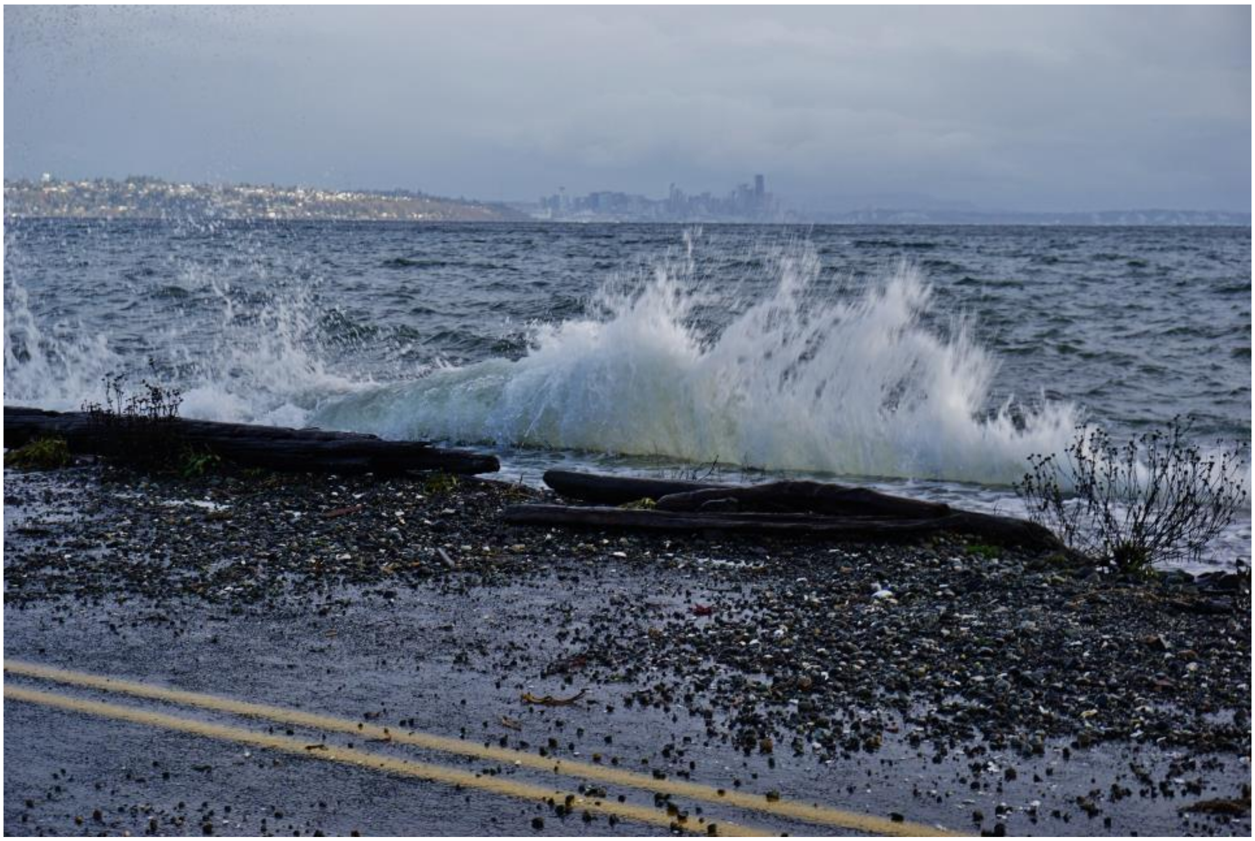
Sea Level Rise on Bainbridge Island

A Preliminary Assessment



Manitou Beach, December 20, 2018, 3:40 pm. Water level: 9.91 ft NAVD88 (12.25 ft MLLW).

Report to the City of Bainbridge Island,
Climate Change Advisory Committee
October 24th, 2019

CITY OF
BAINBRIDGE ISLAND

Acknowledgements

The Climate Change Advisory Committee was established in 2017 by the City Council of Bainbridge Island to take action on climate change and increase the community's resilience (Ordinance no. 2017-13). The Committee's work plan calls for an evaluation of climate impacts and recommendations to the City for adaptation and mitigation actions.

The following document fulfills Action 10.1 in the 2019-20 Draft Work Plan, which specifically calls for an evaluation of the vulnerability of City assets and other infrastructure to the impacts of sea level rise. Identified by the Committee as a high priority action item, this report is also intended to provide a template for subsequent assessments.

The principal author of and photographer for this report is James Rufo Hill, who began the effort while serving on the Climate Change Advisory Committee. This report builds upon the 2016 Bainbridge Island Climate Impacts Assessment, which was written by Lara Hansen, Stacey Nordgren, and Eric Mielbrecht. Finally, generous assistance was provided by City of Bainbridge Island staff, especially Christy Carr and Gretchen Brown. Thank you, all.

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Summary

Among climate change impacts, sea level rise stands out because even if humans stopped emitting greenhouse gases today, global oceans would continue to absorb excess heat, expand, and rise for centuries (Clark et al 2016). Because we are nowhere close to stopping greenhouse gas emissions, sea level rise is among the more certain impacts—it's not a question of if, but rather when. Given that Bainbridge is an island, we are acutely vulnerable to this phenomenon.

Puget Sound has risen by more than 9 inches during the past century (NOAA 2019). Continued global warming is expected to accelerate rising sea levels over the next century and beyond. The most likely projections, i.e. central estimates, from the best available science (Miller et al 2018) indicate that relative to the year 2000, Bainbridge Island will experience one foot of sea level rise by the year 2060, 2.3 feet by 2100, and 3.8 feet by 2150. High end projections give Bainbridge one foot of sea level rise by 2040, 5.2 feet by 2100, and 10.4 feet by 2150. Considerable uncertainty remains with respect to emissions scenarios and timing, but again each of the above amounts are certain to eventually occur around Puget Sound and worldwide.

This preliminary assessment provides the City of Bainbridge Island with mapping and planning methodologies, a framework for adaptation, and an understanding of its exposure to sea level rise. It is expected that the City follow-up this report by using high-resolution Geographic Information Systems (City of Seattle 2019) to analyze and inform final decision-making at the parcel level.

