NFA
10	US West White Hall Facili	4	NFA
11	Premier Auto Detail	4	CSCS
12	Mills and Mills Funeral	RC	LUST
13	Kens Tire		LUST
14	Phil Wall and Sons Inc.	RC	LUST
15	Arco # 05031		LUST
16	Stop N Go	4	CSCS
17	Capitol Plumbing and Heat	RC	LUST
18	Skoog Trust Site	RC	LUST
19	Dairygold Olympia Branch	4	CSCS
20	McDonalds	4	NFA
21	Abbey Carpet	RC	LUST
22	ANR Freight	4	NFA
23	US Postal Service	1	NFA
24	City of Oly Right of Way	RC	LUST
25	A-1 Rentals Archie Hotchk	RC	LUST
26	Crazee Expresso	RC	LUST
27	Fourth St. Mobil	4	NFA
28	Oly School Dist. 111	RC	LUST
29	Olympia Dry Cleaners		
30	Chevron 95311	4	CSCS
31	Unocal Station 0266	RC	LUST
32	Former Chevron Wash. Gran		LUST
33	Former Shell Station	RC	LUST
34	7 & Capitol Right of Way		
35	Cascade Pole	3	CSCS
36	Franklin St. Dump		
37	Columbia St. Right of Way		
38	7th St. Right of Way		
39	Unocal Hulco	4	CSCS
40	Columbia Square Propertie	RC	LUST
41	Creative Nails Utility Po	1	CSCS

0 0.25 0.5 Miles

Sewer Utility

- ssSTEPMain
- ssCombinedMain
- ssGravityMain
- ssForceMain
- Toxic Site
- Artesian Wells
- City Property
- Land

Data Sources: City boundaries, sewer utility from City of Olympia, Roads, water features, toxic sites, artesian wells from Thurston County.

Artesian wells data is based on old records, field studies, and interviews with property owners. Last updated in February 2002. Toxic site data is derived from information from the Department of Ecology.

N

Map created 2009 April 27
Whitney K. Bowerman, GIS Analyst
wbowerma@ci.olympia.wa.us
(360) 753-8578

APPENDIX B
Report Limitations and Guidelines for Use

APPENDIX B
REPORT LIMITATIONS AND GUIDELINES FOR USE[1]

This appendix provides information to help you manage your risks with respect to the use of this report.

Hydrogeological Services are Performed for Specific Purposes, Persons and Projects

GeoEngineers has performed this preliminary hydrogeological and geotechnical evaluation as a part of the overall sea level rise study that Coast and Harbor Engineering is performing, in general accordance with the scope and limitations of our proposal. This report has been prepared for use by Coast and Harbor Engineering and members of the design team. This report is not intended for use by others, and the information contained herein is not applicable to other sites.

GeoEngineers structures our services to meet the specific needs of our clients. No one except Coast and Harbor Engineering and the City of Olympia should rely on this report without first conferring with GeoEngineers. This report should not be applied for any purpose or project except the one originally contemplated.

This Report is Based on a Unique Set of Project-Specific Factors

This report has been prepared for part of the sea level rise study of the downtown Olympia area in Olympia, Washington. GeoEngineers considered a number of unique, project-specific factors when establishing the scope of services for this project and report. Unless GeoEngineers specifically indicates otherwise, do not rely on this report if it was:

- not prepared for you,
- not prepared for your project,
- not prepared for the specific site explored, or
- completed before important project changes were made.

If important changes are made to the project or site after the date of this report, GeoEngineers should be retained to review our interpretations and recommendations and to provide written modifications or confirmation, as appropriate.

Information Provided by Others

GeoEngineers makes no warranties or guarantees regarding the accuracy or completeness of information provided or compiled by others. The information presented in this report is based on the above-described research and a single recent site visit. GeoEngineers has relied upon information provided by others in our description of hydrogeological and geological conditions at the site. No subsurface explorations or samples of groundwater were completed/obtained as a part of our study. The available data do not provide definitive information with regard to all past uses, operations or incidents at the site or adjacent properties.

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[1] Developed based on material provided by ASFE, Professional Firms Practicing in the Geosciences; www.asfe.org.

Site Conditions Can Change

This report is based on conditions that existed at the time the study was performed. The findings and conclusions of this report may be affected by the passage of time, by events such as a change in property use or occupancy, or by natural events, such as floods, earthquakes, slope instability or groundwater fluctuations. Always contact GeoEngineers before applying this report so that GeoEngineers may evaluate reliability of the report to changed conditions.

Read These Provisions Closely

Some clients, design professionals and contractors may not recognize that the geoscience practices (geotechnical engineering, geology and environmental science) are far less exact than other engineering and natural science disciplines. This lack of understanding can create unrealistic expectations that could lead to disappointments, claims and disputes. GeoEngineers includes these explanatory "limitations" provisions in our reports to help reduce such risks. Please confer with GeoEngineers if you are unclear how these "Report Limitations and Guidelines for Use" apply to your project or site.

Biological Pollutants

GeoEngineers' Scope of Work specifically excludes the investigation, detection, or assessment of the presence of Biological Compounds which are Pollutants in or around any structure. Accordingly, this report includes no interpretations, recommendations, findings, or conclusions for the purpose of detecting, assessing, or abating Biological Pollutants. The term "Biological Pollutants" includes, but is not limited to, molds, fungi, spores, bacteria, and viruses, and/or any of their byproducts.

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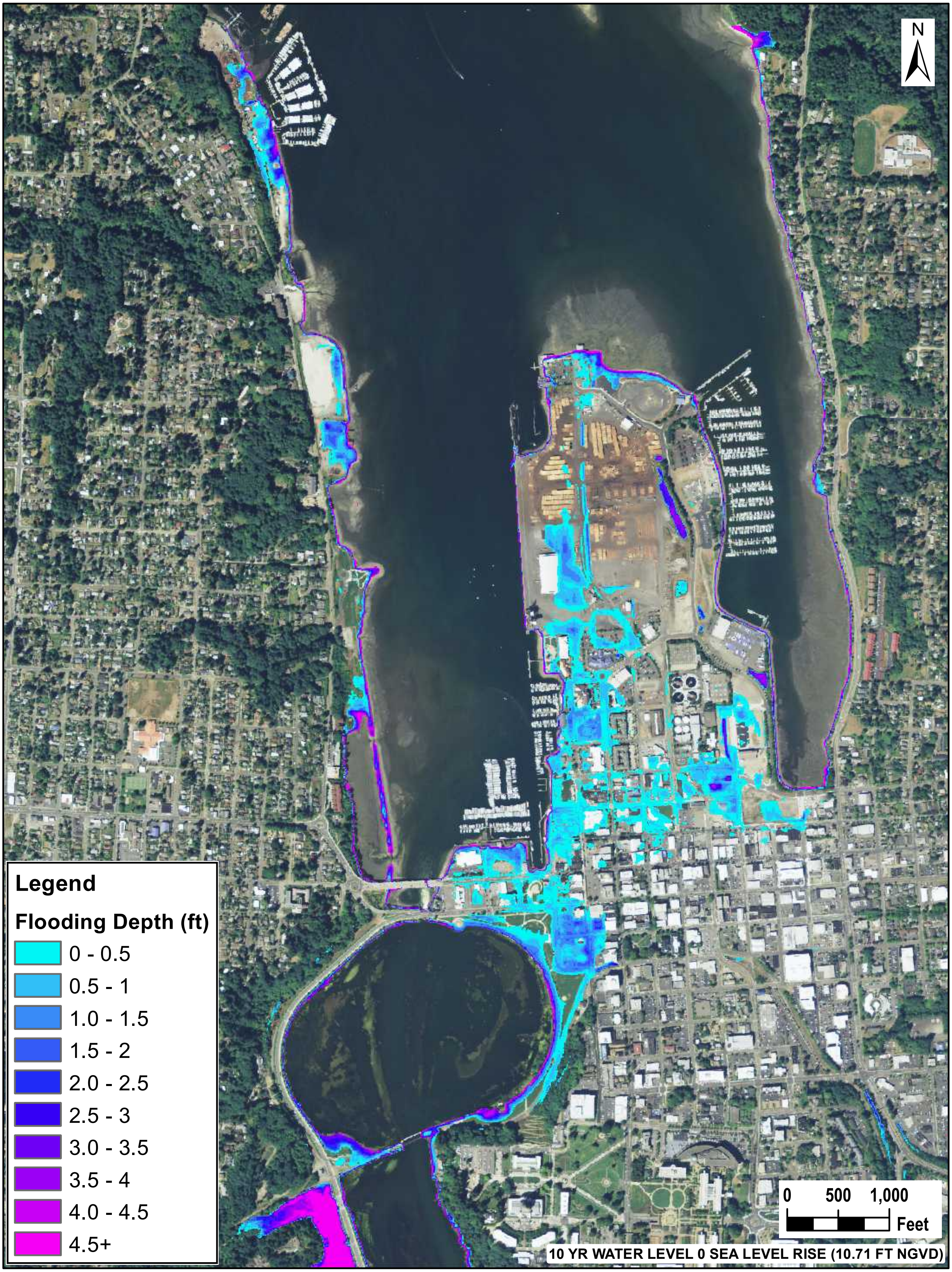
APPENDIX B

