Task 700 Climate Change Assessment

Kitsap County

September 2019

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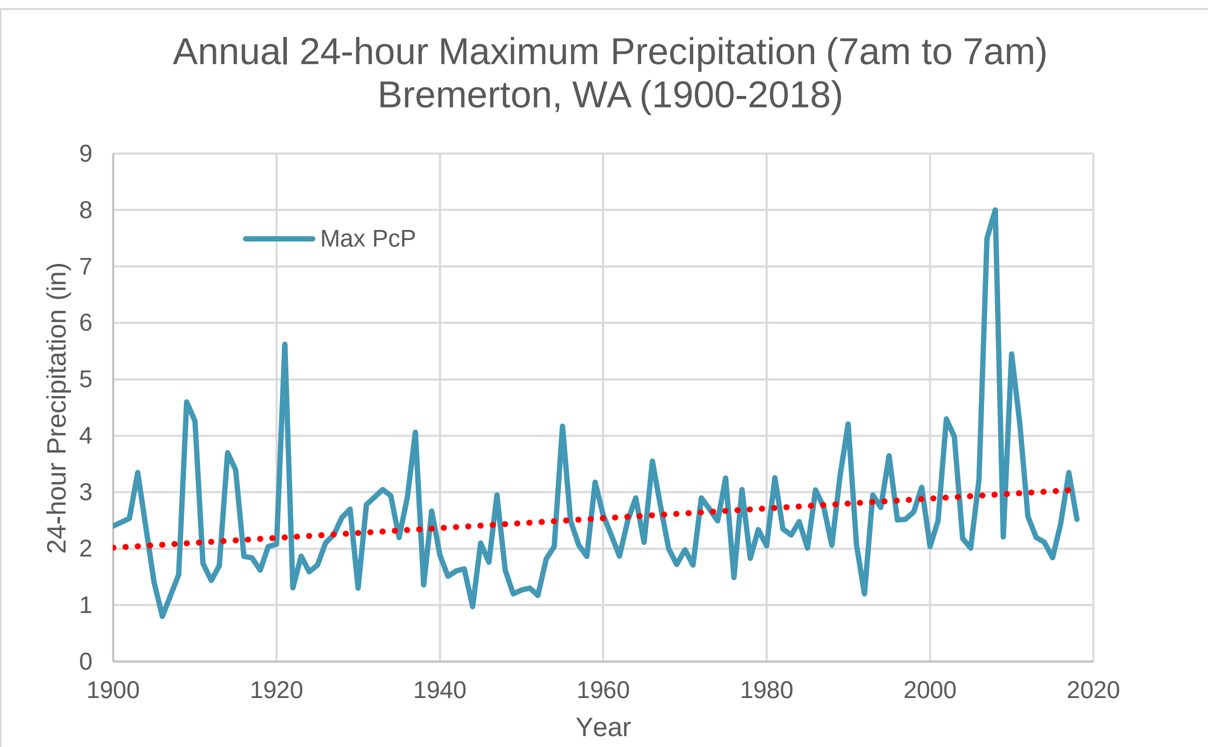
Executive Summary

This portion of the broader study of the Kitsap County stormwater system was related to investigating the current and potential future impacts of climate on the system. This required both an up-to-date analysis of observed trends for changes in sea level around the county's coastal environment, as well as a look at the potential impacts future projections of sea level rise (SLR) will bring. Observed sea level trends showed a steady increase in sea level over the last 120 years to be on the order of approximately 1 inch every 12.3 years. Projected changes in SLR, according to the most recent study by the University of Washington (UW) Climate Impacts Group (CIG 2018), indicate an elevated increase in this rate of rise that ranges from 0.22 ft. for a low emissions scenario by the year 2030 to 1.37 ft. for a high emissions scenario by the year 2100. This analysis included a detailed accounting of the impact of these future SLR scenarios on individual system outfall conveyances (Appendix A).

This study also investigated both current and projected trends in precipitation intensities for Kitsap County. The analysis of historic trends in precipitation intensities discovered a 50 percent increase has occurred since 1900 in the annual 24-hour maximum precipitation in southern Kitsap County as seen in the figure below. This identified trend was further corroborated by a recent study of changes in observed precipitation intensities that was completed on behalf of Seattle Public Utilities (SPU 2017) for the region. This study showed a significant increase from previous estimates (i.e., NOAA Atlas 2) in the amount of precipitation associated with the higher return frequencies (i.e., 25, 50, and 100 year) for the 24-hour storm event. The 24-hour, 100-year event was shown to have increased 43 percent through the use of the post-1973 precipitation dataset that occurred after NOAA Atlas 2 was developed.



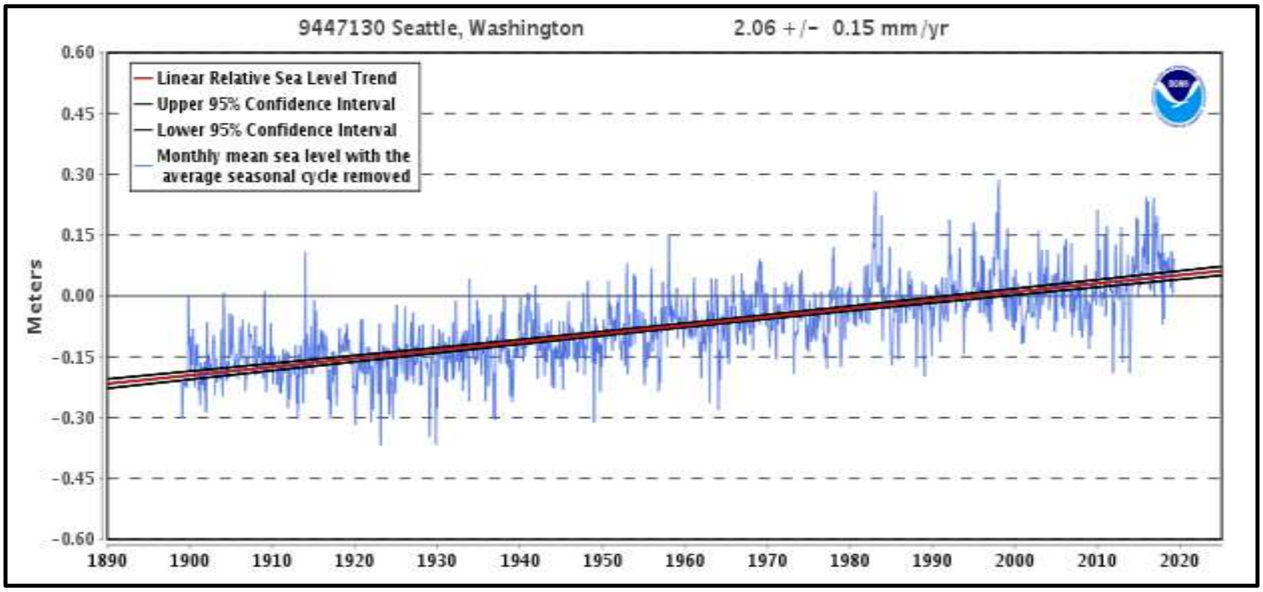
Future climate projections, as developed in a recent study by UW CIG (CIG 2019), showed this observed trend of precipitation intensities increasing in almost every future climate scenario. This analysis, which was attributable to Kitsap County, also showed a wide range for future outcomes with percentage increases ranging from -10 percent for the high emissions scenario in 2030 to as much as 65 percent for the high emissions scenario by 2080.

In order for Kitsap County to better visualize the impacts of these observed and potential increases in future precipitation intensities, HDR provided a spatial accounting of what a current, realistic 24-hour, 100-year design storm would look like and what future 24-hour, 100-year design storms could look like (Appendix B). Once a suitable temporal distribution is applied to these values, they will render a model-ready input to make quantifiable estimates of system capacity for adaptation decision support.

1 Historic Sea Level Trends and Future Sea Level Rise (SLR) for Kitsap County

Before the discussion of Sea Level Rise (SLR) begins, it is necessary to have an understanding of the historic sea level trend in the region. The nearest and most appropriate tide gauge in the region is located in Seattle at the Seattle to Bremerton ferry terminal on Elliott Bay (9447130) (NOAA Tides and Currents 2019). This site has a period of record from 1899 to 2018, which can be seen in Figure 1. This graph shows an average yearly sea level rise of 2.06 millimeters per year (mm/yr) or 0.081 inches per year (in/yr), or 1 inch every 12.3 years. Thus, at the very minimum, this rate of rise should be the baseline for which planning should consider.

Figure 1. Sea level trend at Seattle, WA during the period of record 1899-2018.