Key Findings:

- Most of the City's infrastructure is not immediately vulnerable to sea level rise. A limited number of assets, primarily related to sewer service around Eagle Harbor, plus some low-lying streets, already experience or will soon experience inundation from sea level rise, especially during astronomical high tides, a.k.a. king tide events.
- The most significant impact will be to private property owners around the island, many of whom currently experience occasional nuisance flooding (EPA 2019). By the middle of this century, many of these waterfront residences will face severe inundation. Areas most exposed include Hedley Spit/Point Monroe, Manitou Beach, and Schel Chelb Estuary/Point White Drive.
- Other vulnerable community assets include Washington State Ferries (both the terminal and maintenance facility), the Wyckoff Superfund site, Fay Bainbridge Park, and to a lesser extent, the Winslow Wastewater Treatment Plant.
- Accelerated bluff erosion will threaten additional high-bank properties and septic systems.
- Increased saltwater intrusion will stress water resources adjacent to the shoreline.
- Next steps include meeting with City staff, briefing City council, engaging community members, and performing additional high-resolution analyses.

1. Introduction

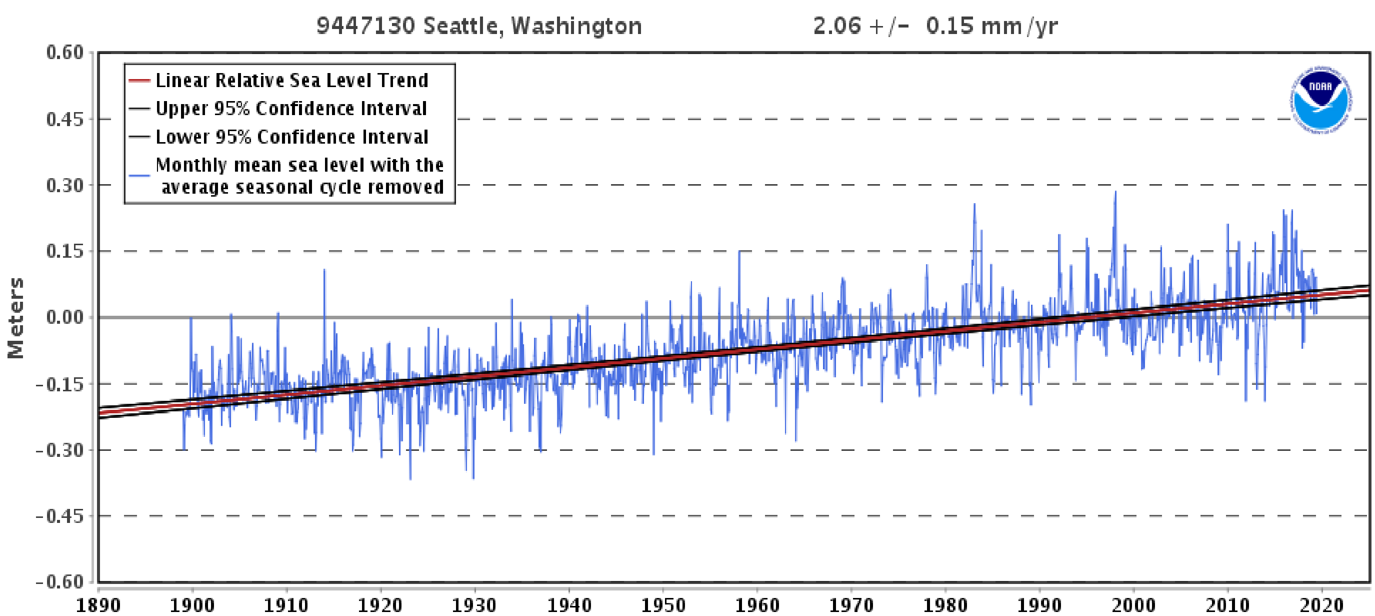
1.1 Sea Level Trends

Sea levels have been rising globally for a century or two, but the heating of oceans and melting of ice has caused sea level rise to accelerate in recent decades. Local water levels have risen slowly and steadily since measurements began in 1899. Figure 1 below details the trend, which has averaged approximately 2.06 millimeters per year, good for almost 10 inches of sea level rise.

Whereas coastal flooding once rarely occurred on Bainbridge Island, "nuisance flooding" has become at least an annual event in some areas (EPA 2019, NOAA 2019). Sea level rise is especially apparent each winter during "King Tide" events when gravitational forces acting on Earth are strongest.

Planners globally and locally noticed these trends and have started to act. Around Puget Sound, organizations are collaborating to minimize risk. The City of Olympia, which has experienced a rapid increase in flooding events, has developed a detailed adaptation plan (City of Olympia 2019). The City of Seattle, The Port of Seattle, and King County are in the process of writing joint sea level rise guidance and policies (City of Seattle 2019). The Swinomish Tribe is already monitoring adaptive management practices (Swinomish Indian Tribal Community 2009).

Figure 1: Long-term sea level trend, Colman Dock, Seattle.



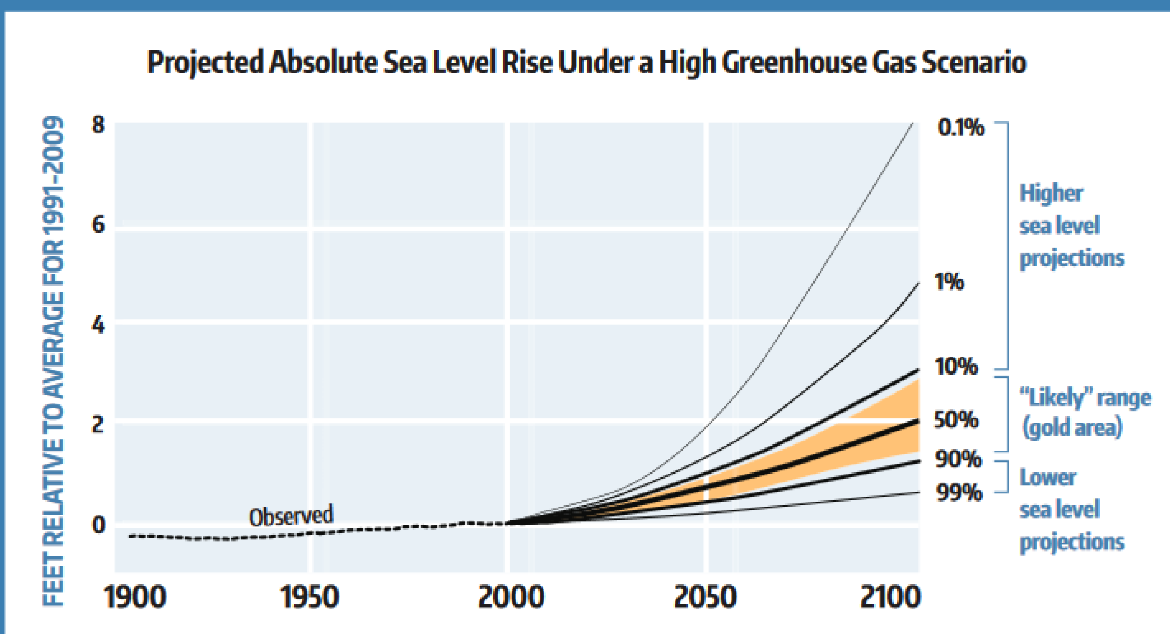
Above: since records began in 1899 (x-axis), sea levels have risen locally at a rate of 2.06 millimeters per year (y-axis), which equals almost 10 inches total.
Source: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9447130