Flooded Areas According to Return Periods and Sea Level Rise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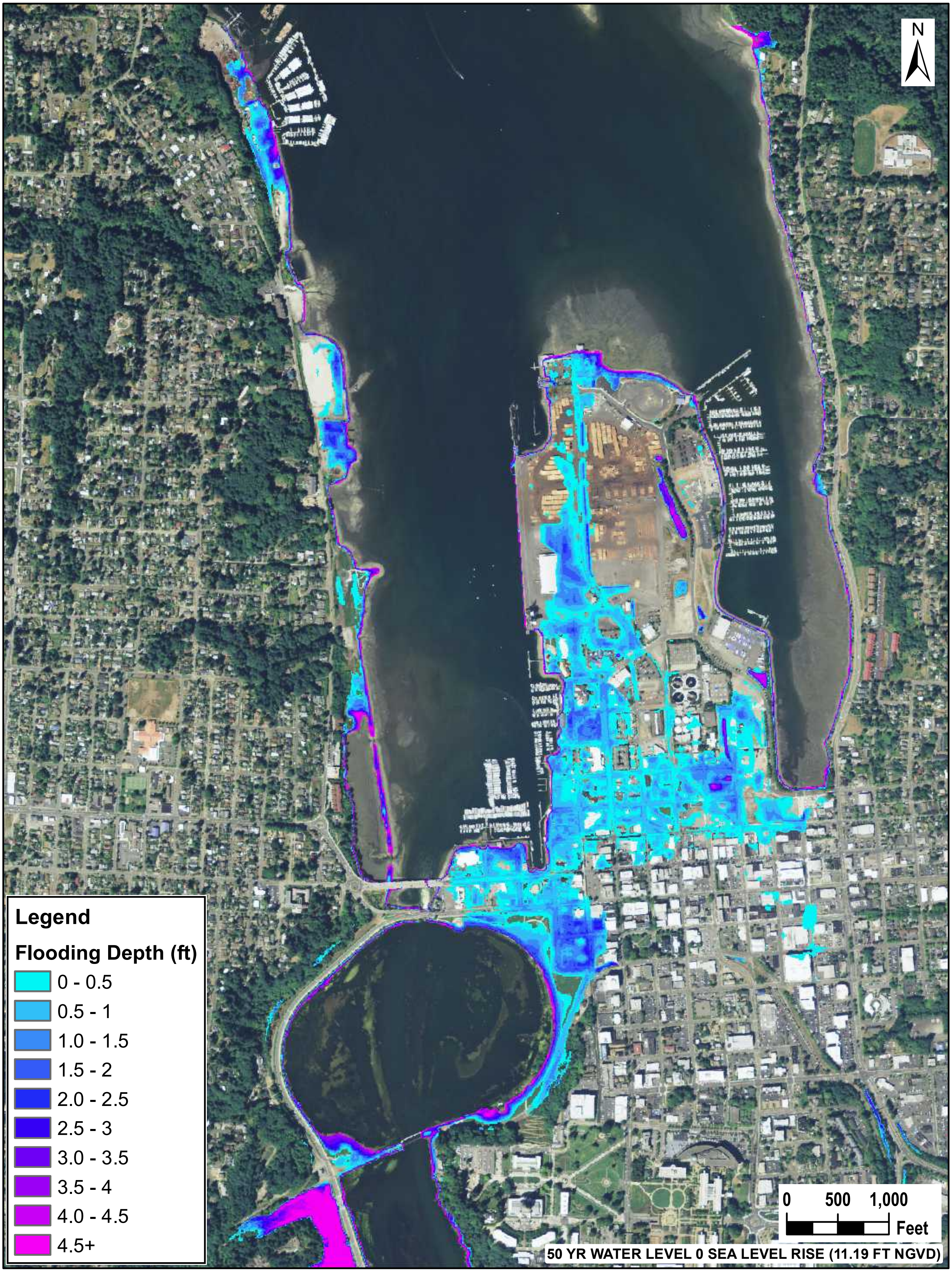
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0
500
1,000
Feet
10 YR WATER LEVEL 0 SEA LEVEL RISE (10.71 FT NGVD)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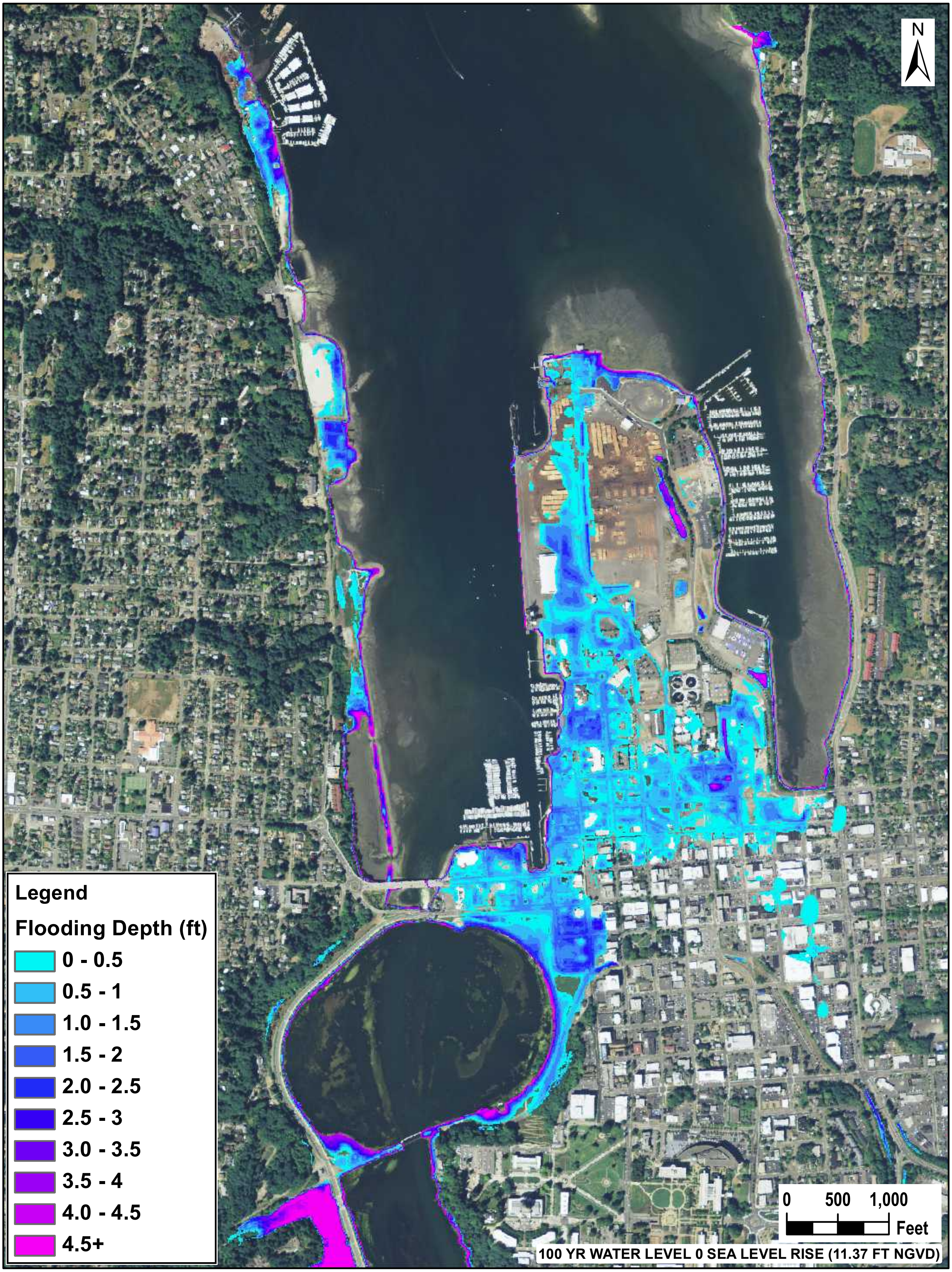
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0
500
1,000
Feet
50 YR WATER LEVEL 0 SEA LEVEL RISE (11.19 FT NGVD)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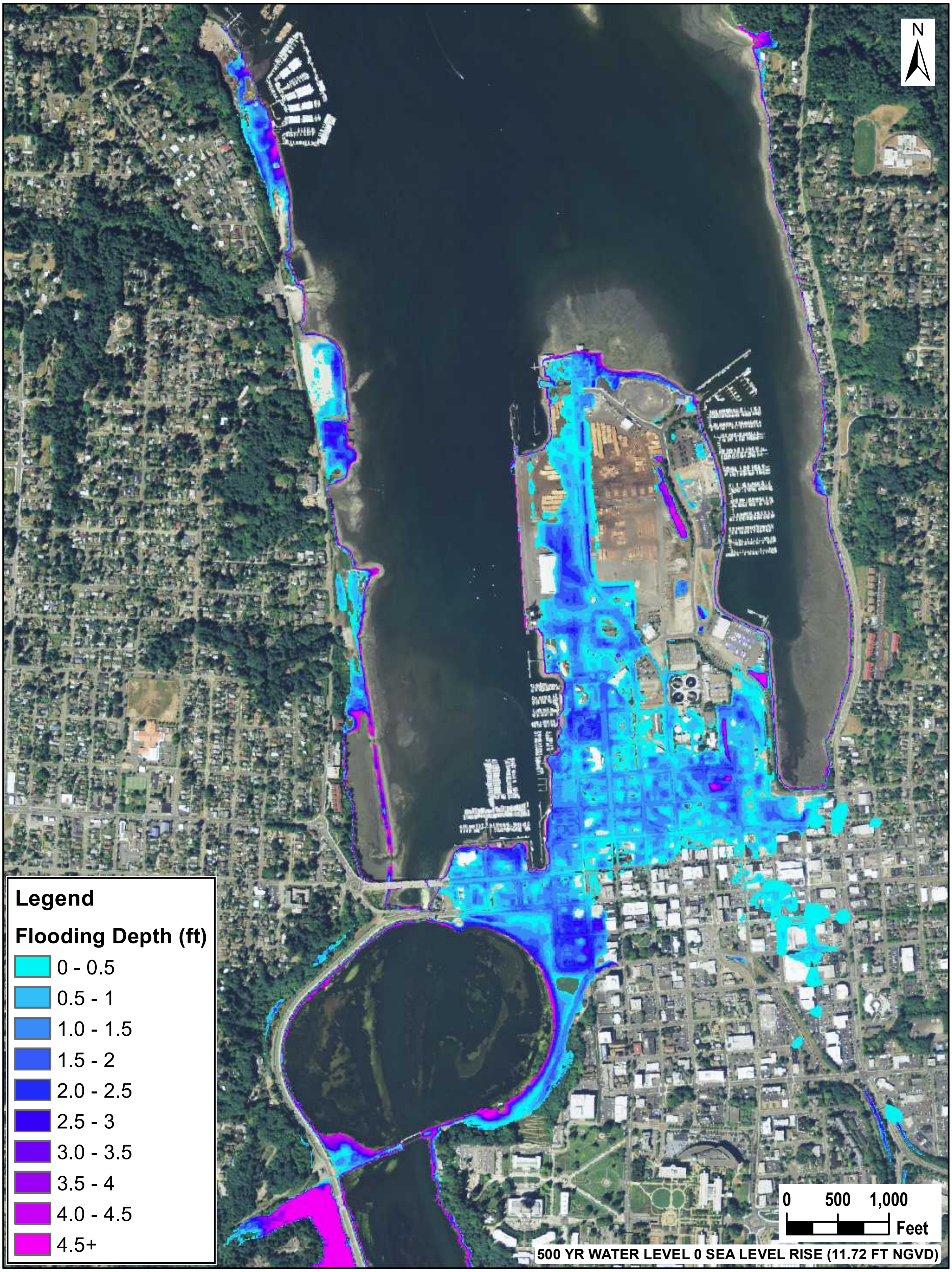
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
100 YR WATER LEVEL 0 SEA LEVEL RISE (11.37 FT NGVD)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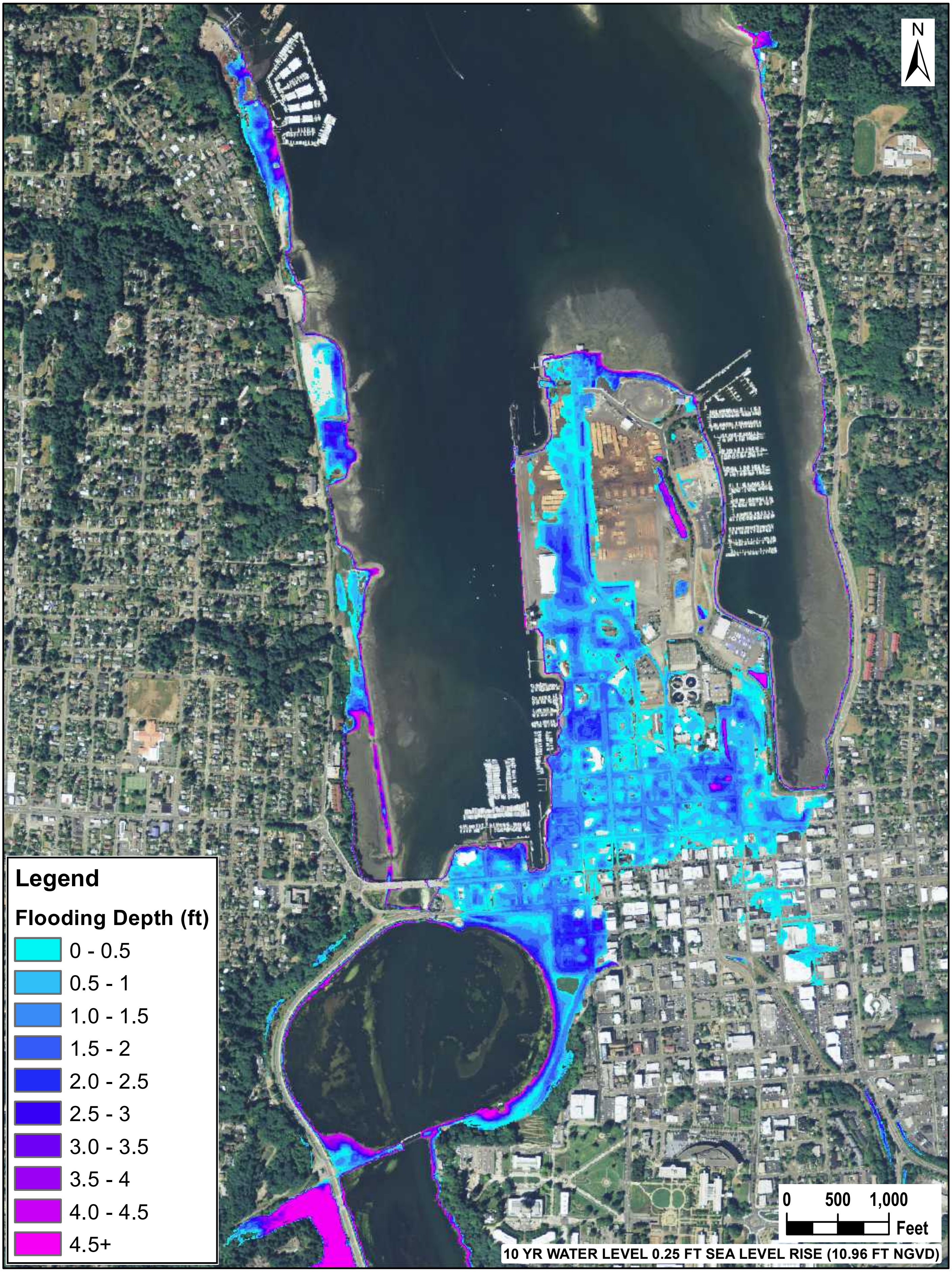
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0
500
1,000
Feet
500 YR WATER LEVEL 0 SEA LEVEL RISE (11.72 FT NGVD)