The most recent study of SLR (CIG 2018) within the Puget Sound region was completed by the Washington Sea Grant and the University of Washington's (UW) Climate Impacts Group (CIG). The report includes SLR projections for 171 sites along Washington's coast, including an excellent coverage of the coastal areas within Puget Sound. This UW CIG study included 13 locations (modeling nodes) for determining future SLR along the coast of Kitsap County. In order to make determinations as to the impact of SLR on Kitsap County's stormwater infrastructure, HDR utilized the 90 percent SLR probability of exceedance estimates from this study to identify and quantify potential future inundation levels at specific outfall locations provided by the county.

The analysis of the impact of SLR on stormwater infrastructure required the use of specific tidal datum so that the understanding of sea level rise can be developed as a function of the highest ***regular*** water surface elevation that occurs. The National Oceanic and Atmospheric Administration (NOAA) uses what is called Mean Higher High Water (MHHW) as their base tidal datum. For inundation studies for which increased water level scenarios are required to determine the amount of land affected by sea level inundation, the elevation of a tidal datum (such as mean higher high water, or MHHW, in areas with diurnal tides) is often used as the base elevation. This is because the high water datum represents the elevation of the normal daily excursion of the tide where the land area is normally inundated. Taking this normal extent of inundation into account is important when trying to delineate land areas inundated by abnormal events such sea level change.

As with all climate change studies, the UW CIG study could have utilized an endless array of modeling scenarios and climate models, but chose to simplify the results by providing projections for only two climate (emissions) scenarios: Representative Concentration Pathway (RCP) 4.5 and RCP 8.5. RCP 4.5 projects a reduction scenario in which a significant Greenhouse Gas (GHG) mitigation policy is implemented, and RCP 8.5 calls for very high GHG emissions without additional efforts to constrain emissions. This study provided projected SLR data for Kitsap County for the years 2030, 2050, and 2100. Table 1 and Table 2 show the location points for this analysis around Kitsap County and the projected SLR relative to current MHHW tidal datum from NOAA at these locations for the years 2030, 2050, and 2100 at RCP 4.5 and 8.5, respectively.

Table 1. Projected SLR estimates for various locations along the Coast of Kitsap County for RCP 4.5.

Location		Year (ft.)		
Lat	Lon	2030	2050	2100
47.5	-123.0	0.2	0.3	0.8
47.6	-122.9	0.2	0.4	0.9
47.7	-122.7	0.2	0.4	1.0
47.8	-122.7	0.3	0.5	1.2
47.9	-122.6	0.1	0.3	0.8
47.9	-122.5	0.3	0.5	1.2
47.8	-122.5	0.4	0.7	1.5
47.7	-122.6	0.2	0.4	1.0
47.7	-122.5	0.2	0.5	1.1
47.6	-122.7	0.2	0.4	0.9
47.6	-122.6	0.1	0.3	0.7
47.6	-122.5	0.2	0.3	0.9
47.5	-122.5	0.2	0.4	0.9
Average		0.22	0.42	0.99

Table 2. Projected SLR estimates for various locations along the Coast of Kitsap County for RCP 8.5

Location		Year (ft.)		
Lat	**Lon**	**2030**	**2050**	**2100**
47.5	-123.0	0.2	0.4	1.2
47.6	-122.9	0.2	0.4	1.1
47.7	-122.7	0.3	0.6	1.6
47.8	-122.7	0.3	0.5	1.5
47.9	-122.6	0.1	0.4	1.2
47.9	-122.5	0.3	0.5	1.5
47.8	-122.5	0.4	0.7	1.8
47.7	-122.6	0.2	0.5	1.4
47.7	-122.5	0.2	0.5	1.5
47.6	-122.7	0.2	0.4	1.3
47.6	-122.6	0.1	0.3	1.1
47.6	-122.5	0.2	0.4	1.3
47.5	-122.5	0.2	0.4	1.3
Average		0.22	0.46	1.37

The county provided HDR with geospatial data associated with the stormwater outfalls in their service region. The original "Storm Outfall" data layer we received from Kitsap had 1,582 outfalls listed (some marked as "active" and some as "inactive"). When the county went in and measured the outfall elevations for HDR, our team ended up with a dataset that had 556 outfalls (and their elevations) listed. Out of those 556, we determined which outfall elevations were less than the current MHHW tidal surface (basis of NOAA SLR Calculations) in feet, and then which outfalls had elevations less than the six SLR RCP scenarios (RCP 4.5 and RCP 8.5 for 2030, 2050, 2100).

The average SLR estimates for each of the three future time periods, as seen in Table 1 and Table 2, were used to develop an understanding of the impacts to stormwater outfalls as described in the previous paragraph. The majority of these outfalls had elevations below the NOAA MHHW Tidal Surface, but with the advent of SLR, outfalls would become even more submerged during this tidal state. Figure 2 through Figure 7 identify stormwater outfall locations that are expected to be impacted by the given SLR scenarios at the future time steps. An electronic appendix (Appendix A) is attached to this report. It provides an accounting of the inundation levels and/or water surface elevations at the various future scenarios at each of the stormwater outfall locations identified in these maps.

Figure 2. Locations of outfalls impacted by the RCP 4.5 SLR Scenario by 2030 in Kitsap County.

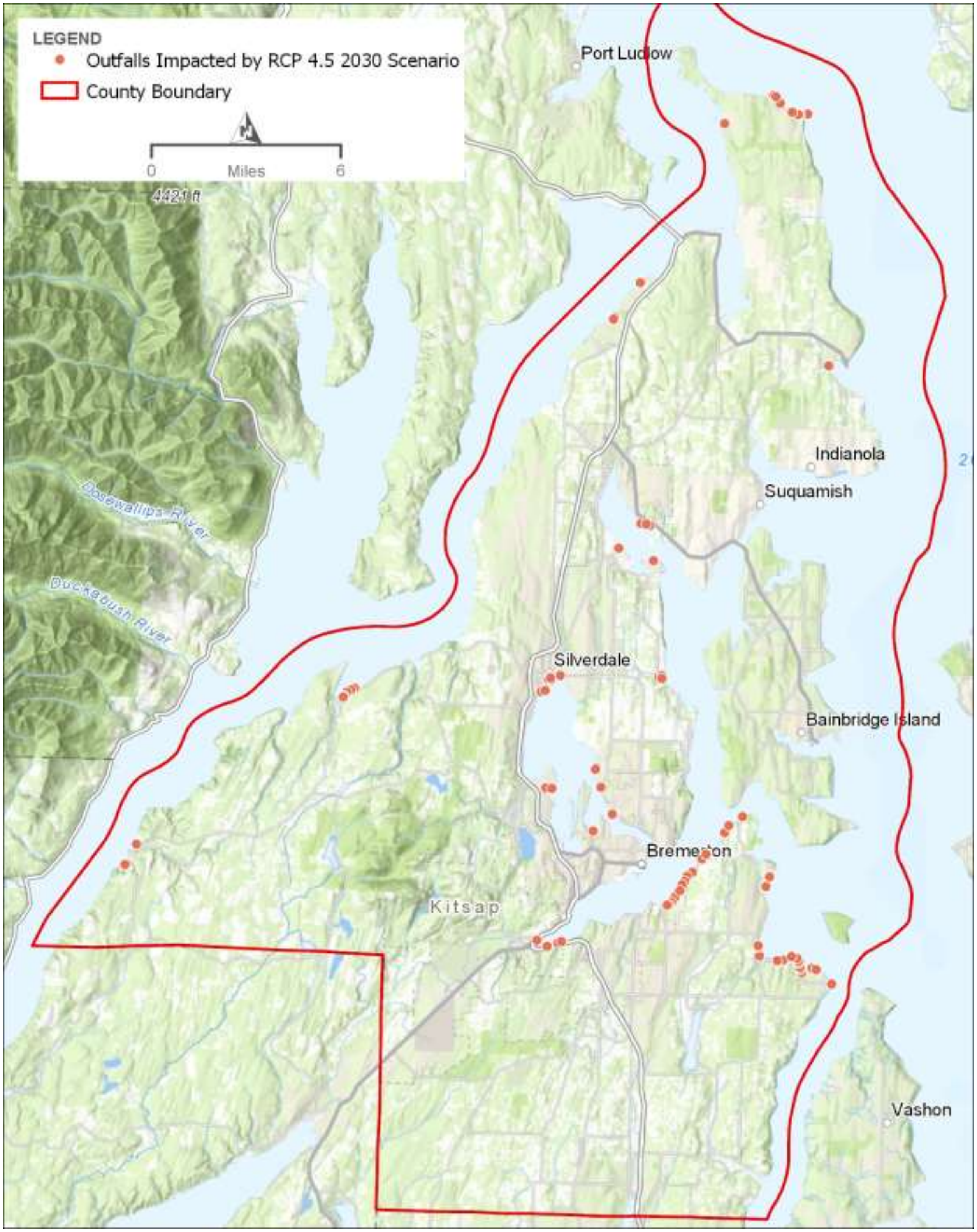


Figure 3. Locations of outfalls impacted by the RCP 4.5 SLR Scenario by 2050 in Kitsap County.