1.2 Sea Level Rise Projections

Changes in sea level will be both absolute and relative. The former refers to the height of the ocean surface in response to global warming. The latter includes local geological, hydrological, and atmospheric effects. For example, the Olympic Mountains are undergoing post-glacial rebound, meaning they are still rising in response to the weight of ice sheets having been removed. Therefore, communities along the Strait of Juan de Fuca are currently experiencing *dropping* sea levels, because the rate of rebound is outpacing the rate of sea level rise. Eventually, the rate of sea level rise in such locations will surpass the rate of rebounding vertical land movement.

Absolute projections tend to make splashy headlines, but for planning purposes, relative projections are required. For example, Hansen and Sato (2011) assert that "multi-meter sea level rise on the century time scale are not only possible, but almost dead certain." That said, sea level rise is driven by global phenomena, and absolute projections represent a baseline from which relative projections are made. Figure 2 (Miller et al 2018) below underscores the large range in absolute projections.

FIGURE 2: Absolute sea level rise projections, through 2100, for a high greenhouse gas scenario (RCP 8.5), for Washington State. Projections are based on Kopp et al. (2014) and observed variations in absolute sea level are shown for 1907-2007.[4] All results are shown relative to the average for 1991-2009. The probability values are "probabilities of exceedance", i.e., the current best assessment of the likelihood that absolute sea level will rise by at least a given change in elevation.



Fortunately, over the past few decades there have been a series of studies that account for local Puget Sound geography. The most recent report, Projected Sea Level Rise for Washington State (Miller et al 2018), represents the best available science. Beyond having updated methods, the report is unique in that it features new probabilistic projections, and it provides community-scale information, including four different, albeit nearly identical projections for Bainbridge Island.

Considerable uncertainty exists for the rate at which polar ice will contribute to sea level rise. Uncertainty related to global emissions scenarios is perhaps even more complex. Despite warnings and policy efforts, humanity has generally followed the path of high greenhouse gas scenarios. This report therefore only examines this "business as usual" approach. If we start emitting fewer greenhouse gases, then lower sea level projections could be considered across Puget Sound and worldwide.

Central ("most likely") estimates from the best available science indicate that Bainbridge Island will experience 1 foot of sea level rise by the year 2060, 2.3 feet by 2100, and 3.8 feet by 2150 (see yellow box below). The "one percent chance" scenario, i.e. rapid ice melt, projects 10.4 feet of rise by 2150 (see red box below). Again, due to climate dynamics sea level rise is likely to accelerate over the course of the next century, and it's less a matter of how much, but when.

Table 1: Projected average sea level magnitude, in feet,
for different assessed likelihoods and time periods (Bainbridge Island).

	Assessed Probability of Exceedance:								
19 year period centered on:	99	95	90	83	50	17	10	5	1	0.1
2010	-0.1	0	0	0	0.1	0.2	0.2	0.2	0.3	0.3
2020	0	0	0.1	0.1	0.2	0.3	0.4	0.4	0.5	0.6
2030	0	0.1	0.2	0.2	0.4	0.5	0.6	0.7	0.8	0.9
2040	0	0.2	0.3	0.3	0.6	0.8	0.9	1	1.1	1.4
2050	0.1	0.3	0.4	0.5	0.8	1.1	1.2	1.3	1.6	2.1
2060	0.2	0.4	0.5	0.7	1	1.4	1.6	1.7	2.1	3.1
2070	0.2	0.6	0.7	0.9	1.3	1.8	2	2.2	2.7	4.2
2080	0.3	0.7	0.9	1.1	1.6	2.2	2.4	2.7	3.4	5.7
2090	0.4	0.9	1.1	1.3	1.9	2.6	2.9	3.2	4.2	7
2100	0.5	1	1.3	1.5	2.3	3.1	3.5	3.9	5.2	8.8
2110	0.6	1.1	1.4	1.7	2.4	3.4	3.7	4.2	5.8	10.2
2120	0.7	1.3	1.6	1.9	2.8	3.9	4.3	4.9	6.9	11.8
2130	0.8	1.4	1.8	2.1	3.1	4.3	4.9	5.6	8	14
2140	0.9	1.6	1.9	2.3	3.5	4.9	5.5	6.3	9.1	16.5
2150	0.9	1.7	2.1	2.5	3.8	5.4	6.1	7.1	10.4	18.8

Note: similar to how climate is often defined as 30-year average weather, tides are observed and summarized over a 19-year period known as an "epoch," hence the centering around decades.
Source: http://www.wacoastalnetwork.com/files/theme/wcrp/SLR-Report-Miller-et-al-2018.pdf

2. Methods

2.1 Datums

A tidal datum is a standard elevation tied to a certain height or phase of the tide (NOAA 2019). When measuring and planning for sea level rise it is critical that datums and references to elevation remain consistent.

Because of its importance to marine navigation, the most popular datum (e.g., often cited by NOAA) is mean lower-low-water (MLLW). Mean higher-high water (MHHW) is frequently used in sea-level rise literature because of the implied risk associated with "average daily" high tides. Under Washington State's Public Trust Doctrine, public ownership of tidelands, with some exceptions, begins at extreme low water. Sometimes municipalities use their own references (e.g., King County METRO datum). Land-based surveys, including most Geographic Information systems, use the North American Vertical Datum (NAVD88).