N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
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Feet
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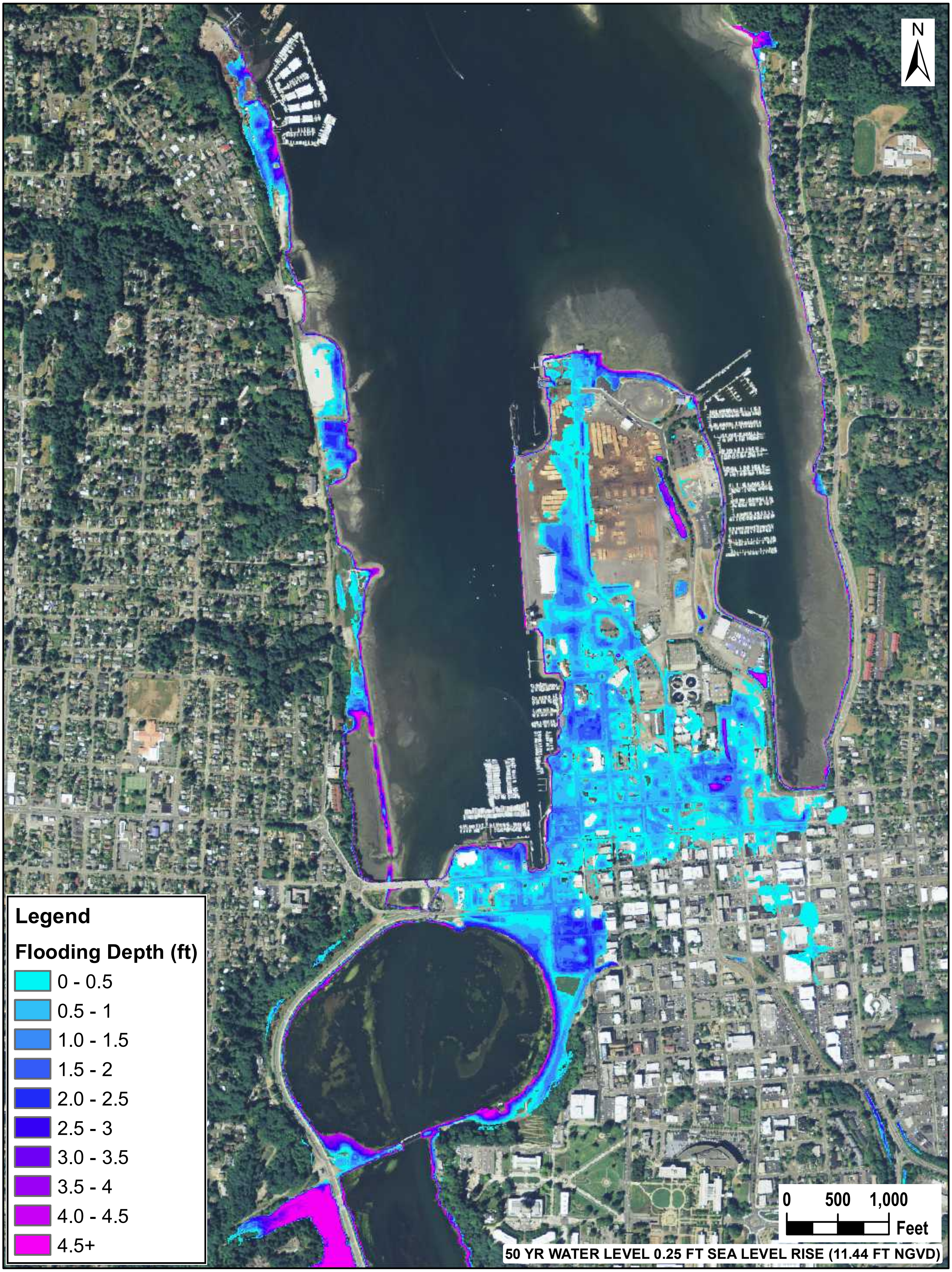
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Legend
Flooding Depth (ft)
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0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
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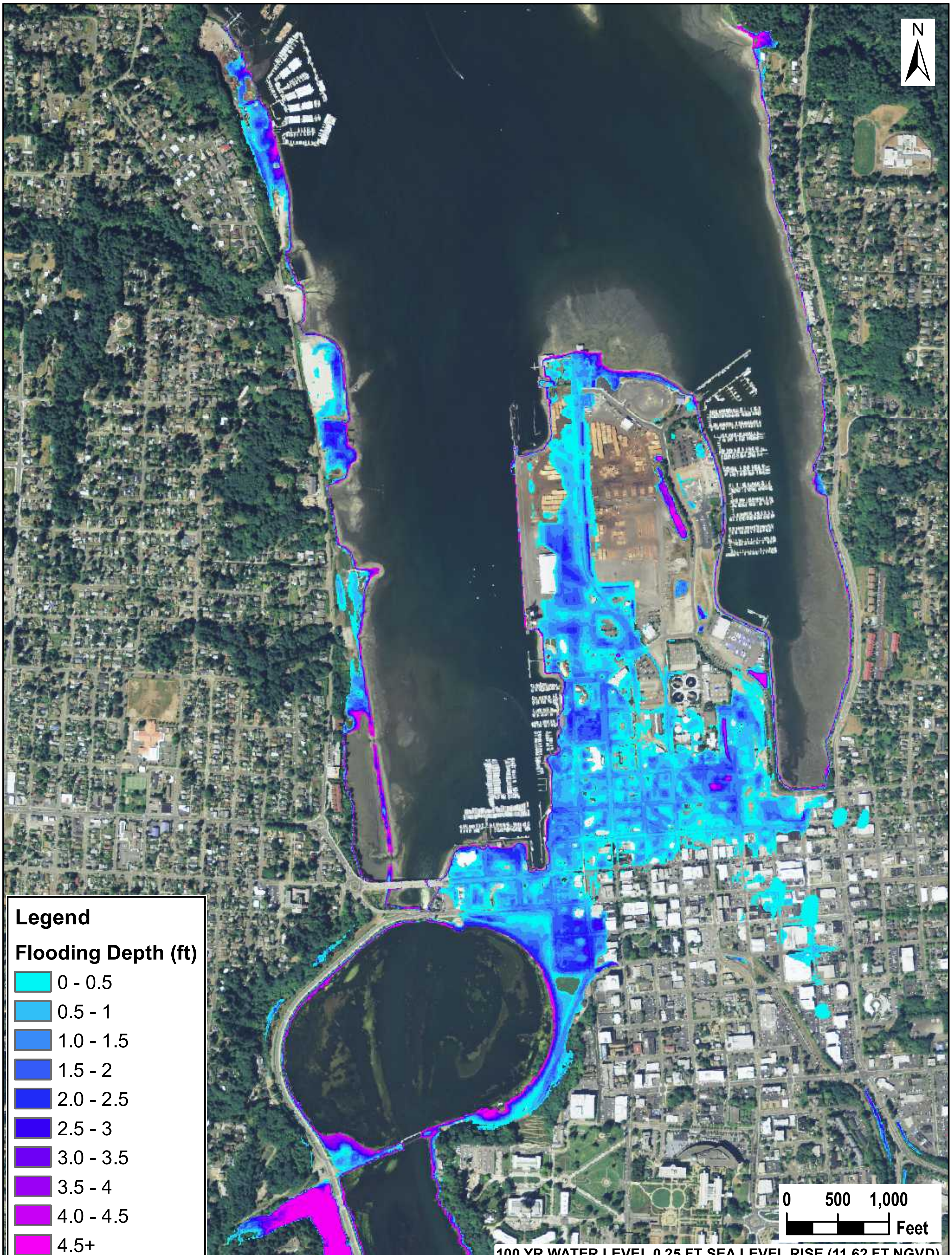