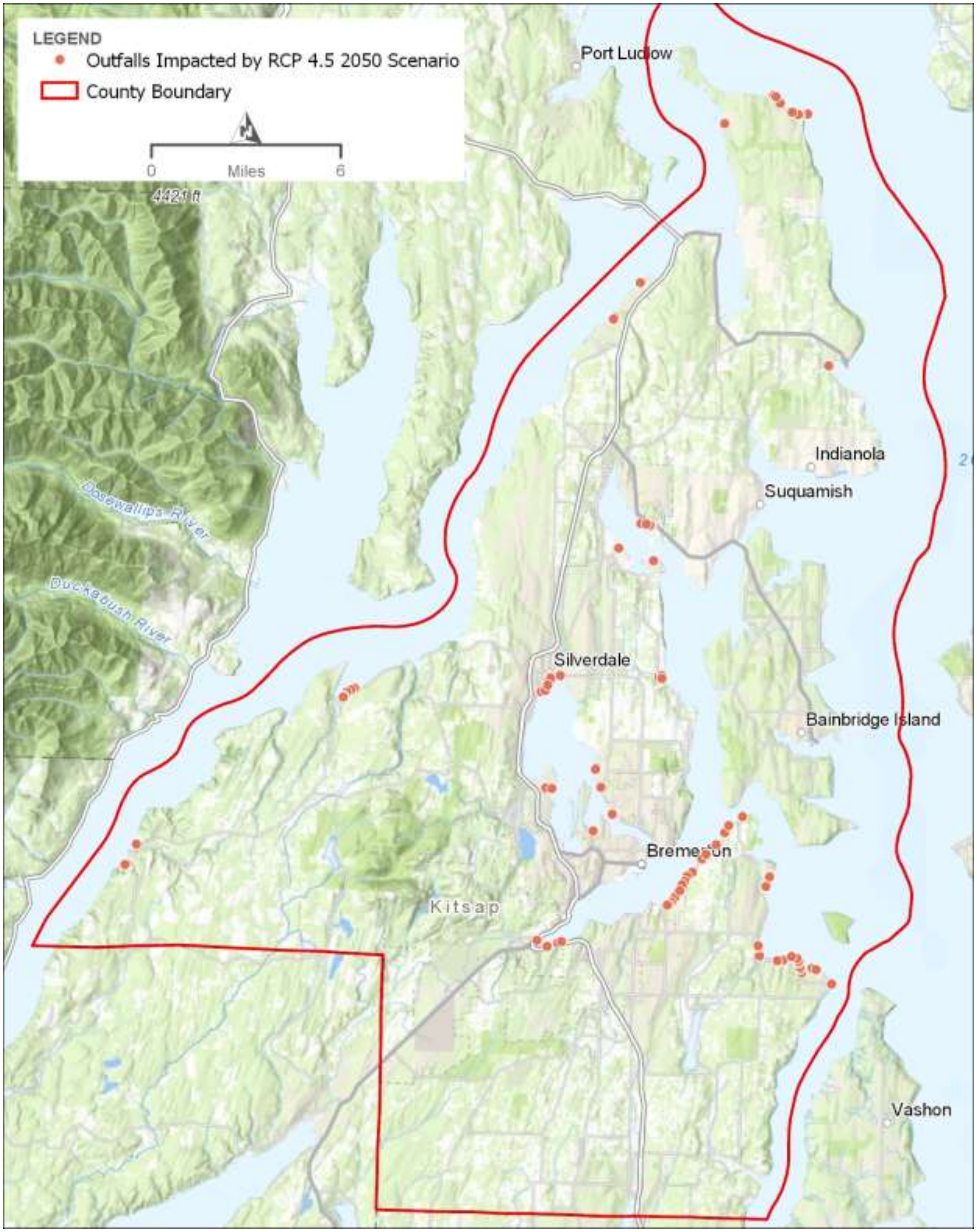


Figure 4. Locations of outfalls impacted by the RCP 4.5 SLR Scenario by 2100 in Kitsap County.

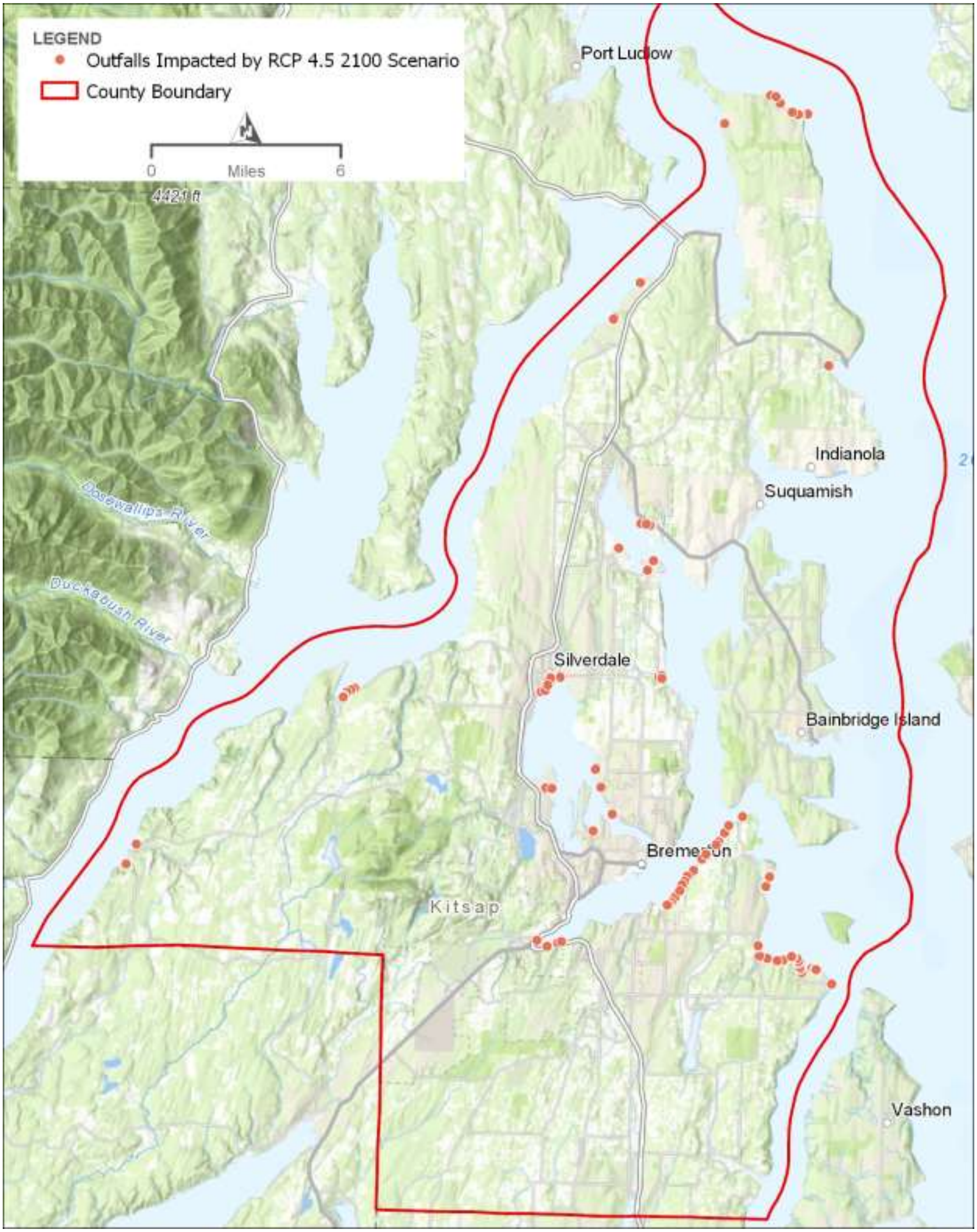


Figure 5. Locations of outfalls impacted by the RCP 8.5 SLR Scenario by 2030 in Kitsap County.