Note: tidal datums are updated on a regular basis. NOAA's National Ocean Service uses a 19-year period (National Tidal Datum Epoch, 1983-2001) as the standard. The epoch is revised every 20-25 years. Certain regions with anomalous sea level changes, including Puget Sound, use a modified epoch; however, this report references the 1983-2001 epoch. Since this assessment is examining land-based assets, all elevations reference NAVD88 unless otherwise noted.

2.2 Station Datum

The National Oceanic and Atmospheric Administration has been measuring water levels nationally for over a century. When measuring and planning for sea level rise it is critical that the highest quality datums available are used.

There are a handful of official NOAA tide gages in the Central Puget Sound region. The closest to Bainbridge Island exist in Poulsbo, Brownsville, and Bremerton. Each of those gages, however, suffers from incomplete data or relatively short periods of record.

We are fortunate in to have a gage close by with one of the longest periods of record in NOAA's entire network (Coleman Dock, Seattle). Established on January 1, 1899 NOAA's Seattle tide gage not only provides quality data, but it puts long-term global climate change and sea level rise into perspective. Furthermore, a comparison of current water levels between all functioning Central Puget Sound tide gages reveals only minor differences in datums (NOAA 2019).

Given Coleman Dock's superior data quality and regional consistency, it is used exclusively in this report to reference water levels on Bainbridge Island.

2.3 Tidal Datums and Exceedance Probability Levels

As previously mentioned, when measuring and planning for sea level rise it is critical that datums and references to elevation remain consistent. Just as important is an understanding of exceedance probabilities. For example, an asset located near mean lower-low water will almost always be under water. An asset located at mean higher-high water will experience, on average, daily flooding. A “50^{th} percentile” water level should be expected to occur every other year, and so forth.

Locally, Mean Higher-High Water (MHHW), also known as an average daily high tide, measures 9.02 feet NAVD88. An annual extreme water level, or a 99^{th} percentile event, measures 10.50 feet NAVD88. A biennial extreme water level measures 11.29 feet NAVD88, and a “100-year” water level, or 1% event measures 12.20 feet NAVD88.

These distinctions are especially important to consider when viewing maps. Maps can only depict one datum at a time, typically MHHW. A map highlighting 3 feet of sea level rise on Bainbridge at the same time depicts today’s 1% water level.

2.4 Mapping

The first step in assessing sea level rise usually involves mapping, which typically involves manipulating geographic information systems (GIS) to portray future inundation. The most common method in which a single (sea) surface is raised, is referred to as the “bathtub” approach. More sophisticated methods, such as hydraulic grade line analyses, better capture local variability and features.

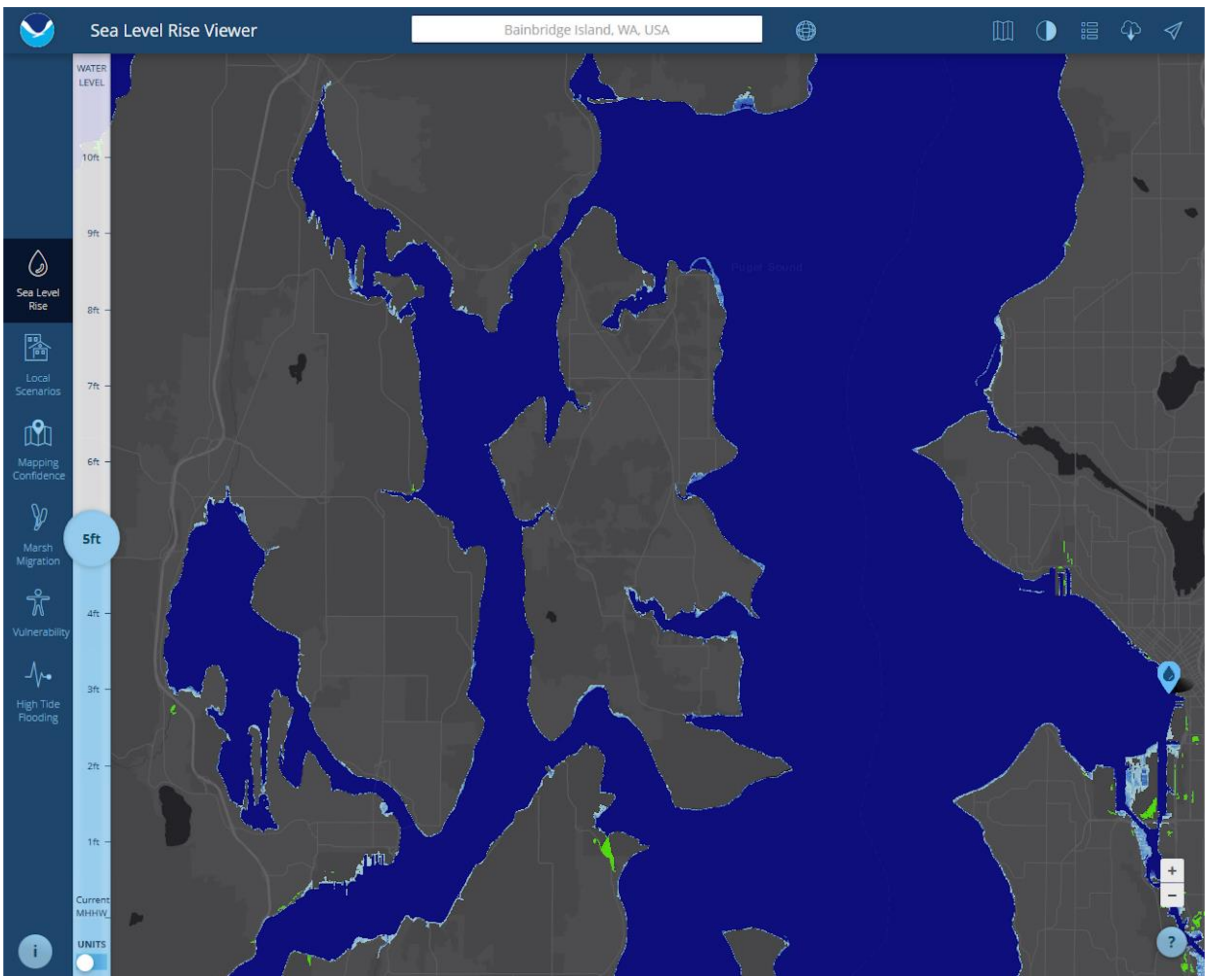
This assessment and report build upon methods developed by NOAA, which they describe as a modified bathtub approach (NOAA 2017), but it is necessary that COBI replicate the NOAA methods using its own GIS. For example, Seattle Public Utilities’ high-resolution maps have been used for planning for a decade and were featured in the 2014 National Climate Assessment (City of Seattle 2019).