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Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
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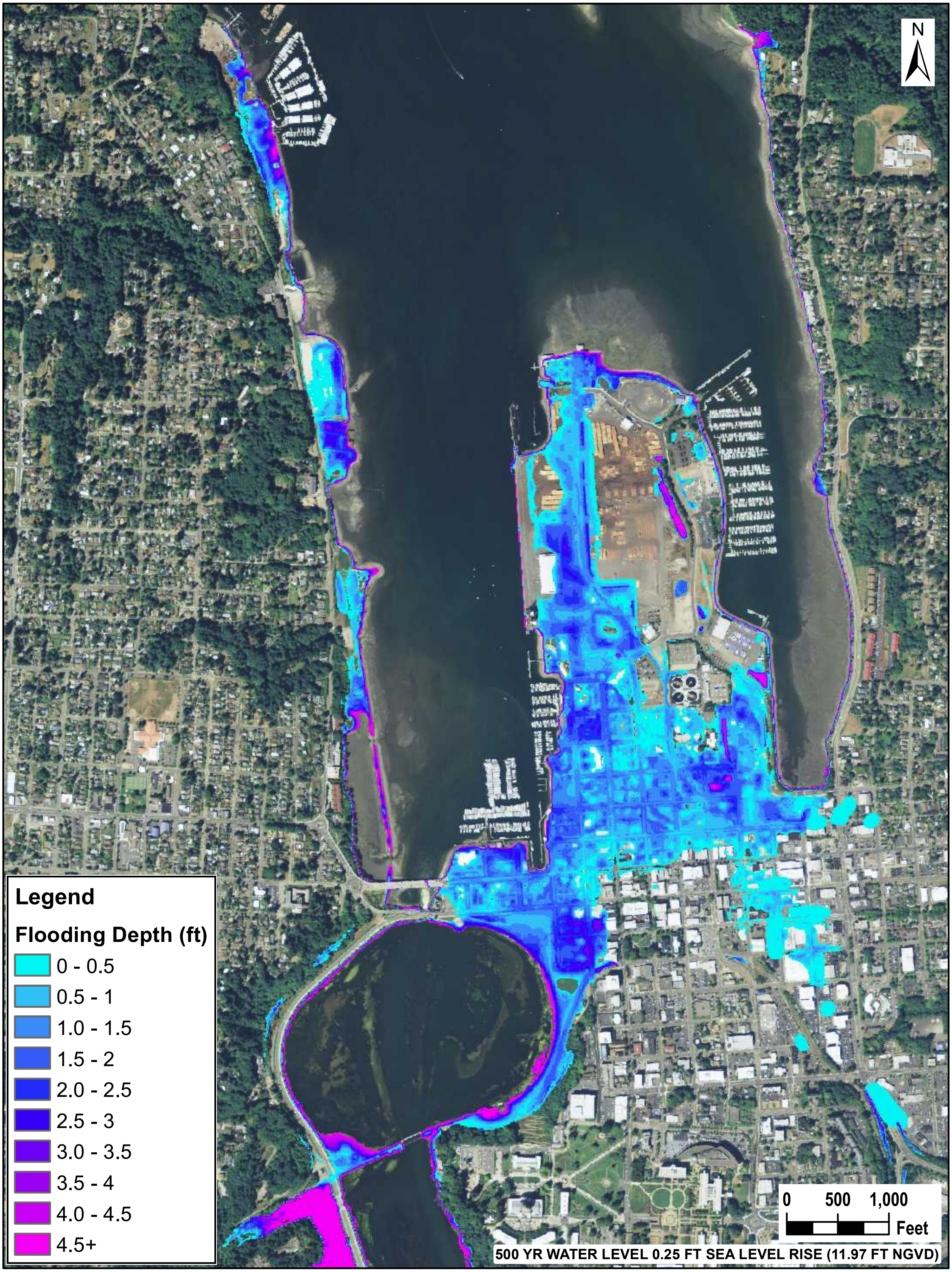
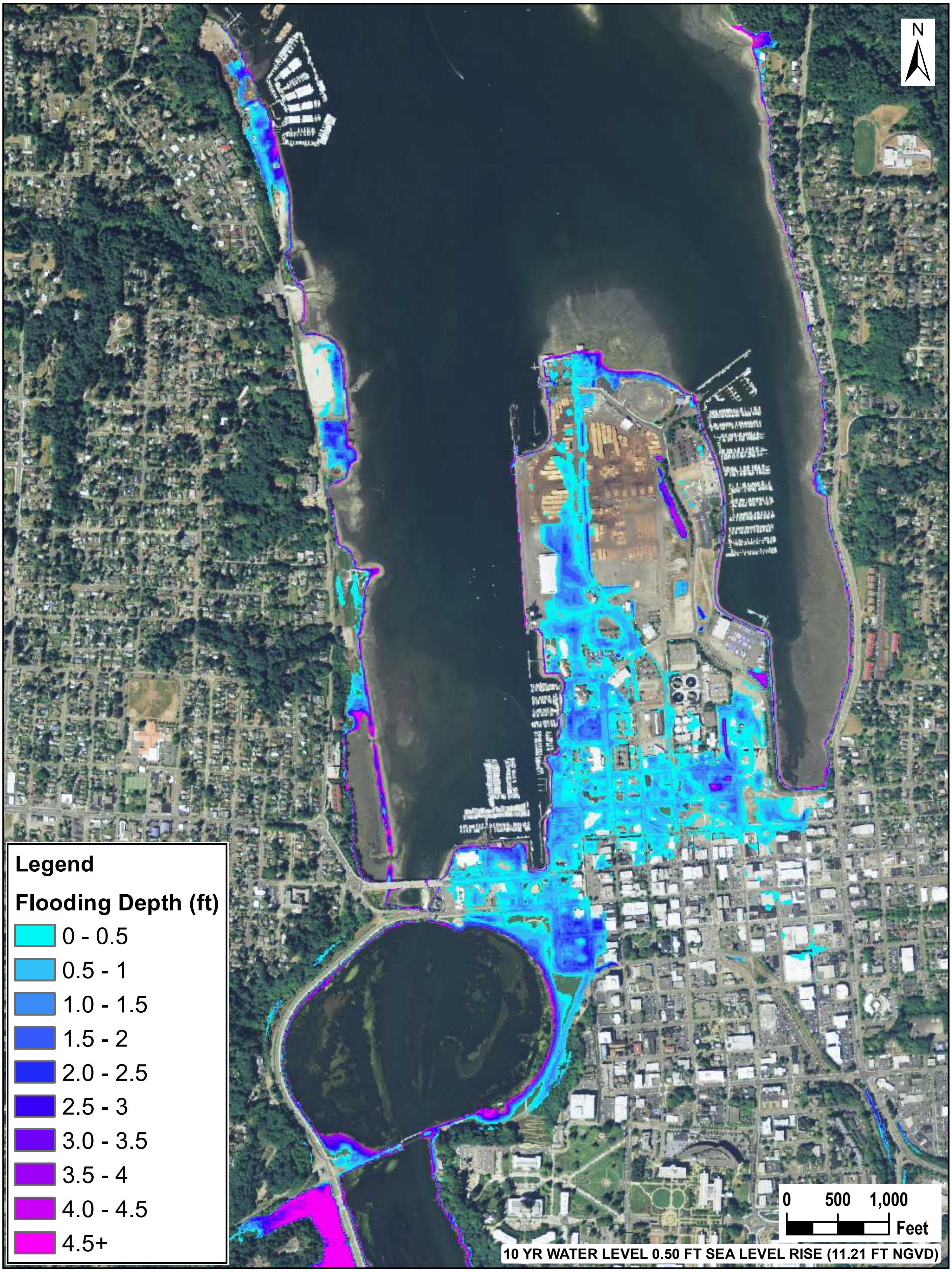
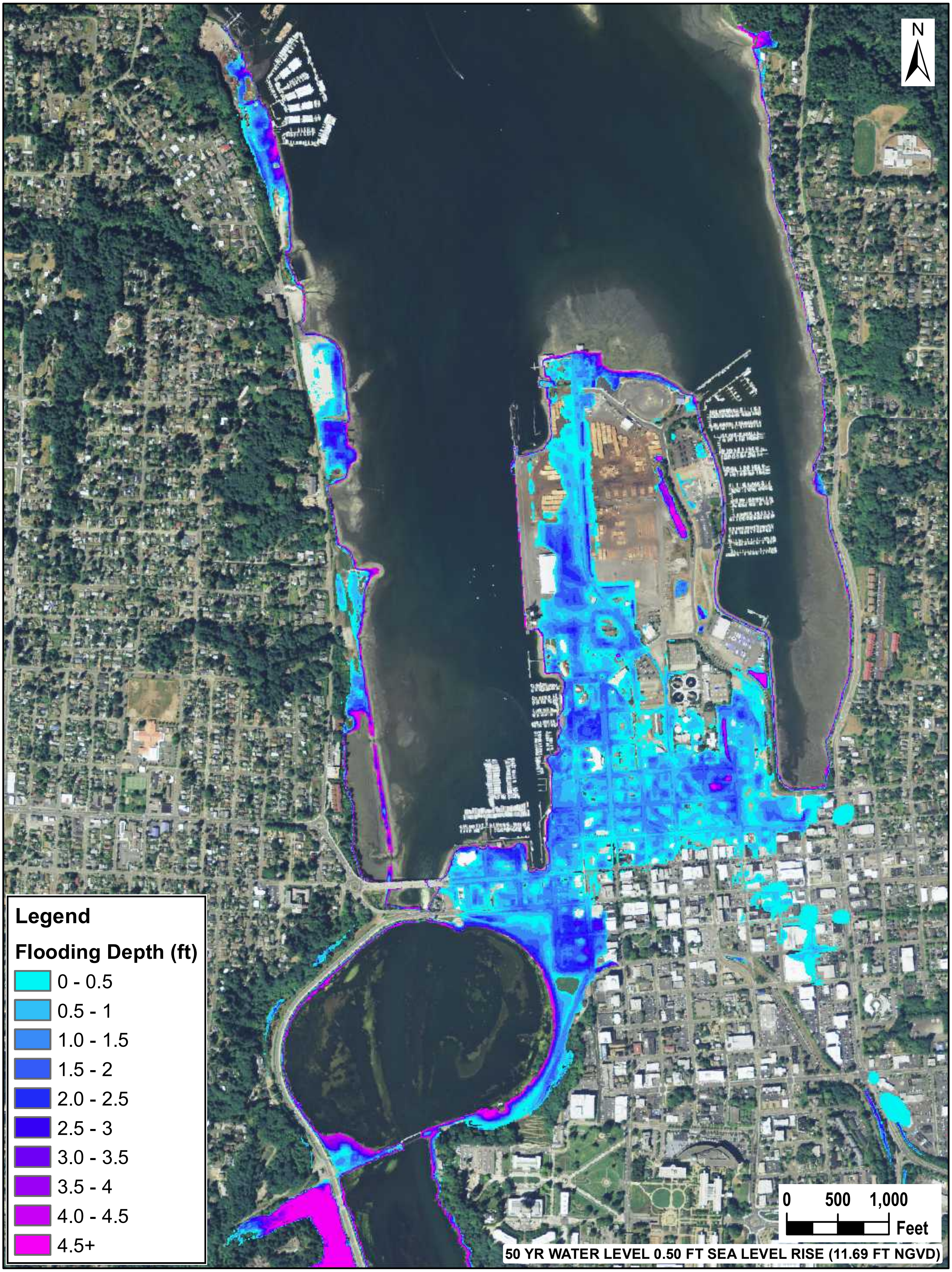
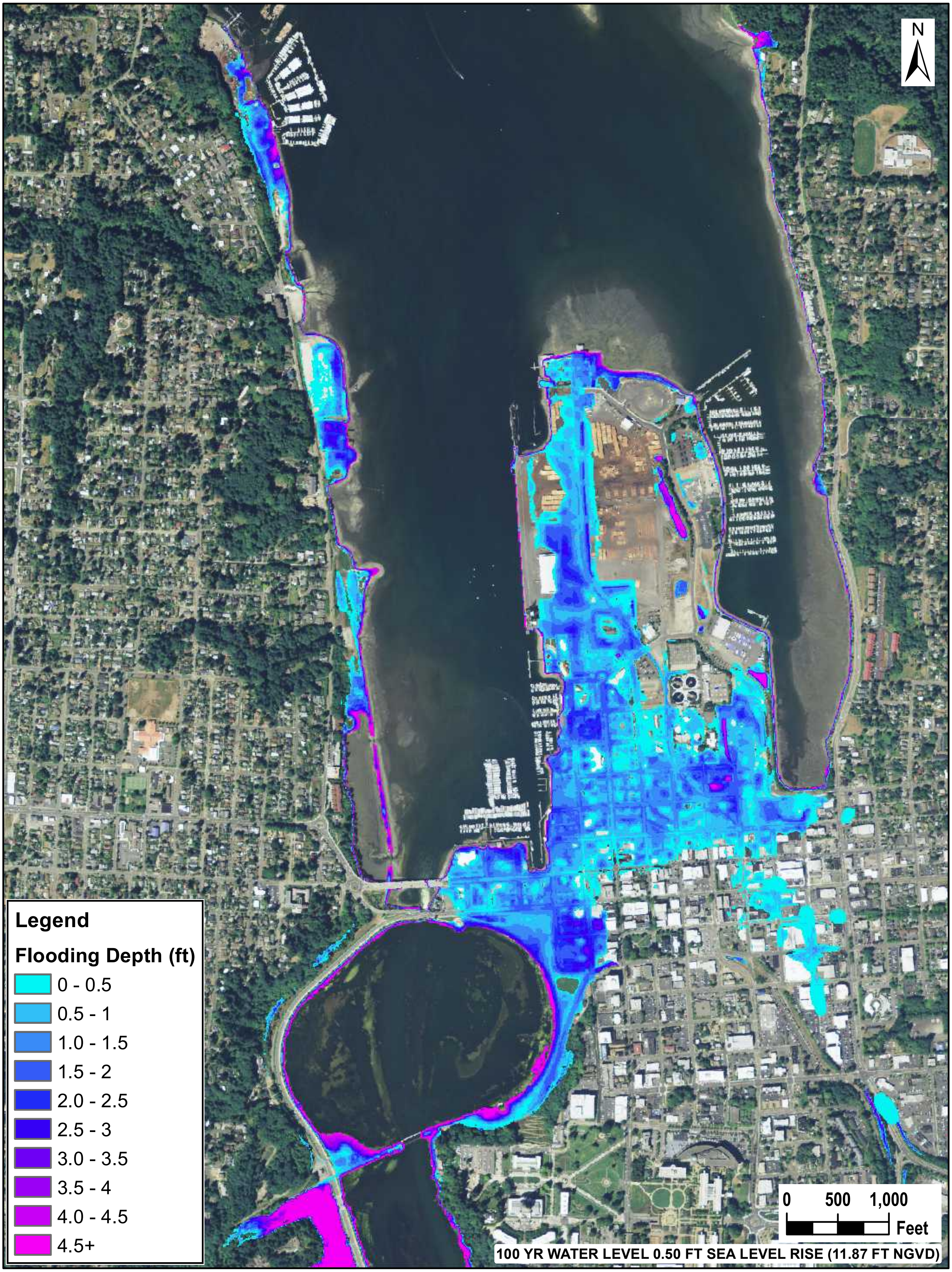
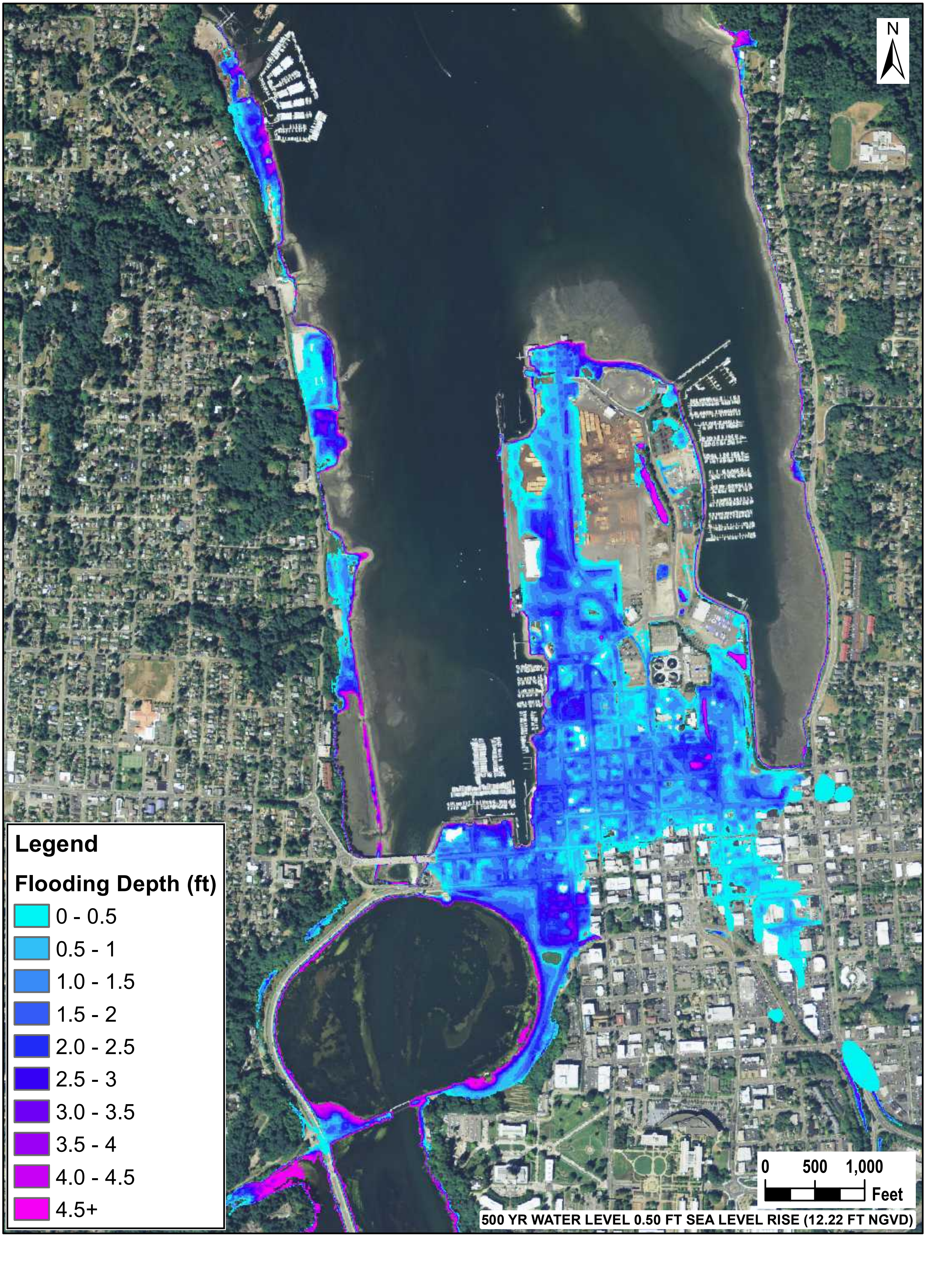
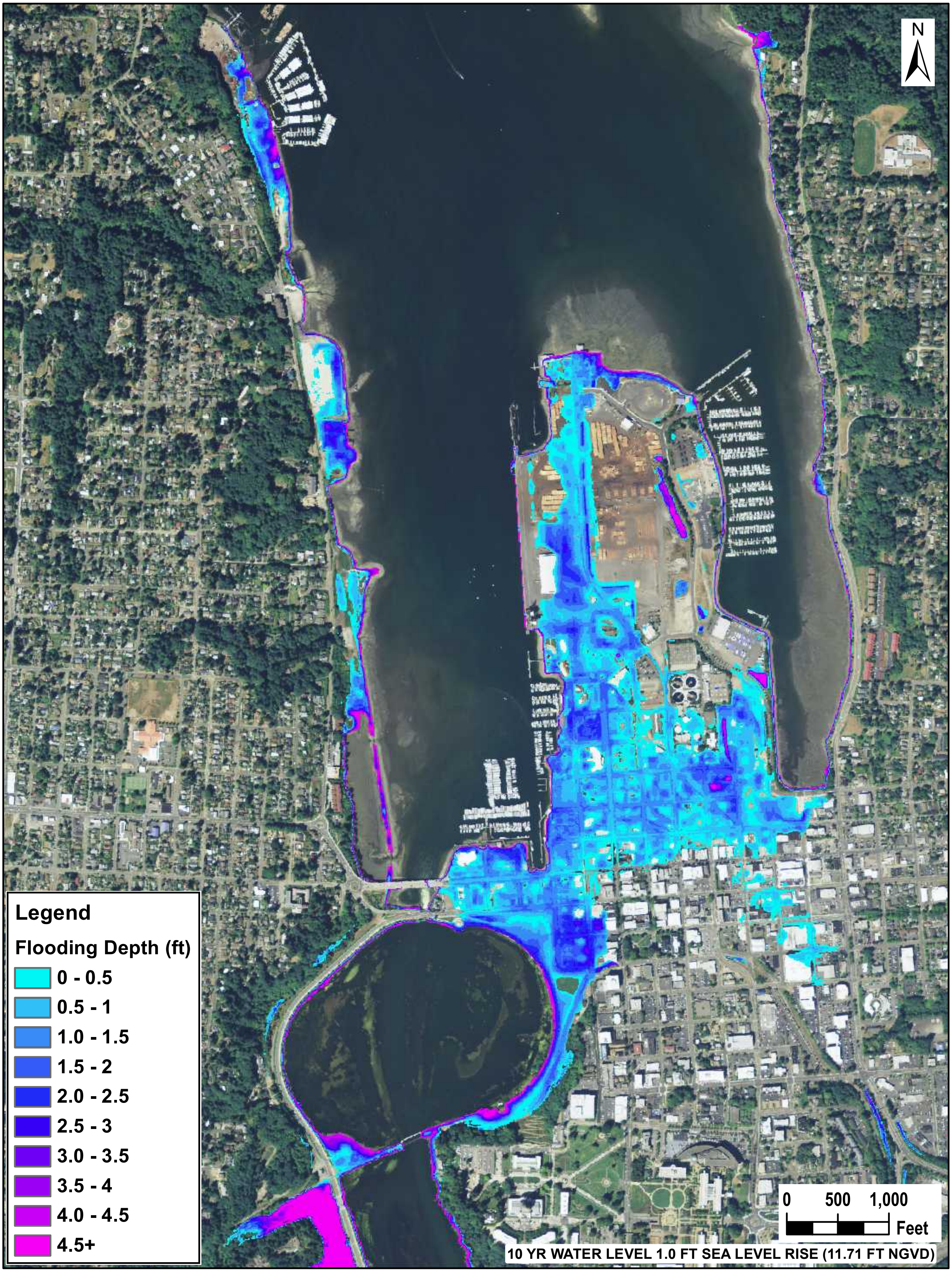