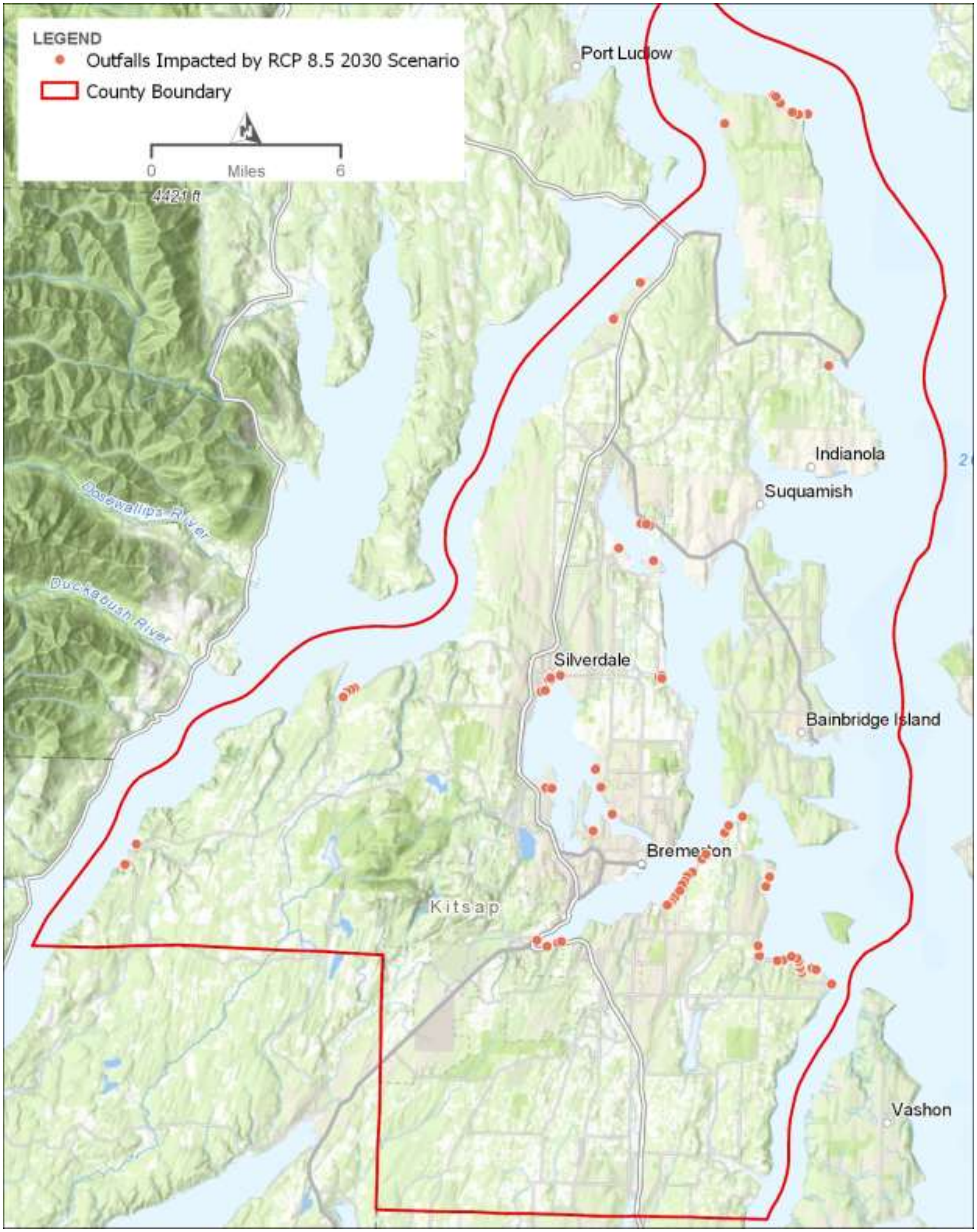


Figure 6. Locations of outfalls impacted by the RCP 8.5 SLR Scenario by 2050 in Kitsap County.

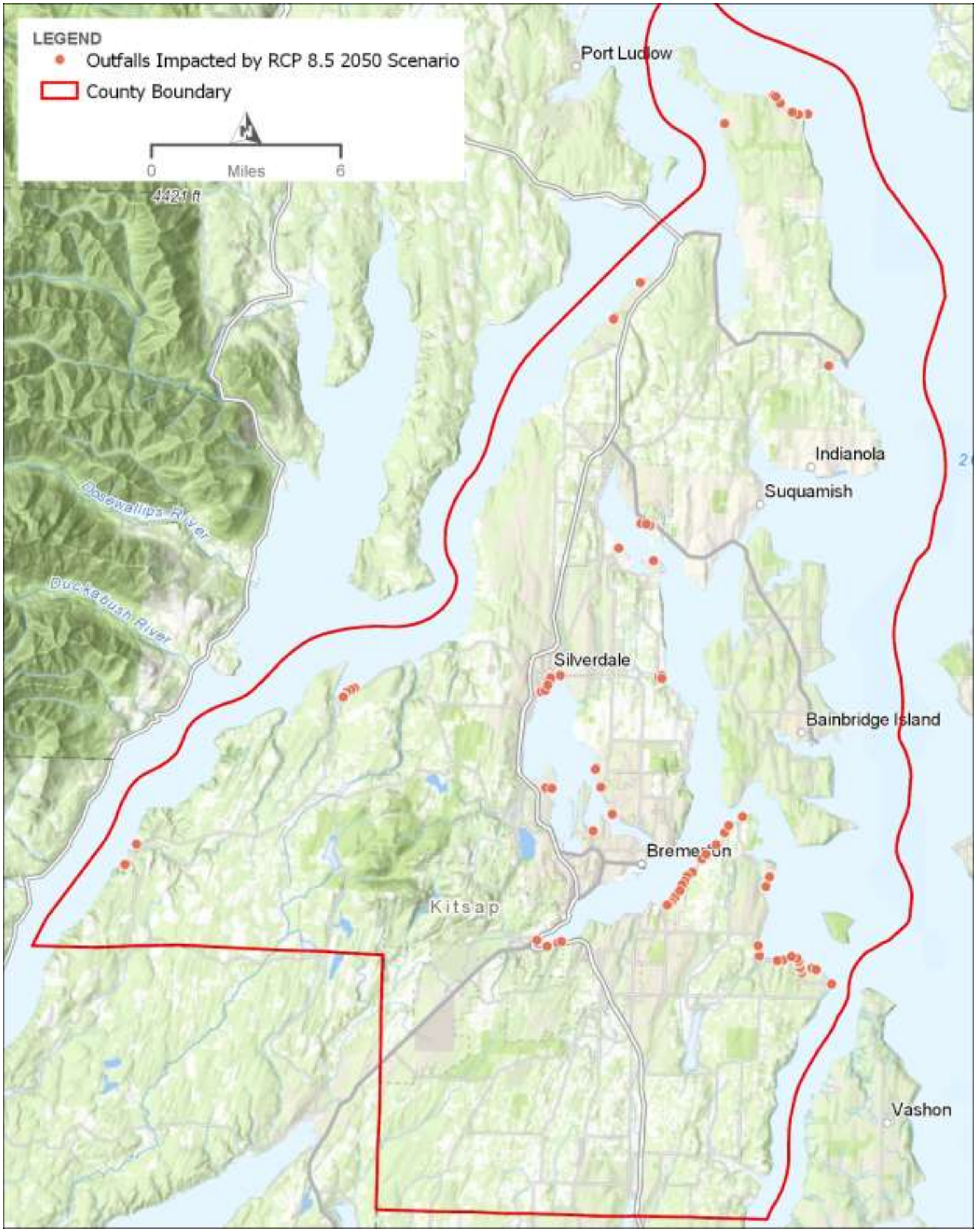
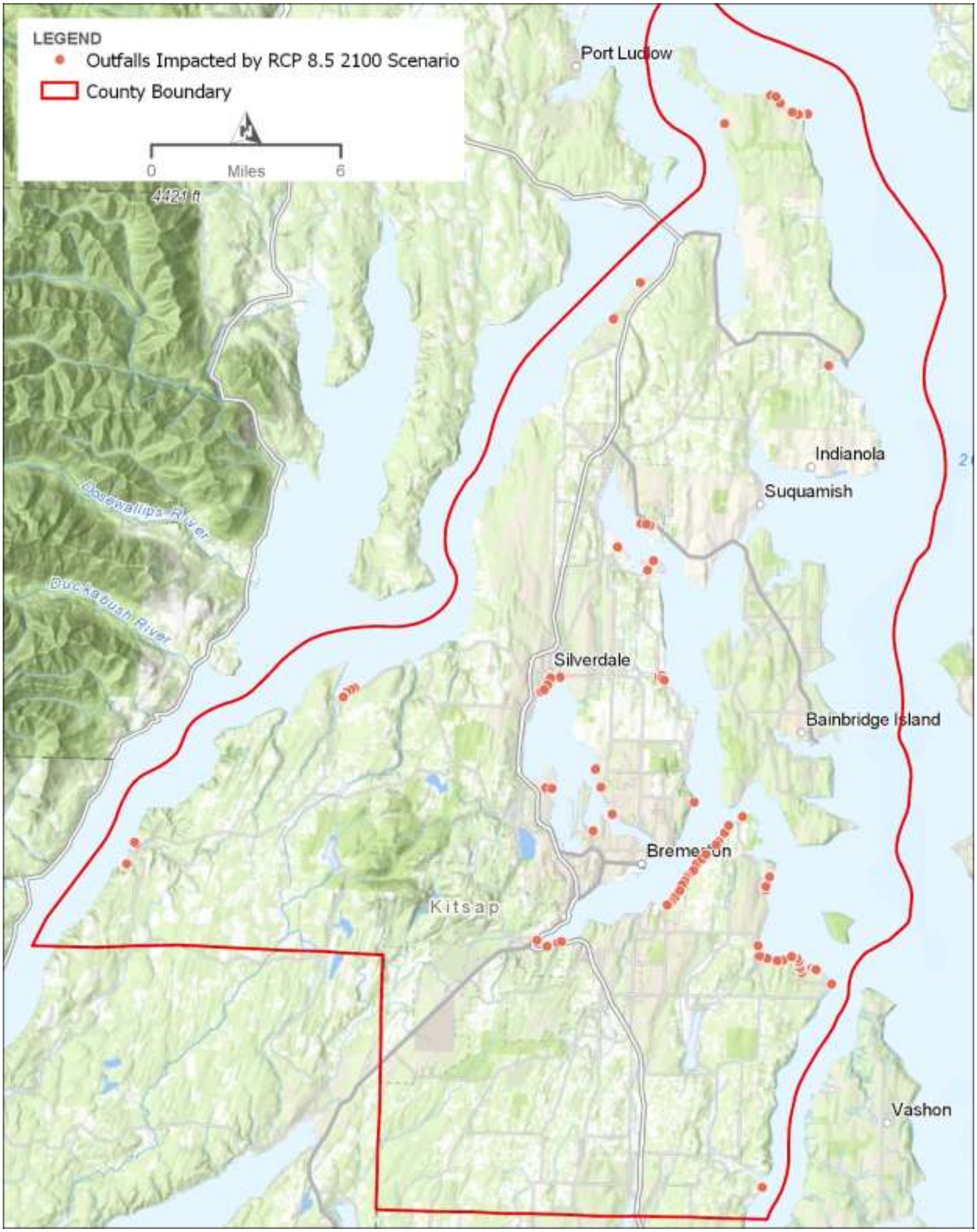