3. Results

Fortunately, the resolution and accuracy of web-based GIS maps have advanced in recent years. Initial drafts and related presentations of this report utilized low resolution GIS (Kitsap County Parcel Search and Google Earth). In 2019, NOAA published a Sea Level Rise Viewer (Figure 5) that incorporates the latest digital elevation model (Puget Sound LiDAR Consortium). NOAA's viewer should be used as a first order assessment tool—it only zooms-in so far.

It is recommended that City of Bainbridge Island staff utilize full GIS when surveying coastal assets, so that elevations can be assessed at the parcel level or even smaller. That said, a user need not zoom-in to fully understand basic risk. Some areas simply stand out. What follows in the results section are a series of screen captures of Bainbridge Island's most obviously vulnerable areas.

Figure 5: NOAA Sea Level Rise Viewer.



Source: https://coast.noaa.gov/slr/#/layer/slr/5/-13641138.69260028/6043609.973720823/13/dark/93/0.8/2050/interHigh/midAccretion

Note: there are a few ways to interpret the water level of 12 feet NAVD88 depicted in the following series of screen captures. That water level has been exceeded twice on record, most recently in 2012, and has nearly been exceeded a handful of other times (NOAA 2019). It therefore represents today's extreme water level. According to central estimates, the depicted water level will occur annually by the 2060s, monthly by the 2090s, and nearly every day by the 2030s.

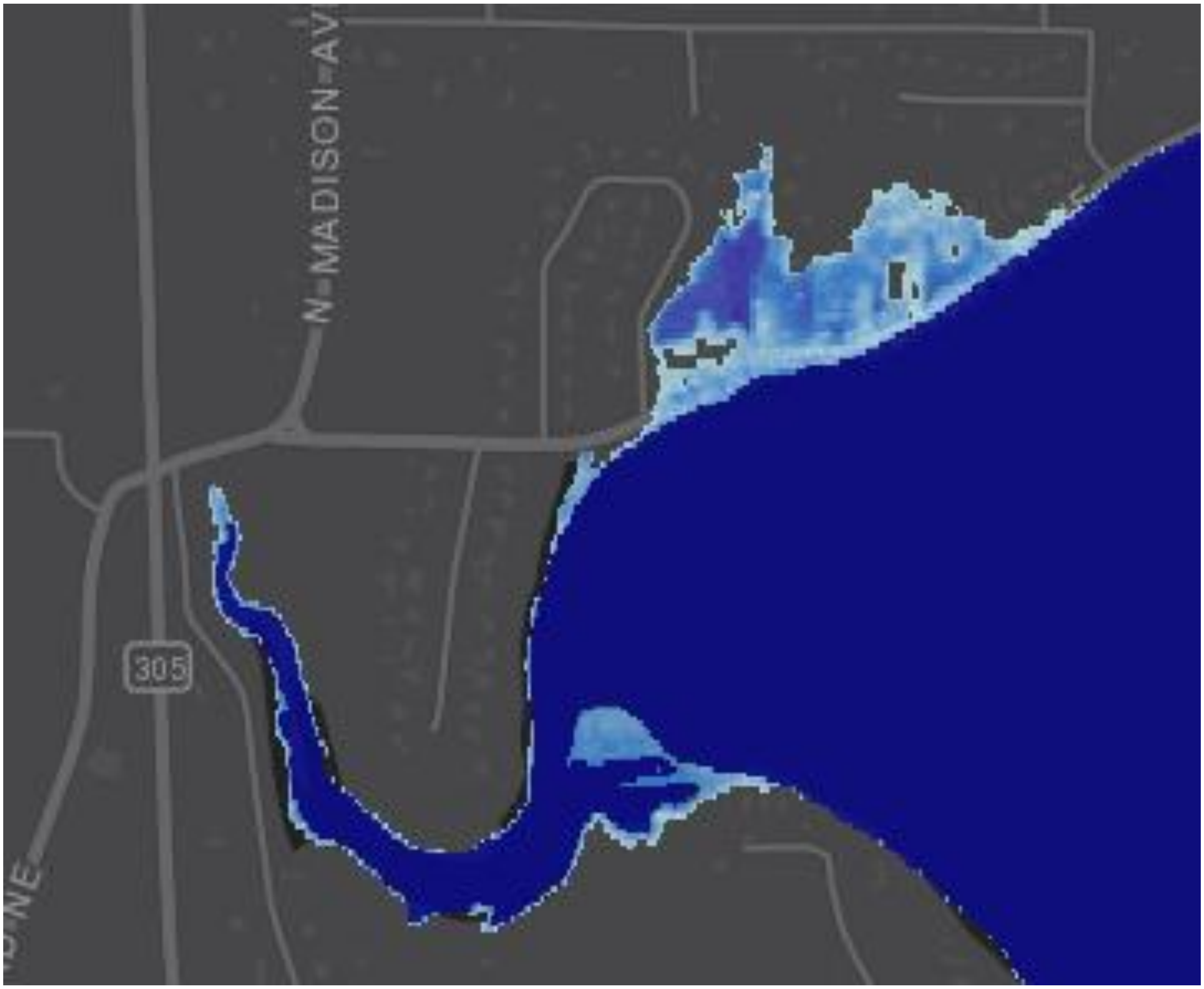
According to the “rapid ice loss” scenario, the depicted water level of 12 feet NAVD88 would occur annually by the 2040s, monthly by the 2060s, and daily by the 2070s. For further reference, the photograph on the cover of this report features a water level of less than 10 feet NAVD88.

Figure 6: Eagle Harbor (12 feet NAVD88)

The depicted water level of 12 feet NAVD88 represents today’s extreme tide. According to central estimates it will occur annually by the 2060s, monthly by the 2090s, and daily (MHHW) by the 2130s. According to the “rapid ice loss” scenario, 12 feet NAVD88 will occur annually by the 2040s, monthly by the 2060s, and daily (MHHW) by the 2070s.

From north to south, notably low-lying areas of Eagle Harbor include beach deposits on Wing Point (approximately 6 properties), Hawley Cove (approximately 4 properties), the modified land that is the Washington State Ferries maintenance facility, the old Strawberry Cannery area, much of the inner harbor, Pritchard Park, and the Wykoff Superfund Site.