N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
500 YR WATER LEVEL 0.25 FT SEA LEVEL RISE (11.97 FT NGVD)

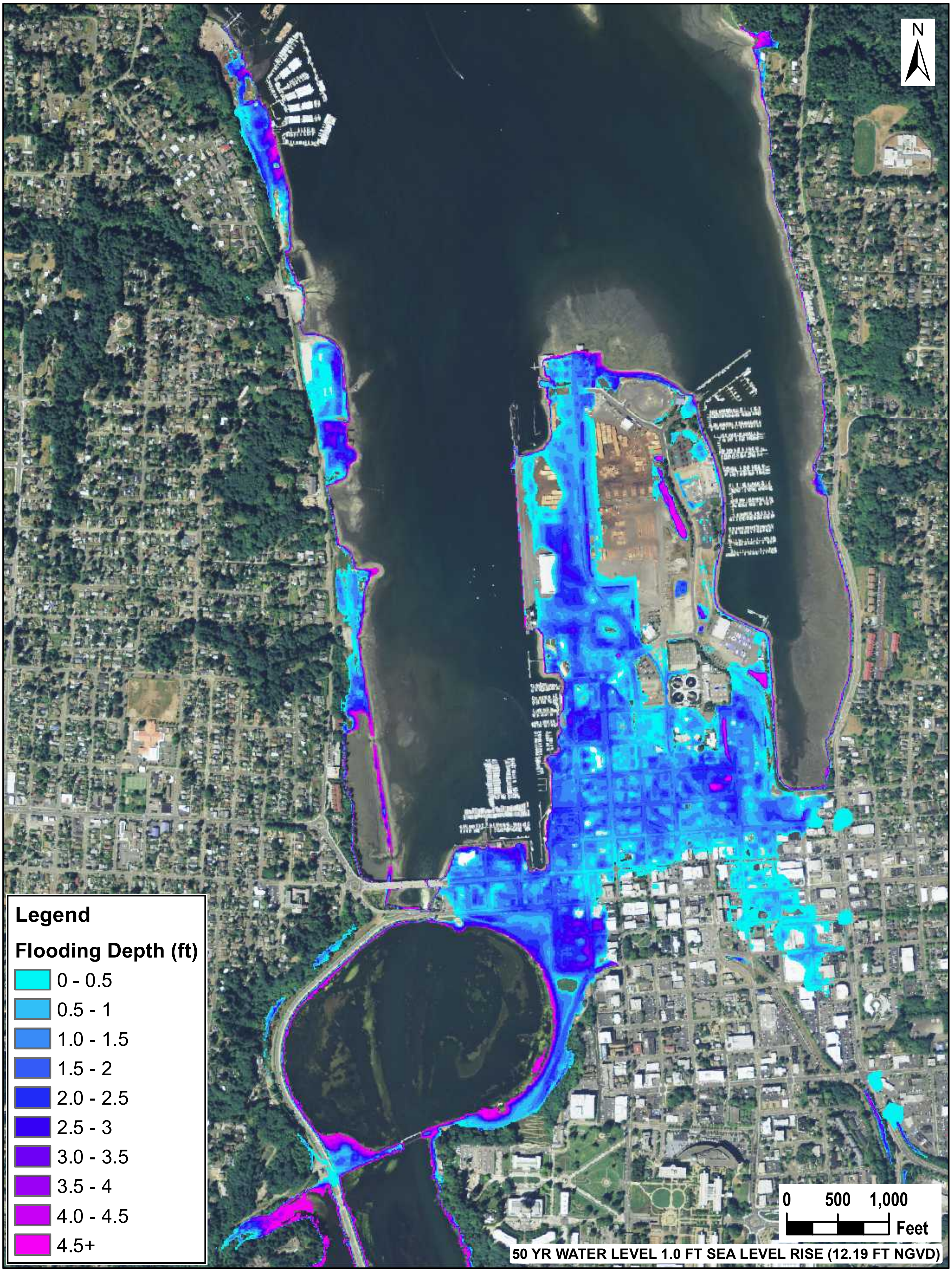

N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
10 YR WATER LEVEL 0.50 FT SEA LEVEL RISE (11.21 FT NGVD)

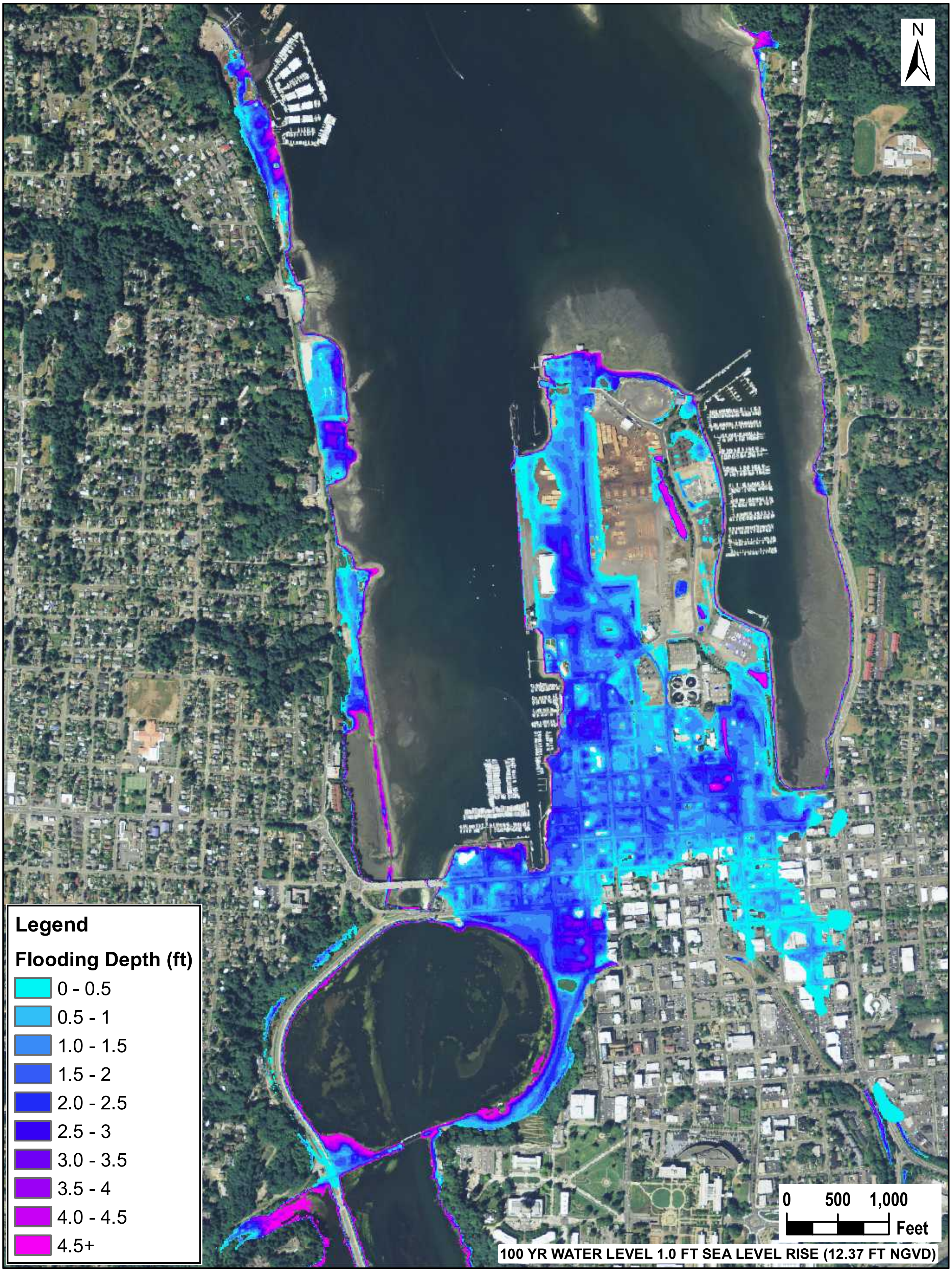

N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
50 YR WATER LEVEL 0.50 FT SEA LEVEL RISE (11.69 FT NGVD)