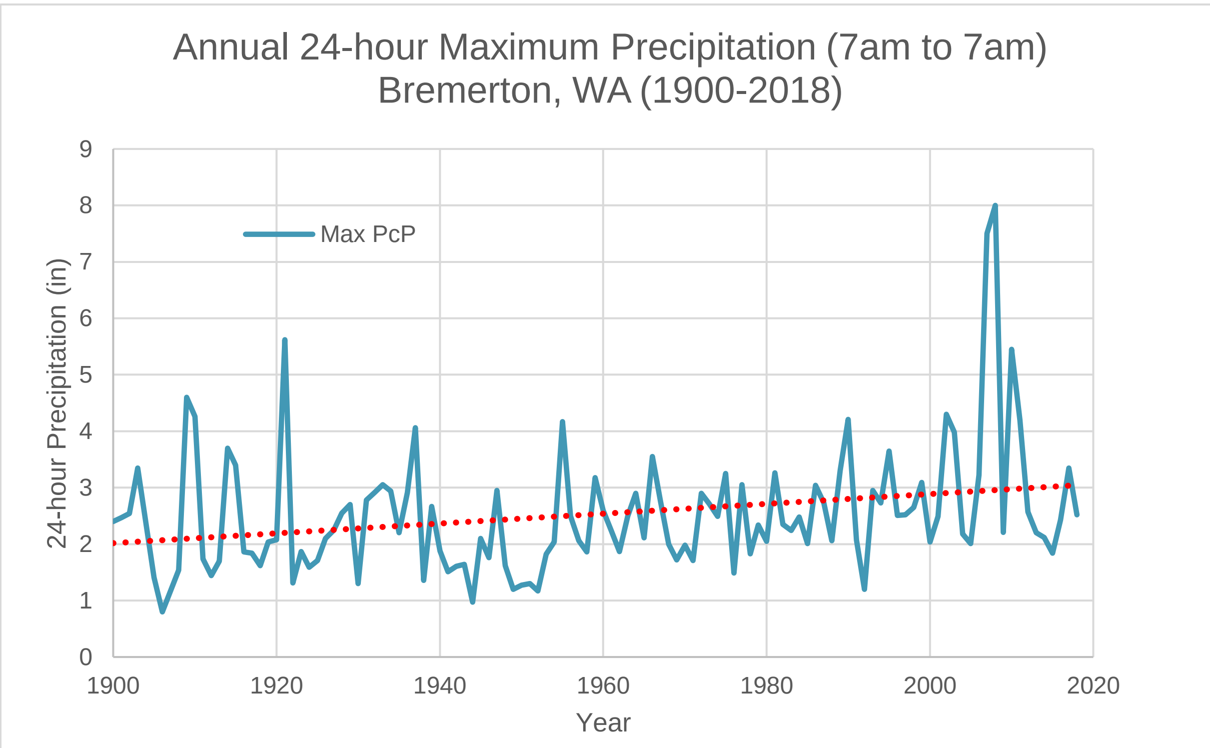
Figure 7. Locations of outfalls impacted by the RCP 8.5 SLR Scenario by 2100 in Kitsap County.



2 Historical Trends and Changes in Precipitation Intensities

Similar to the discussion of SLR, changes in precipitation intensities should begin with an understanding of the long-term historic trend in this parameter over Kitsap County. HDR looked at the historic trend in 24-hour maximum annual precipitation at Bremerton, WA during the period of record 1900-2018. Figure 8 shows this trend increasing by 50 percent over this time period from a value of 2 inches in a 24-hour period to a value of 3 inches in a 24-hour period. This trend, like the trend in SLR, should be considered the baseline for continued change in the coming years.

Figure 8. Annual 24-hour maximum precipitation at Bremerton, WA.



The current version of the Kitsap County Stormwater Design Manual (Kitsap County 2016) identifies the precipitation Intensity-Duration-Frequency (IDF) curves from U.S. Weather Bureau Technical Paper 25 (TP25) as the current IDF standard for design for short-duration precipitation events. Since that time, NOAA Atlas 2 (NOAA 1973) and the Washington State Department of Transportation (WSDOT 2002), which used NOAA Atlas 2 data to determine rainfall intensities (WSDOT 2002. Chapter 2, page 11-12) have provided similar guidance for regional precipitation frequency estimates specific to Kitsap County. An initial comparison between TP25 and the WSDOT study for events of 2-hour durations (Table 3) indicate very little change in these values for short-duration events.

Table 3. Comparison between TP25 precipitation return frequencies and WSDOT Regional precipitation frequencies for storms of 2-hour durations.

Comparison between TP25 and WSDOT Regional Precipitation Frequencies (2-hour)		
Return Freq. (yrs)	**TP25 for Bremerton**	**WSDOT for S. Kitsap Co.**
5	0.94	0.94
10	1.14	1.08
25	1.26	1.26
50	1.42	1.39
100	1.62	1.52

Consequently, a recent study (SPU 2017) performed on behalf of Seattle Public Utilities (SPU) investigated the nature of these trends in precipitation intensities in the region. This study, entitled "Intensity Duration Frequency (IDF) Curves and Trends for the City of Seattle," investigated the nature of the current IDF values using averaged historic precipitation data from 17 rain gauges in the region, which included the Bremerton daily gauge in Kitsap County and other gauges in close proximity to Kitsap County. Table 4 converts these newly developed IDF values into 2-hour return frequency estimates and compares them to the previously derived return frequency values (Table 3) for WSDOT for Kitsap County (Bremerton).

Table 4. Comparison between TP25, WSDOT, and the SPU study precipitation return frequencies for storms of 2-hour durations.

Comparison between TP25, WSDOT, and SPU Precipitation Frequencies (2-hour)			
Return Freq. (yrs)	**TP25 for Bremerton**	**WSDOT for S. Kitsap Co.**	**SPU values from IDF Curves**
5	0.94	0.94	0.84
10	1.14	1.08	0.96
25	1.26	1.26	1.16
50	1.42	1.39	1.30
100	1.62	1.52	1.46

In order to provide a comparative analysis between recently observed precipitation return frequencies and projected values as reported in the next section, Table 5 provides a similar comparison of return frequency data for storms of 24-hour durations for WSDOT (NOAA Atlas 2) and the SPU data. Return frequency values that were available from TP25 only provided information up to storms of 2-hours in duration. Although the values for storms of a 24-hour duration are similar at the lower return frequencies (i.e., 5-year and 10-year), a marked increase was noted in the SPU study at the higher return frequencies.