Figure 7: Murden Cove, Manitou Beach



The depicted water level of 12 feet NAVD88 represents today's extreme tide. According to central estimates it will occur annually by the 2060s, monthly by the 2090s, and daily (MHHW) by the 2130s. According to the "rapid ice loss" scenario, 12 feet NAVD88 will occur annually by the 2040s, monthly by the 2060s, and daily (MHHW) by the 2070s.

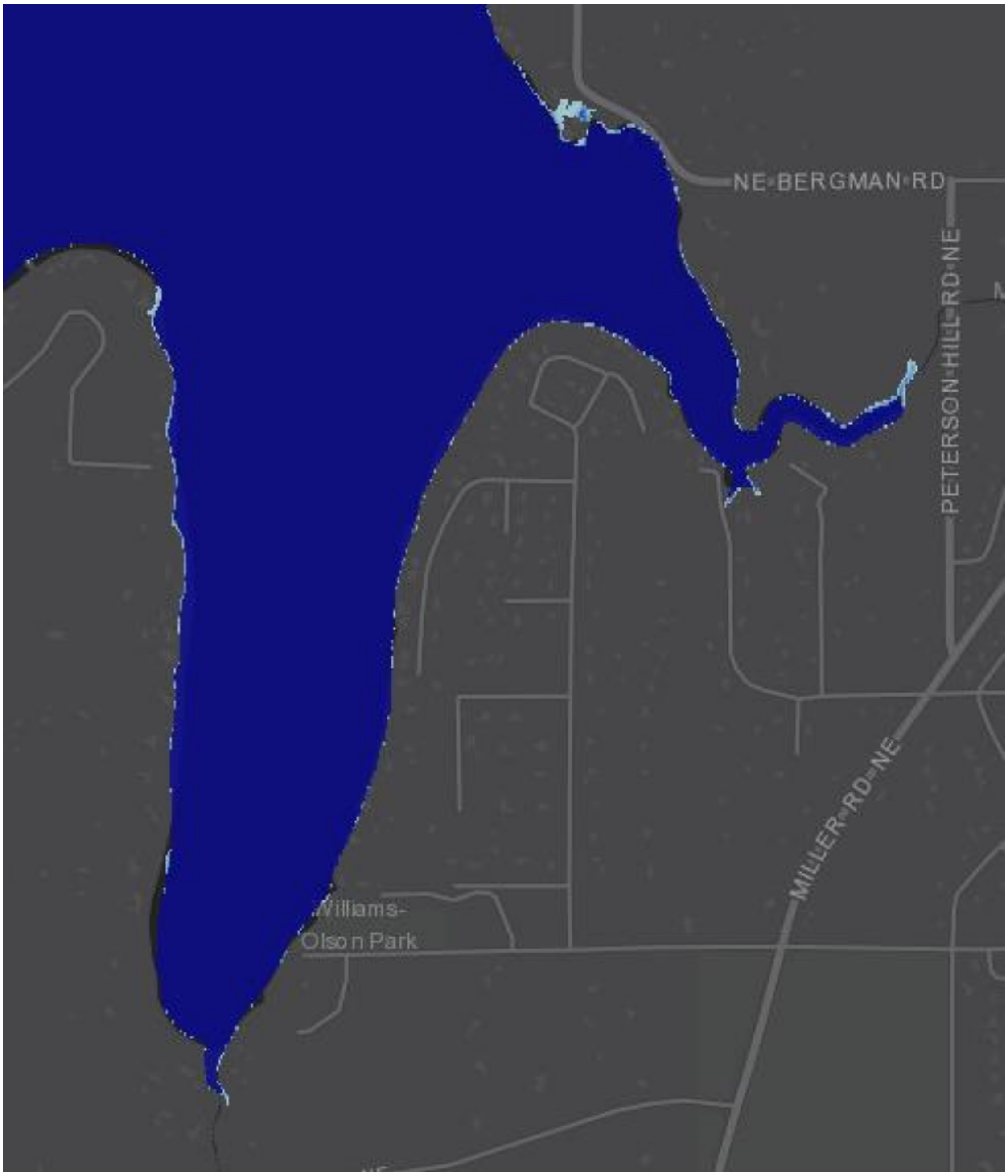
Approximately 15 affected properties, mostly behind Manitou Beach Drive. Areas around Murden Cove will also likely face increased erosion. For reference, see cover photo and Figure 14 (Appendix).

Figure 8: Hedley Spit, Fay Bainbridge Park

The depicted water level of 12 feet NAVD88 represents today's extreme tide. According to central estimates it will occur annually by the 2060s, monthly by the 2090s, and daily (MHHW) by the 2130s. According to the "rapid ice loss" scenario, 12 feet NAVD88 will occur annually by the 2040s, monthly by the 2060s, and daily (MHHW) by the 2070s.

Up to 70 properties exposed along the spit and beside the park. "Nuisance flooding" is already common in these locations. For reference, see Figure 15 (Appendix).

Figure 9: Manzanita Bay



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Only a few properties affected around Manzanita Bay. Notable are potential impacts to the creek at Peterson Hill Road and the Bergman/Manzanita street connection.

Figure 10: Point White, Lynwood Center, and Pleasant Beach

The depicted water level of 12 feet NAVD88 represents today's extreme tide. According to central estimates it will occur annually by the 2060s, monthly by the 2090s, and daily (MHHW) by the 2130s. According to the "rapid ice loss" scenario, 12 feet NAVD88 will occur annually by the 2040s, monthly by the 2060s, and daily (MHHW) by the 2070s.

Approximately 15-20 properties affect between Pleasant Beach and Point White, plus Point White Drive and Schel Chelb Estuary.

3.1 City of Bainbridge Island Assets and Infrastructure

The City of Bainbridge Island (COBI) owns and manages a relatively limited number of assets in areas exposed to sea level rise. Most obvious are public streets, many of which run adjacent to coastlines or end at the beach. Other exposed assets include City Sewer Service Areas, notably Winslow, Rockaway, South Island, Pleasant Beach, Lynwood Center and Point White.

It is recommended that every COBI asset be listed in a table, created using COBI GIS, then sorted by ("invert") elevation and then ranked by criticality. The table could then be used as a foundation for a more complete risk assessment.