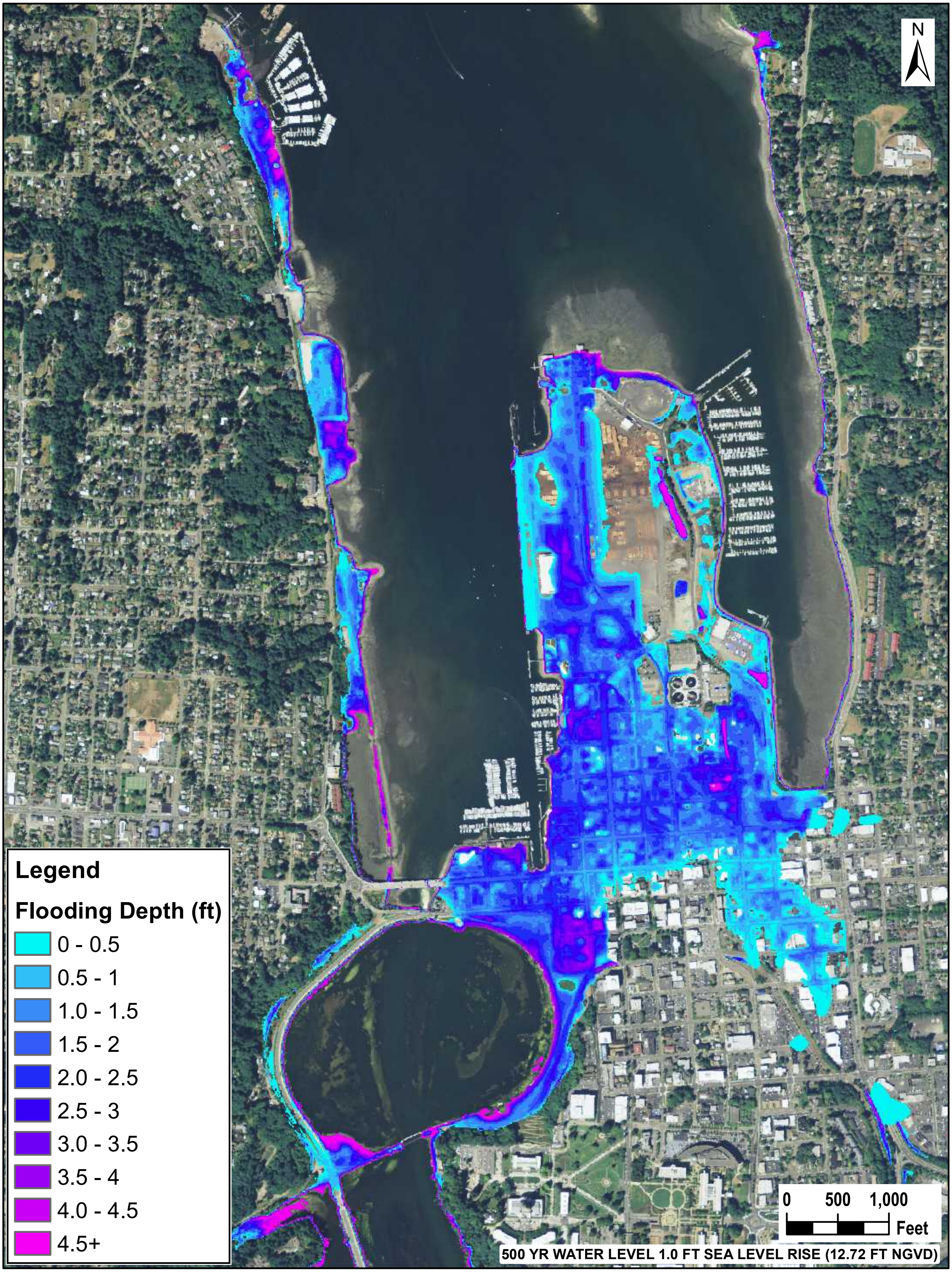

N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
100 YR WATER LEVEL 0.50 FT SEA LEVEL RISE (11.87 FT NGVD)

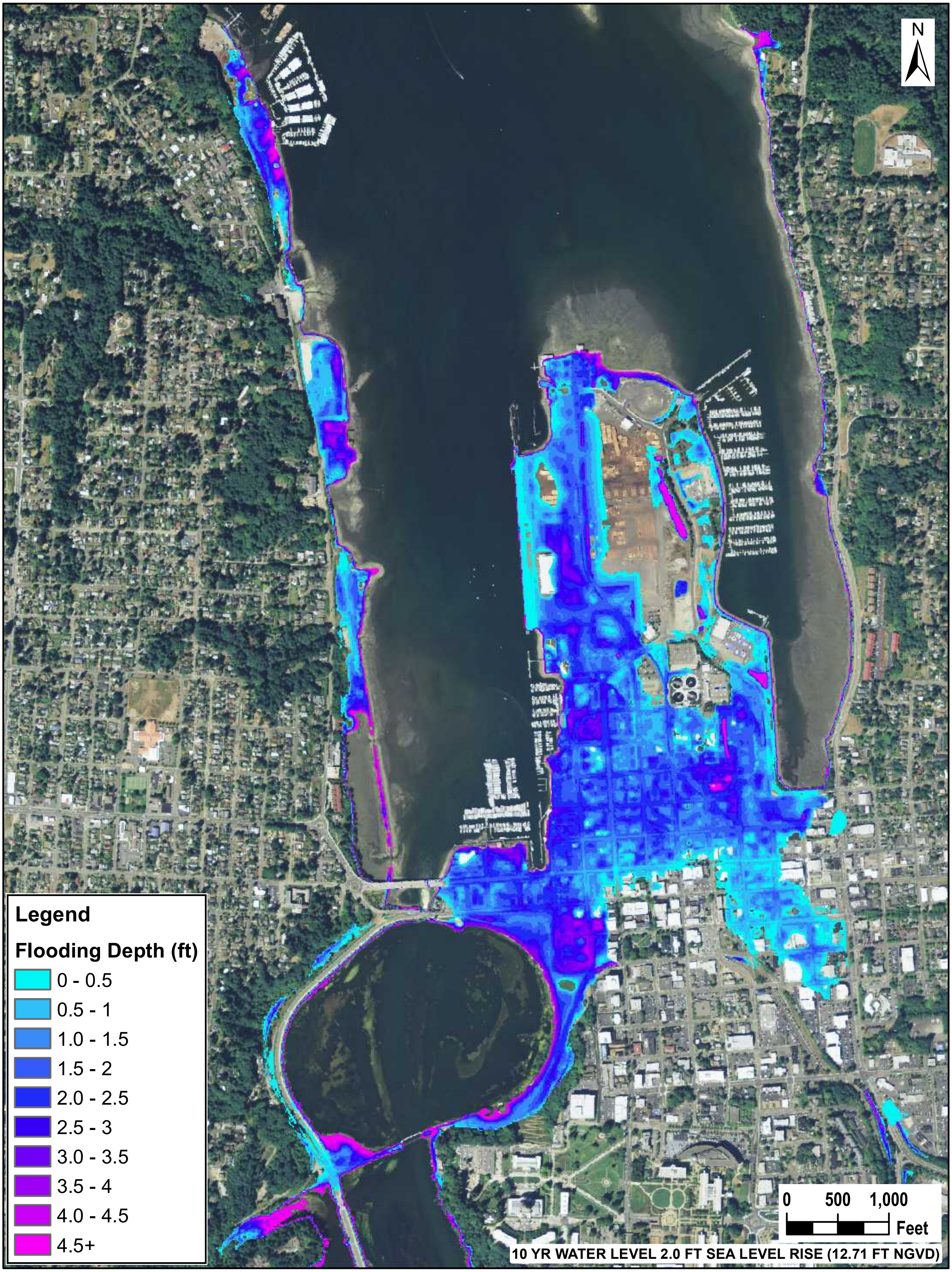

N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
500 YR WATER LEVEL 0.50 FT SEA LEVEL RISE (12.22 FT NGVD)


N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0
500
1,000
Feet
10 YR WATER LEVEL 1.0 FT SEA LEVEL RISE (11.71 FT NGVD)

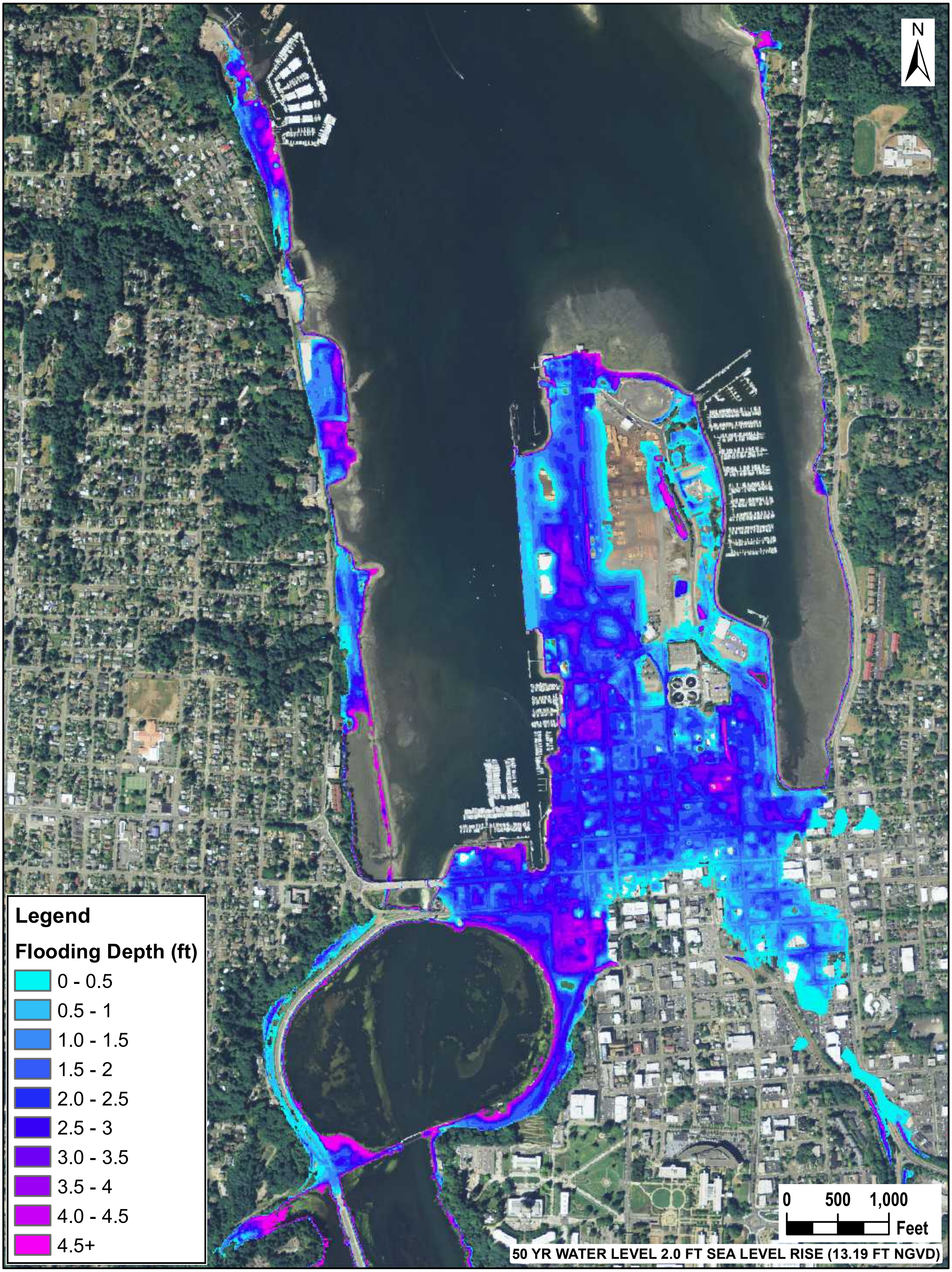

N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
50 YR WATER LEVEL 1.0 FT SEA LEVEL RISE (12.19 FT NGVD)