Table 5. Comparison between WSDOT and the SPU study precipitation return frequencies for storms of 24-hour durations.

Comparison between WSDOT and the SPU Study for Regional Precipitation Frequencies (24-hour)		
Return Freq. (yrs)	**WSDOT for S. Kitsap Co.**	**SPU values from IDF Curves**
5	3.36	3.24
10	3.83	4.03
25	4.41	4.70
50	4.86	5.47
100	5.30	7.58

3 Projected Trends and Changes in Precipitation Intensities

The UW CIG recently developed a study entitled "Regional Model Projections of Heavy Precipitation for Use in Stormwater Planning" (CIG 2019). These future climate projections indicate that the historical trend in increasing precipitation intensities in western Washington is likely to continue and, consequently, produce more intense hydrologic extremes. Although this study did not specifically identify a location in Kitsap County for investigation of future trends in heavy precipitation, it is reasonable to use the data from the Seattle Tacoma International Airport, 8-10 miles to the east southeast of southern Kitsap County, as proxy for this study as they both reside in the same climate region as identified as the Interior Lowlands (Schaefer et al. 2009).

This study utilized a methodology wherein Global Climate Model (GCM) output was used as input to an atmospheric modeling platform called the Weather Research and Forecast (WRF) model. Figure 9 through Figure 11 show the projected change (RCP 4.5 and 8.5 scenarios) in 24-hour precipitation at this location as a percentage of the climatological mean from 1980-2009 at the future time scales of 2030, 2050, and 2080 It is very apparent that the projections of changes in future 24-hour precipitation amounts will be anything but stationary. With the exception of the 2030 RCP 8.5 scenario, each of the projections of future climate scenarios show an increase in precipitation intensities, particularly at the higher return frequencies (i.e., 100-year).

Figure 9. Projected change (in percent) of 24-hour precipitation at Seattle Tacoma International Airport by 2030 relative to the 1980-2009 climatological mean.

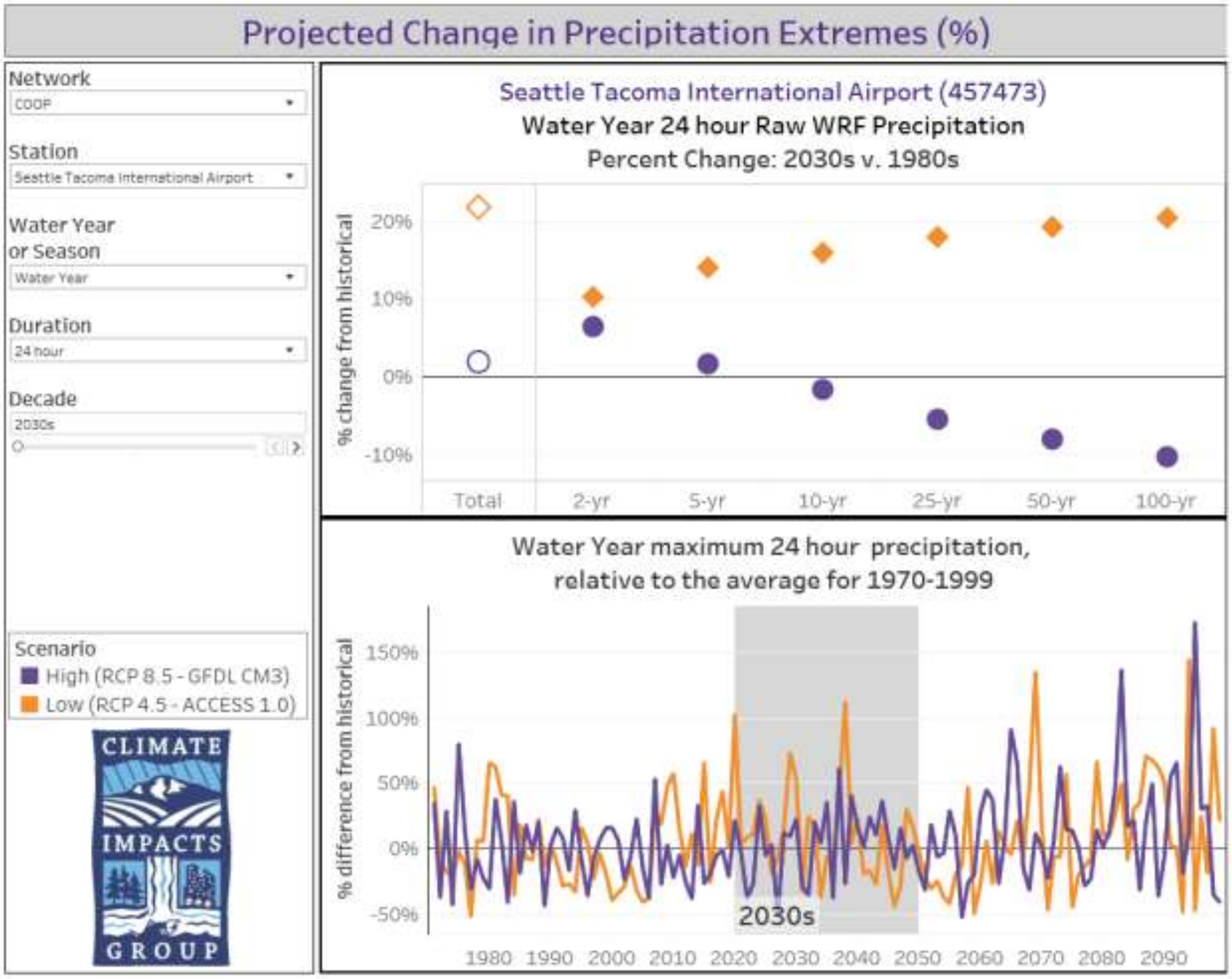


Figure 10. Projected change (in percent) of 24-hour precipitation at Seattle Tacoma International Airport by 2050 relative to the 1980-2009 climatological mean.