Figure 11: Sewer Service Areas

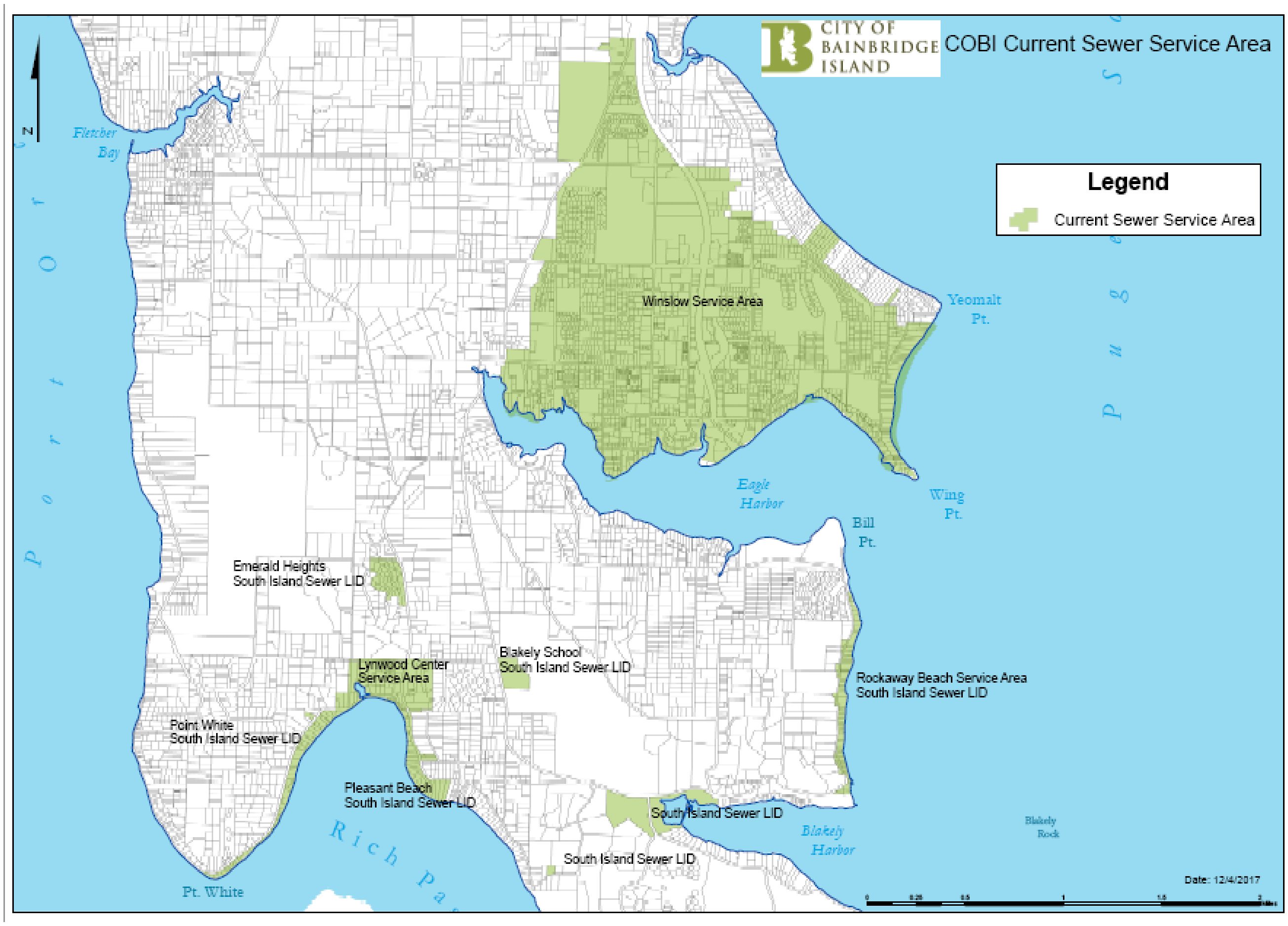
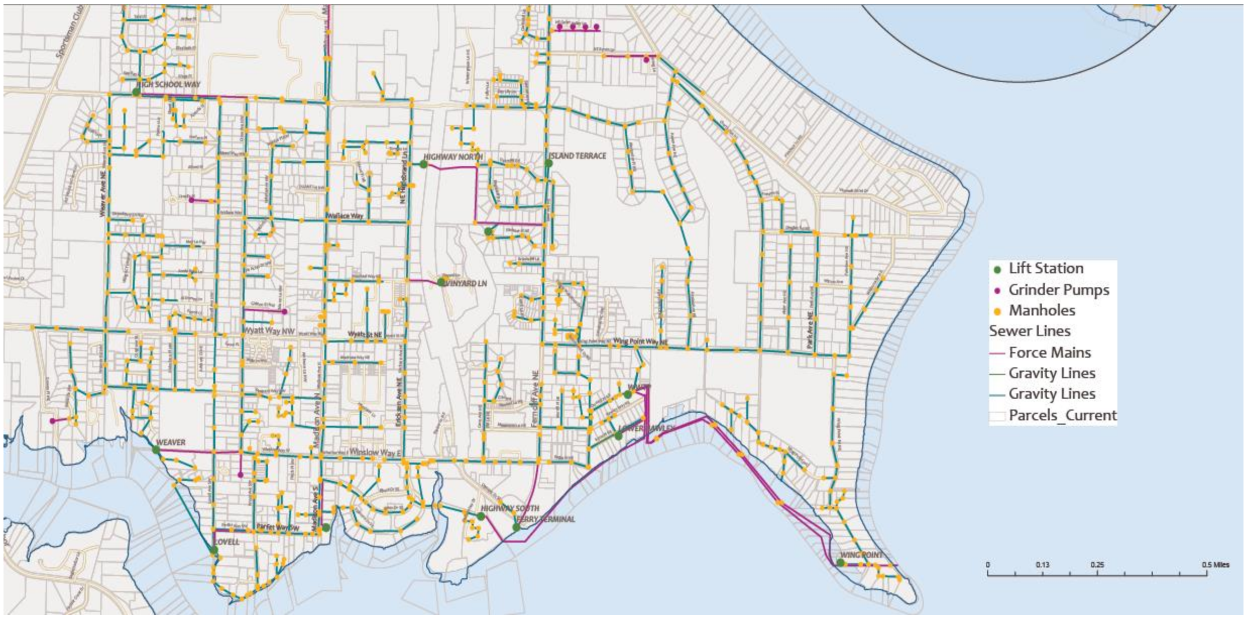
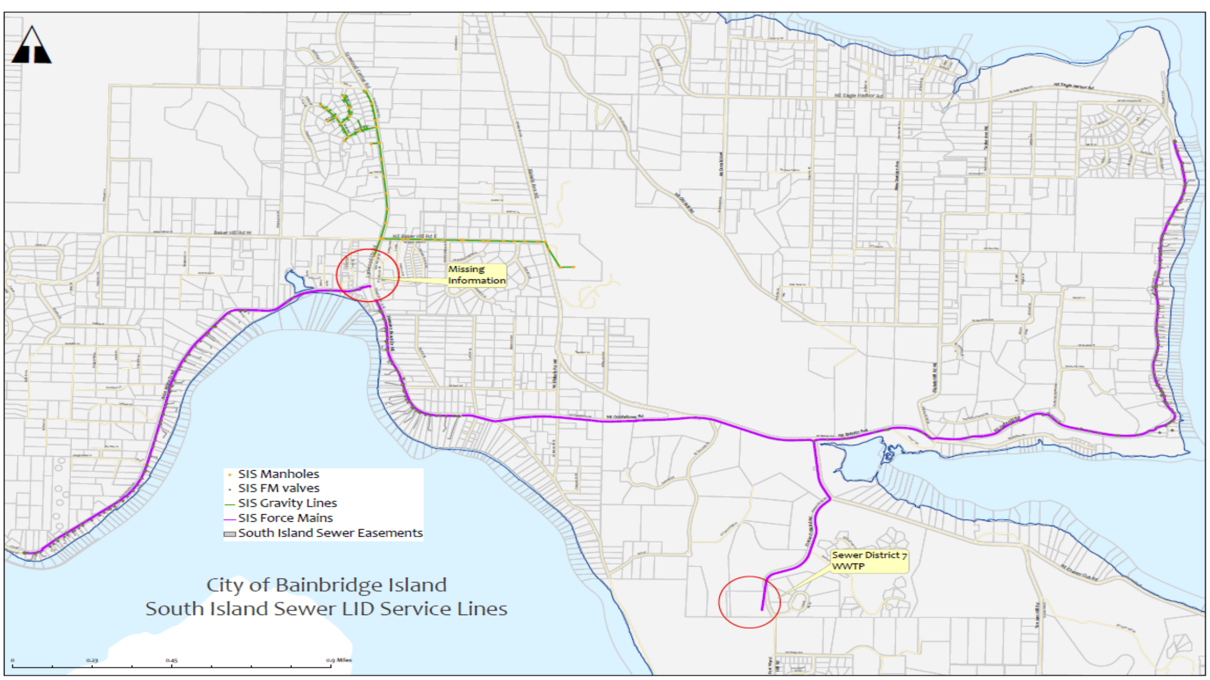