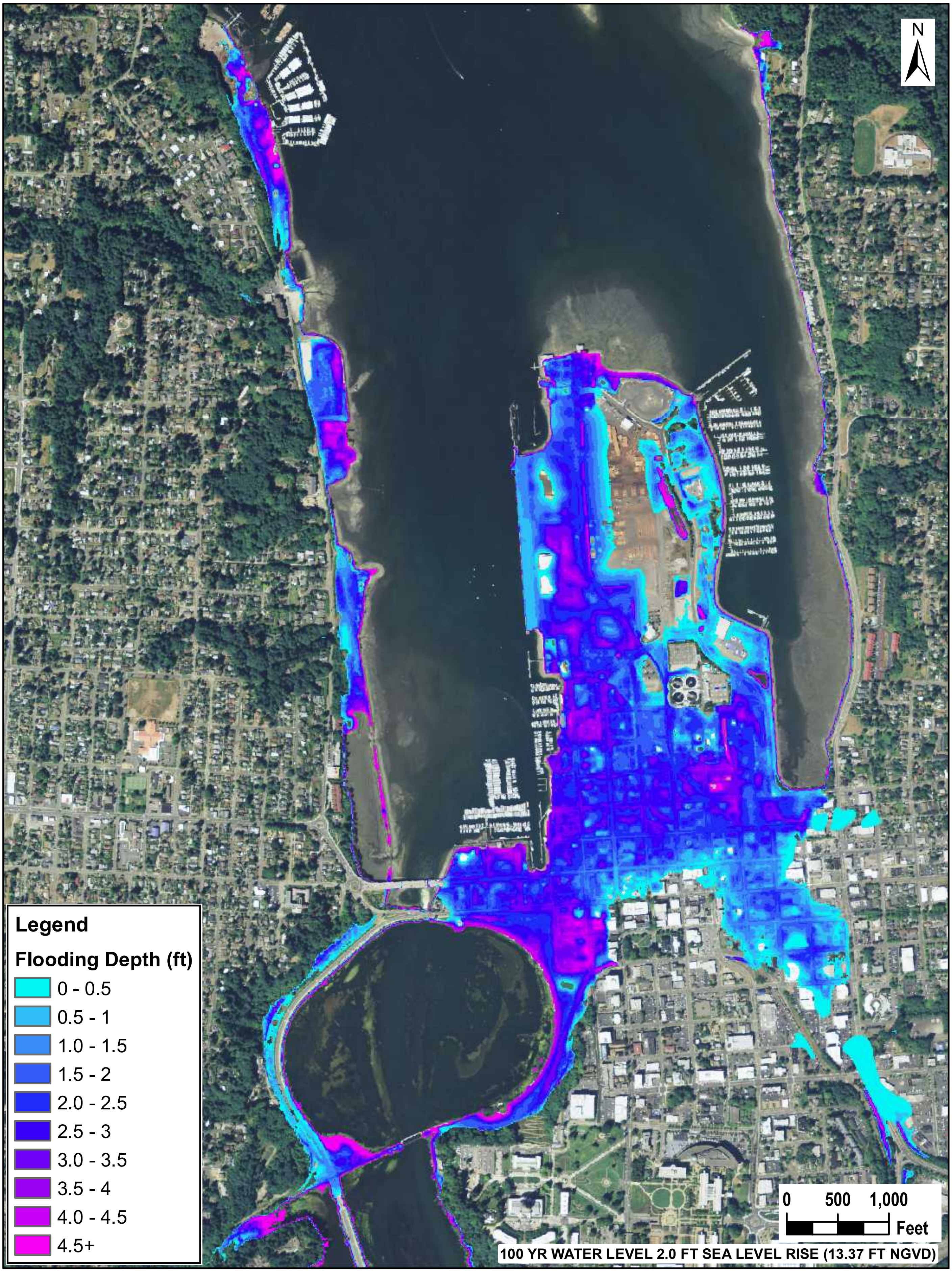

N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
100 YR WATER LEVEL 1.0 FT SEA LEVEL RISE (12.37 FT NGVD)

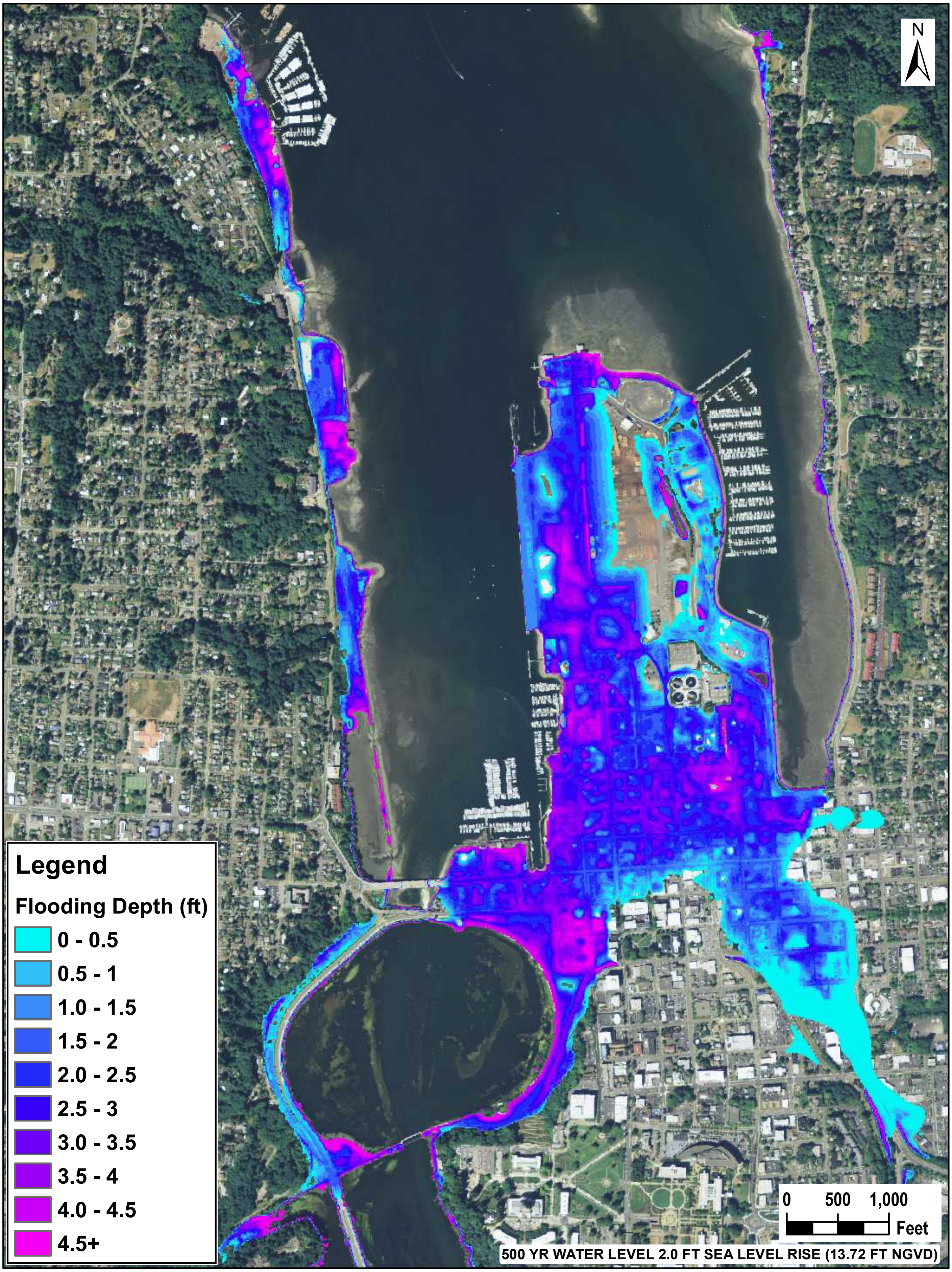

N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
500 YR WATER LEVEL 1.0 FT SEA LEVEL RISE (12.72 FT NGVD)

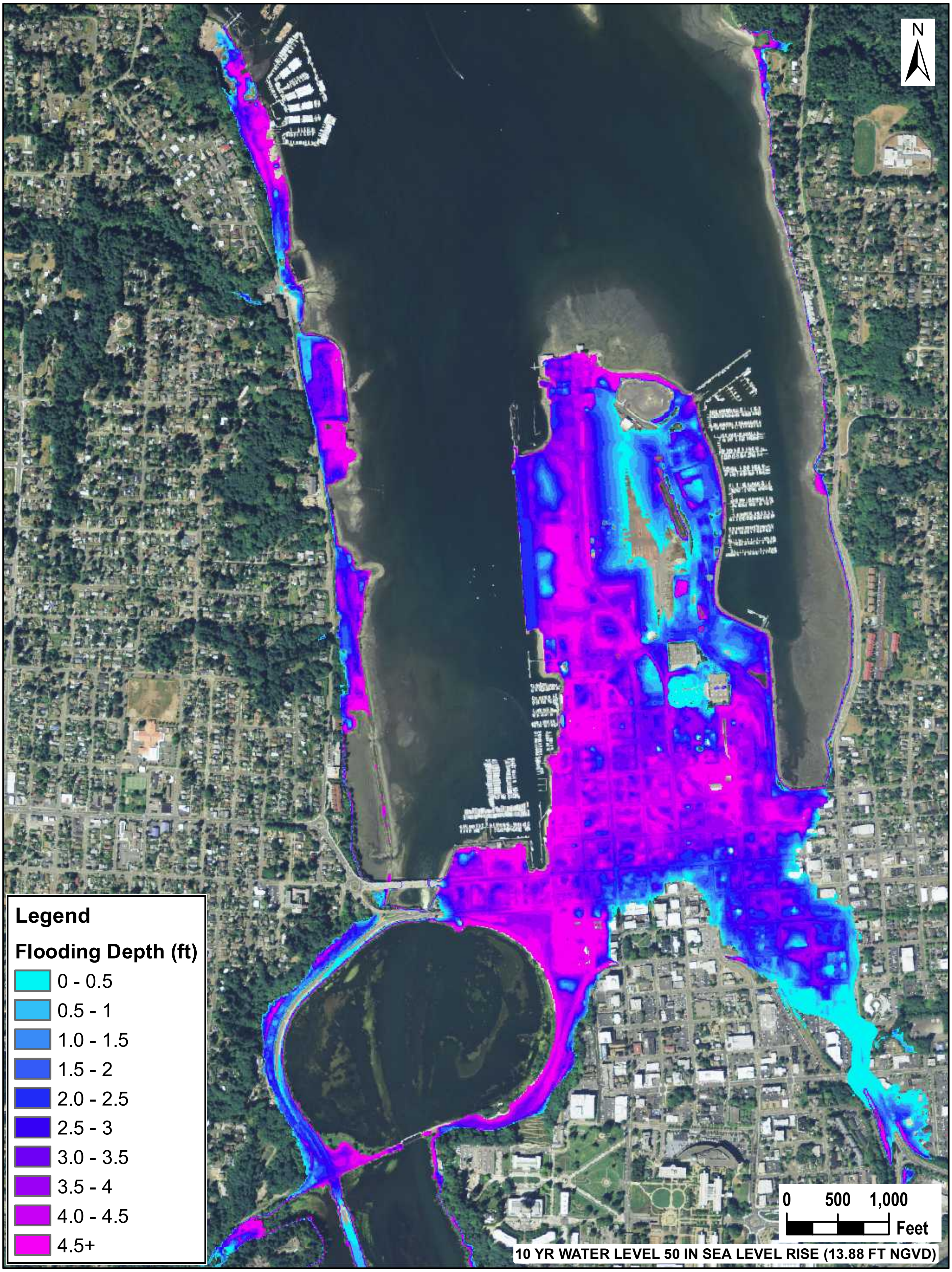


N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0
500
1,000
Feet
10 YR WATER LEVEL 2.0 FT SEA LEVEL RISE (12.71 FT NGVD)