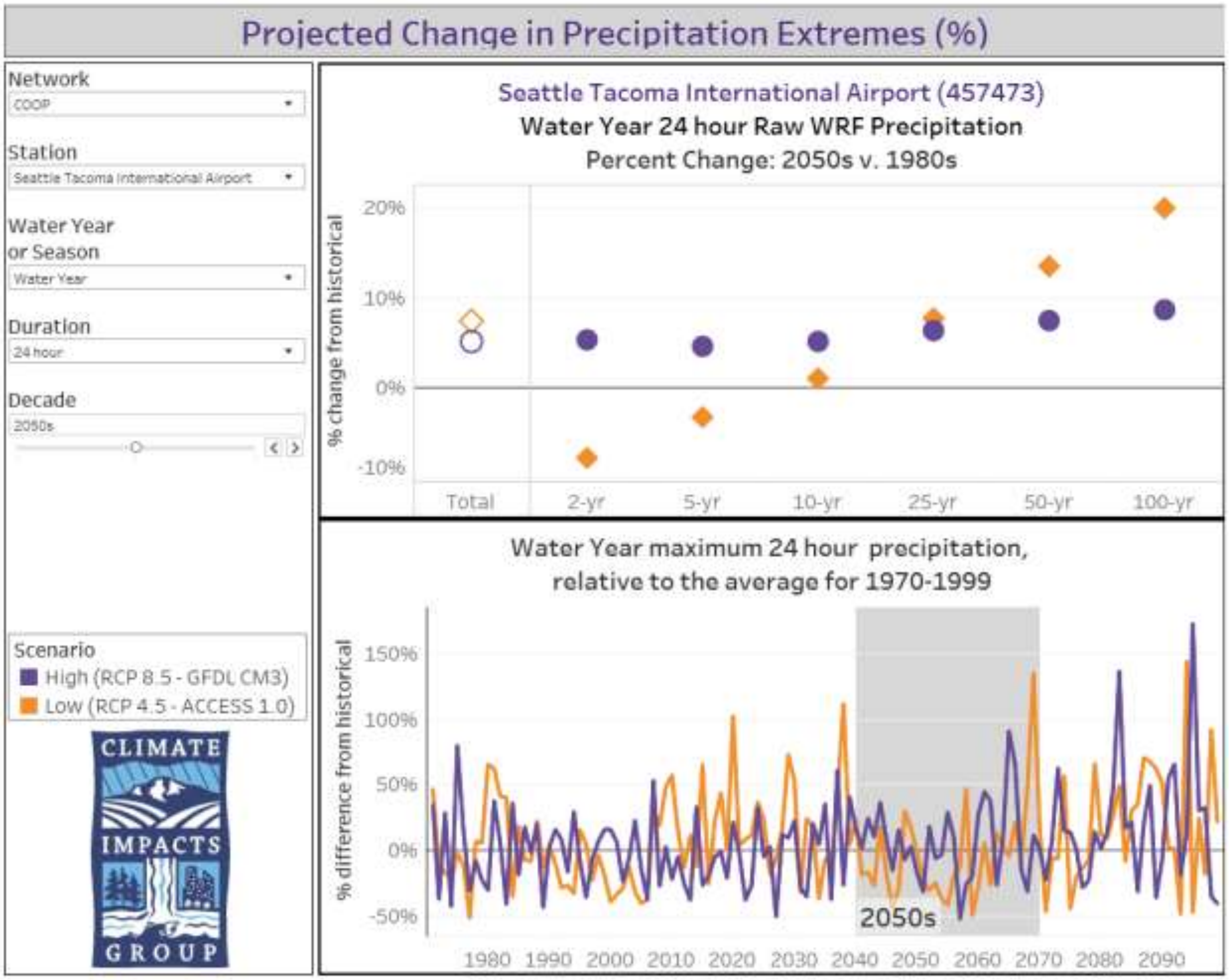
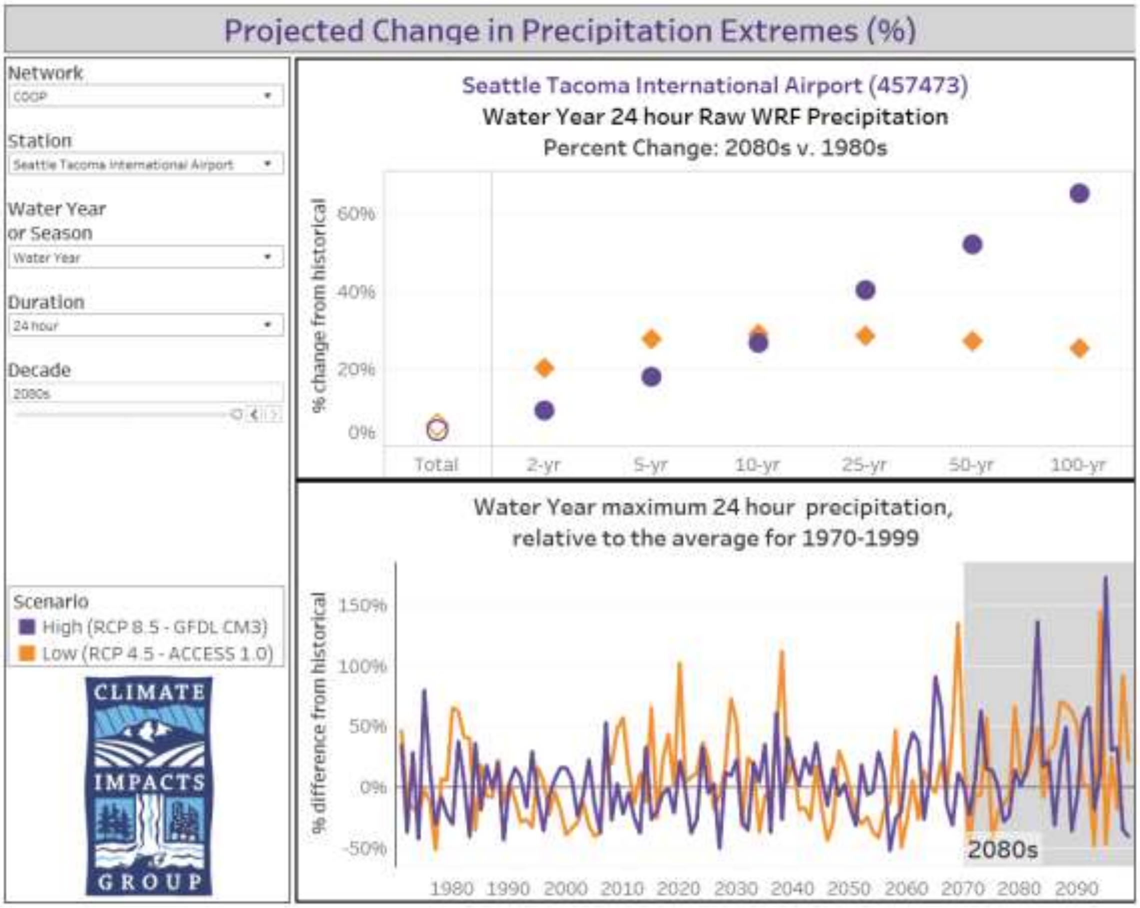


Figure 11. Projected change (in percent) of 24-hour precipitation at Seattle Tacoma International Airport by 2080 relative to the 1980-2009 climatological mean.



4 Observed Changes in the Kitsap County 24-hour, 100-year Design Storm Event

The majority of design storm events in use across the United States are one-size-fits-all design events based on historical data from the previous century and presented with no spatial variation in precipitation climatologically associated with a given region. HDR has developed the means to utilize the latest (up to 2017) historical data that includes observed changes in precipitation intensities in combination with a realistic and climatologically accurate spatial distribution to create a 24-hour, 100-year design event that is site-specific to an application over a given service region or watershed.

Through the use of the observed precipitation analysis from SPU (SPU 2017) and an application of the spatial distribution of rainfall over Kitsap County using climatological data from the Parameter elevation Regression on Independent Slopes Model (PRISM) from Oregon State University (OSU) (OSU 2019), HDR developed a new 24-hour, 100-year design event that is spatially distributed across the county on a 4 kilometer (km) grid. Figure 12 shows a map of this grid as it pertains to the distribution of annual precipitation from PRISM across the county. Table 6 identifies the new design storm grid values as a function of the application of the 24-hour, 100-year return frequency values as derived from the SPU study as they pertain to the spatial distribution provided in the grid in Figure 12.

Figure 12. Gridded (4 km) map showing the distribution of annual precipitation across Kitsap County.

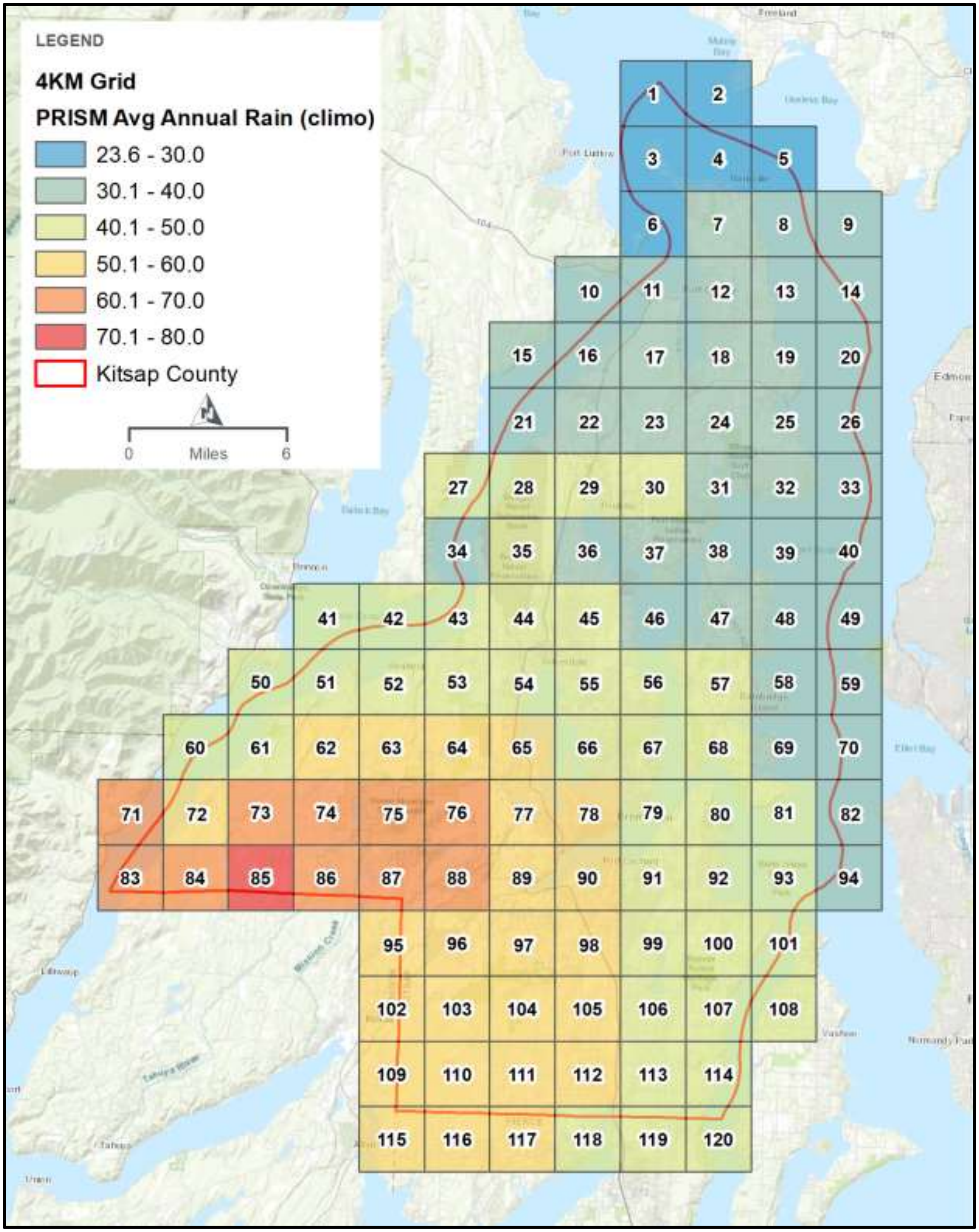


Table 6. Grid profile 24-hour, 100-year design storm event as derived through the use of the observed data from the SPU study and the spatial distribution of precipitation from the PRISM climate analysis in Figure 12.

Profile	100-year Return Frequency (in)	Profile	100-year Return Frequency (in)	Profile	100-year Return Frequency (in)
1	3.49	41	5.95	81	5.94
2	3.68	42	6.06	82	5.68
3	3.76	43	6.12	83	9.35
4	3.98	44	6.54	84	10.20
5	4.16	45	6.07	85	10.44
6	4.18	46	5.78	86	9.09
7	4.53	47	5.79	87	9.10
8	4.54	48	5.68	88	9.06
9	4.90	49	5.48	89	7.95
10	4.73	50	6.43	90	7.66
11	4.72	51	6.44	91	7.39
12	5.01	52	6.80	92	6.60
13	5.02	53	7.14	93	6.05
14	5.22	54	7.03	94	5.69
15	5.40	55	6.51	95	7.73
16	5.30	56	6.11	96	7.91
17	5.42	57	5.97	97	7.92
18	5.46	58	5.76	98	7.64
19	5.43	59	5.56	99	7.35
20	5.38	60	7.37	100	6.72
21	5.61	61	7.37	101	6.20
22	5.88	62	7.85	102	7.95
23	5.84	63	8.45	103	8.09
24	5.70	64	8.23	104	7.99
25	5.56	65	7.59	105	7.47
26	5.44	66	7.31	106	7.19
27	6.01	67	6.74	107	6.72
28	6.01	68	6.19	108	6.27
29	5.96	69	5.87	109	7.91

Profile	100-year Return Frequency (in)	Profile	100-year Return Frequency (in)	Profile	100-year Return Frequency (in)
30	5.98	70	5.63	110	8.14
31	5.78	71	10.01	111	7.92
32	5.62	72	8.56	112	7.44
33	5.46	73	9.19	113	6.93
34	5.82	74	8.97	114	6.47
35	6.33	75	10.10	115	7.60
36	5.91	76	9.54	116	7.92
37	5.87	77	8.17	117	7.78
38	5.75	78	7.58	118	7.32
39	5.62	79	7.03	119	6.86
40	5.46	80	6.39	120	6.35

5 Projected Changes in the Kitsap County 24-hour, 100-year Design Storm Event

There have been numerous studies and papers written regarding the potential for significant changes in precipitation intensities under future climate scenarios around the U.S. in the last several years (i.e., Jalowska 2018 and Kunkel 2019). These studies are primarily based on the relationship between a warmer climate and the ability of the atmosphere to retain and release moisture (precipitable water). This physical relationship is explained by the Clausius-Clapeyron equation (https://chemed.chem.purdue.edu/genchem/topicreview/bp/ch14/clausius.php), which, basically, states that as atmospheric temperature increases, so does the atmosphere's ability to hold and release moisture. A similar physical relationship was used to develop the methodology applied in the projected models in the UW CIG (CIG 2019) and the SPU study referenced earlier in this document (SPU 2017).

Through the use of the percent increase in precipitation intensities for the two climate scenarios, RCP 4.5 and RCP 8.5, from the UW CIG study (Figures 9-11), HDR developed projected 24-hour, 100-year design storm events for the years 2030, 2050, and 2080. The basis for applying these projected values are the recently observed values (SPU 2017) provided in Table 6. The profiles for these future design events, which are synonymous with the profiles as identified in Figure 12, are quantified in electronic Appendix B. It is important to note for the sake of comparison that the projected percentage increases or decreases are being applied to recently statistically calculated return frequencies based on the recent SPU study rather than on a percentage increase or decrease to old NOAA Atlas 2 or TP25 return frequency values.

6 Resources

The Washington State Climate Impacts Group (CIG) maintains an ongoing, publically-available resource library for the effects of climate change on Washington State (https://cig.uw.edu/). It contains analysis tools for obtaining future peak stream flows to aid in culvert design, trends in temperature, precipitation, and snow water equivalent, and a precipitation projection tool. Numerous research publications and special reports.

7 Conclusion and Recommendations

This investigation of the both current and projected climate influences on Kitsap County stormwater infrastructure determined that observed change is already occurring, while projected changes indicate the need for adaptation planning. Sea level rise, although not nearly on the order of what is expected to occur on the east coast of the U.S., was found to be a factor concerning stormwater outfalls. Change in precipitation intensities have shown a steady increase, particularly for 24-hour storm events, in the historic record and projected changes are expected to extend this trend.

HDR recommends a detailed accounting of risk, consequences, and system component criticality associated with the findings of this investigation to enable a cost-to-benefit analysis of remediation and/or adaptation measures for the Kitsap County stormwater system that would provide for increased system resilience and longevity. This cost-to-benefit analysis could take into account the following recommendations for specific action that should promote stormwater resilience over time within Kitsap County. These are presented in the list below in general order of efficacy and importance:

1. **Inspection and maintenance** should be a primary consideration before any attempt to increase system resilience is undertaken. In many cases, recurring system issues or problematic infrastructure is the result of a malfunction of the system due to a maintenance issue or a fault in system integrity. These should be inspected and remedied before making a system resiliency plan.

2. System resilience is not something that occurs overnight. It is a holistic undertaking that is generally incremental and requires a **long-term stormwater resiliency plan** that is implemented with the greatest cost-to-benefit in mind. This long-term plan will provide for a vetting process of the stormwater resilience solutions that are listed in #3 below.

3. **Stormwater infrastructure resilience solutions** can come in all shapes and sizes, and often can serve dual-purpose roles within the community. These can range from:

    - Modifying conveyance design standards to increase capacity of new infrastructure overtime by using different design storms for pipe sizing, increase the use of through-curb grate inlets for improved efficiency of getting runoff into the conveyance network, and/or modifying hydraulic freeboard standards for built pipe networks.

    - Use of green infrastructure/low impact development solutions such as bioswales/bioretention, green spaces, stormwater capture and recharge designs, stormwater retention/detention ponds/wetlands to minimize runoff volumes that protect downstream resources.

- Identify areas where traditional hardening of stormwater infrastructure is the best solution. For example, planning for and installing pump stations in areas to protect critical outfalls from flood risk and other types of gray infrastructure.

- Codified protections of critical areas such as wetlands, riparian corridors, and other natural features that attenuate the effects of flooding.

4. Once a plan is developed options for the greatest cost-to-benefit have been vetted, the plan needs to be **funded**. While traditional funding through the Kitsap County Stormwater Division is feasible, there are currently numerous grant programs available for stormwater resilience that should be explored. These include CoastSmart Communities grants from NOAA, Green Infrastructure Resilience grants from the EPA, National Science Foundation environmental sustainability grants, the Kresge and Rockfeller Foundations, Washington State Stormwater Capacity grants, as well as numerous grant programs that are tied to collaboration with academic institutions.

The design of stormwater infrastructure is based on an underlying assumption that the probability distribution of precipitation events is statistically stationary. This assumption may no longer by valid, resulting in uncertainty about the future performance of systems constructed under this paradigm. Such uncertainty emphasizes the importance of developing a focused and dedicated vulnerability assessment of the County's stormwater system.

8 References

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Appendix A. Electronic Appendix of the Inundation Levels and/or Water Surface Elevations at the Various Future Scenarios at Each of the Stormwater Outfall Locations Identified.

Appendix B. Electronic Appendix of the Profiled Average Annual PRISM Precipitation Distribution in Kitsap County and Future Projections of the 24-hour, 100-year Design Storm Events for 2030, 2050, and 2080