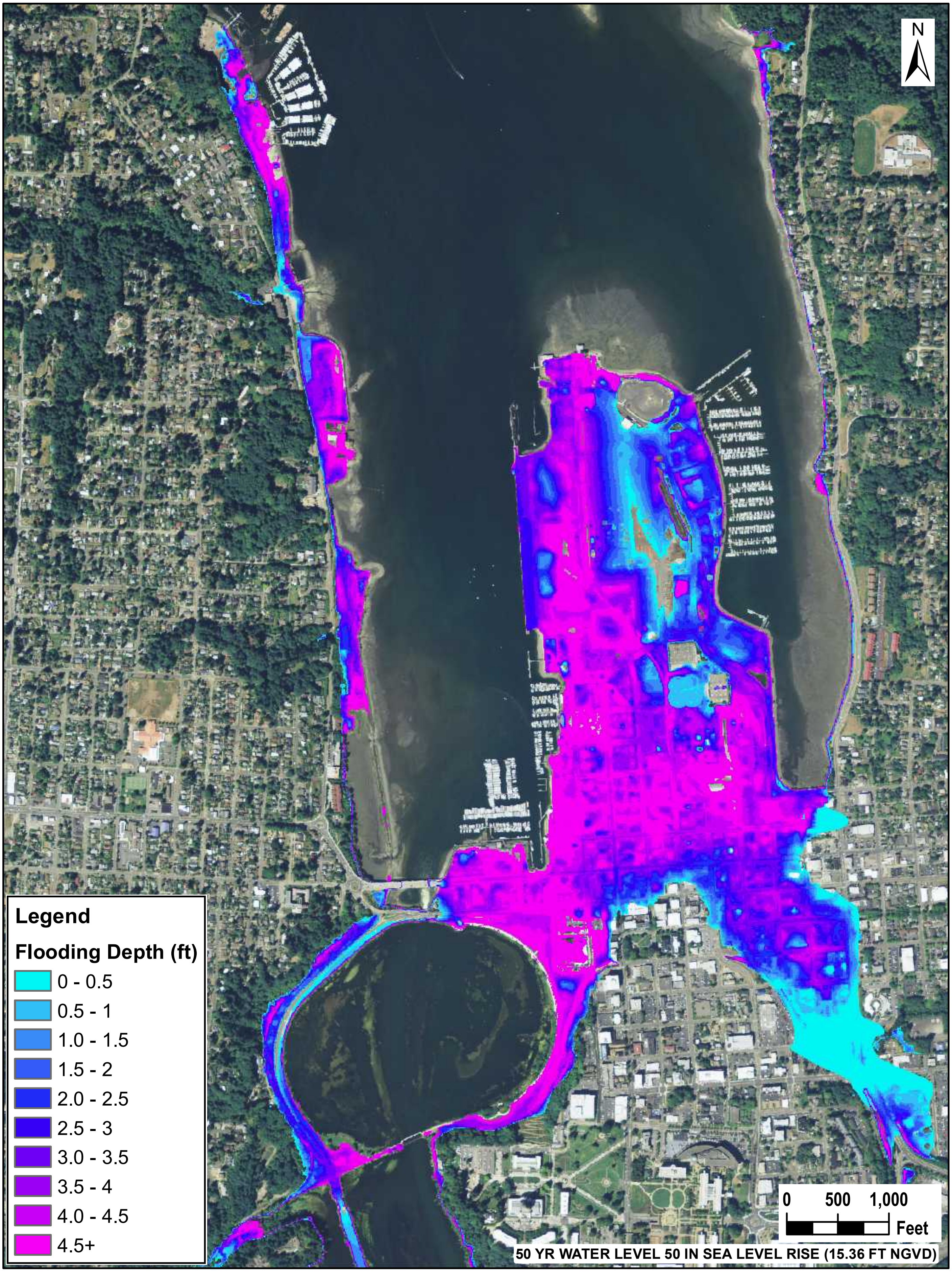

N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0
500
1,000
Feet
50 YR WATER LEVEL 2.0 FT SEA LEVEL RISE (13.19 FT NGVD)

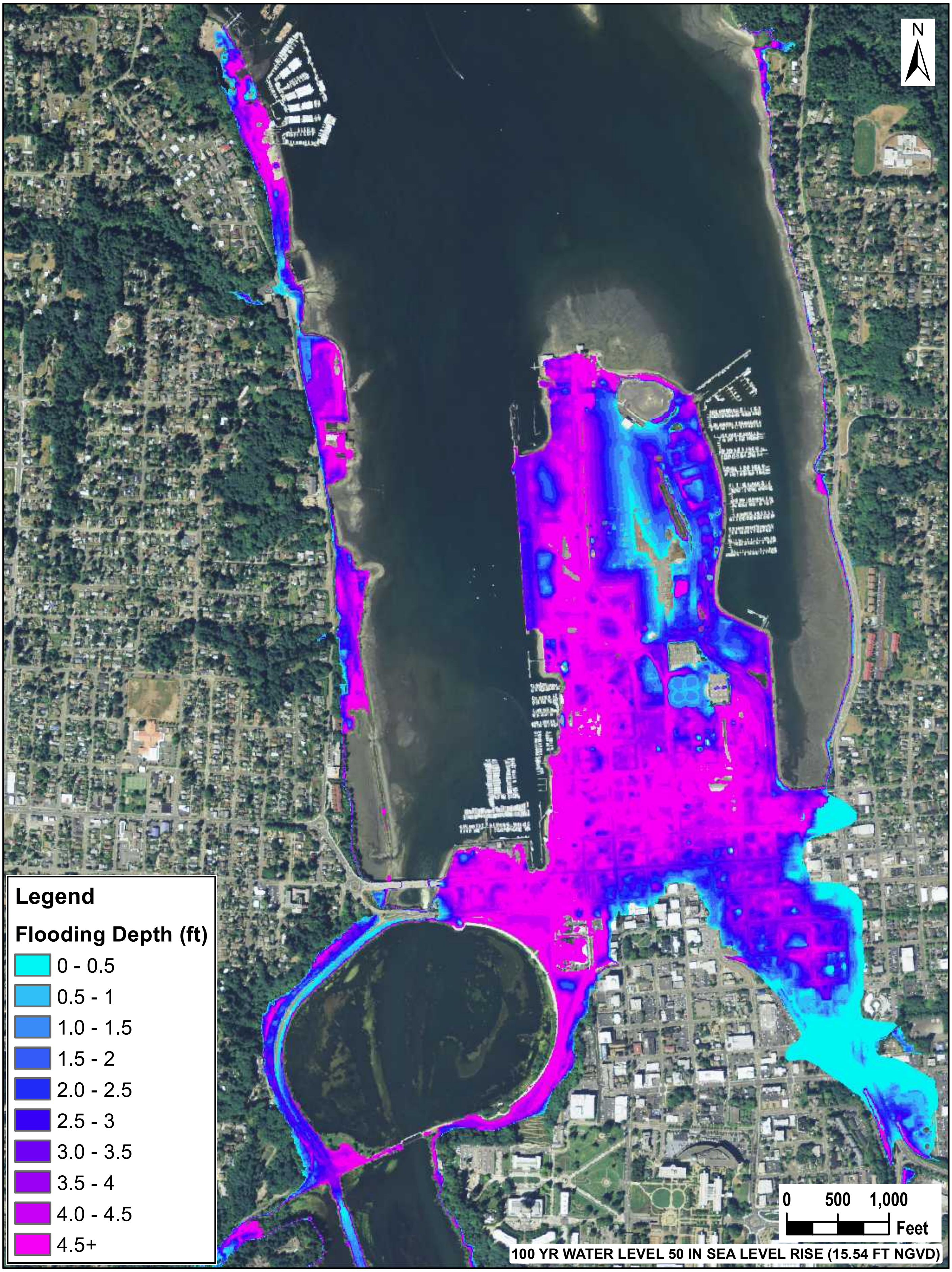

N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
100 YR WATER LEVEL 2.0 FT SEA LEVEL RISE (13.37 FT NGVD)

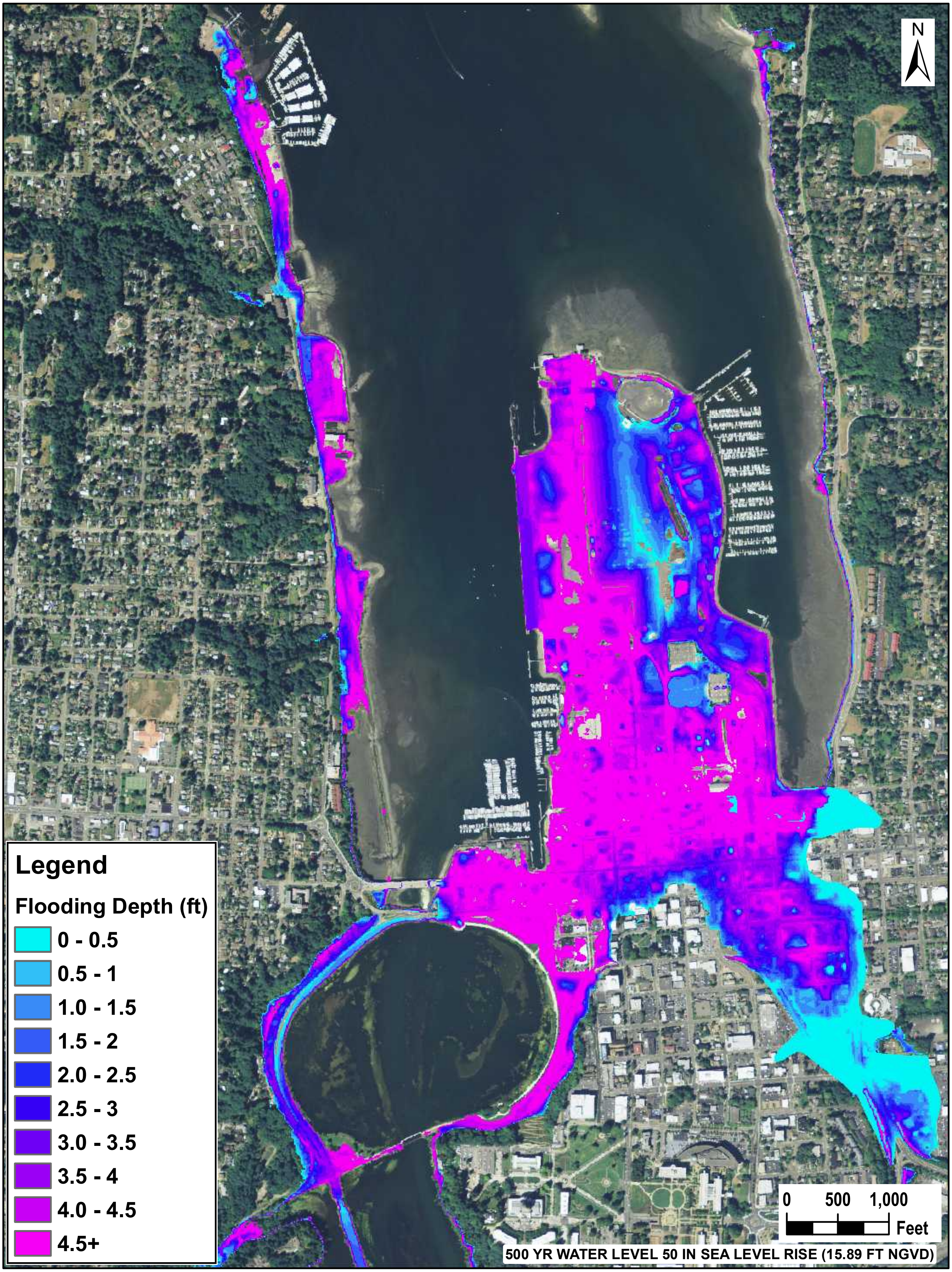

N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
500 YR WATER LEVEL 2.0 FT SEA LEVEL RISE (13.72 FT NGVD)



N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
10 YR WATER LEVEL 50 IN SEA LEVEL RISE (13.88 FT NGVD)


N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0
500
1,000
Feet
50 YR WATER LEVEL 50 IN SEA LEVEL RISE (15.36 FT NGVD)


N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0 500 1,000
Feet
100 YR WATER LEVEL 50 IN SEA LEVEL RISE (15.54 FT NGVD)


N
Legend
Flooding Depth (ft)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 2
2.0 - 2.5
2.5 - 3
3.0 - 3.5
3.5 - 4
4.0 - 4.5
4.5+
0
500
1,000
Feet
500 YR WATER LEVEL 50 IN SEA LEVEL RISE (15.89 FT NGVD)