Figure 12: Winslow Sewer Service Area



Of the City's 500 "manholes," approximately 36 are exposed to sea level rise, as are 5 pump stations and 3 force mains (Figure 12). These estimates were "eyeballed" and underscore the need to use high-resolution GIS for planning purposes. Interviews with City staff also indicate that some of these assets, such as maintenance holes with water-tight lids, are designed to function while submerged.

Figure 13: South Island Sewer Service Lines



4. Discussion

This preliminary assessment attempts to provide an understanding of sea level rise and the ways in which it will impact Bainbridge Island. Puget Sound's shoreline has risen over the past century, and it is certain to rise much more for centuries to come. In some ways, The City of Bainbridge Island is fortunate to have relatively few critical assets exposed. In other ways, it is expressly challenged as a significant portion of the community will be directly impacted. Given this assessment, what follows are some suggested strategies to adapt and increase resilience.

4.1 Adaptation Strategies

One of the more challenging aspects to planning for and adapting to sea level rise is picking a number, year, and/or scenario. Outlined in this report, and in the best available science, are myriad options. It is recommended that any asset being considered for adaptation, build to an elevation no lower than the central estimate, or 50th percentile projection using the "business as usual" scenario. It is also recommended, based on the experiences of the municipalities and agencies cited in this report, that plans articulate a way in which adaptation to the 1% (rapid ice loss) projection *can* happen. In other words, **COBI should protect and build to the "middle" number now and demonstrate a way to get to the "high" number when necessary.**

Regarding specific assets, approximately 36 of COBI's 500 "manholes" and three or more force mains are exposed to sea level rise (Figures 12 & 13). Most appear to be vulnerable within the next 50 years, if not sooner. Each should be inspected, inventoried, and retrofitted (for example, with locking lids) or replaced if necessary. These inherently resilient assets should be able to function when submerged.

At least 5 lift/pump stations are exposed (Figures 12 & 13). Each should be inspected, and elevations of critical elements (for example, electrical panels) should be recorded. Such facilities can be redesigned, protected with barriers, or eventually be replaced.

A handful of roadways are particularly exposed. Some streets could be closed to motorized traffic in anticipation of broader action. Emergency access should be preserved, and non-motorized access could be increased (which itself is a co-benefit that furthers other COBI climate change goals). Examples include:

- Manitou Beach Drive (Figure 14) in the vicinity of the Manitou Beach Open Space area. This road and a few adjacent landward properties already experience regular flooding. Consider re-routing motorized Rolling Bay and Skiff Point area traffic to Valley Rd or alternate routes.
- Point White Drive at Schel Chelb Estuary. Consider re-routing motorized Crystal Springs and Point White area traffic to Baker Hill Rd or alternate routes.
- Manzanita Road at Manzanita Bay. All motorized traffic, notably that which uses the arterial to avoid Highway 305, could be re-routed.
- Eagle Harbor Drive at the head of the Harbor is the primary pathway between the south end of Bainbridge and Winslow. Maintaining a connection to Wyatt Way, if desired, will likely require large and costly infrastructure. A possible alternative would be to re-route traffic to High School Road via Fletcher Bay Road.
- Point Monroe Drive, as seen in Figure 8, cannot be re-routed.

Many private properties, both low-lying and high bank, will be impacted. Conventional flood protection such as bulkheads and seawalls will not prevent sea level rise and in some cases may exacerbate the problem. New waterfront construction or re-development, if not prohibited outright, should be guided by prudent shoreline policy. The City should evaluate whether current building and shoreline regulations sufficiently mitigate risk associated with the impacts of sea level rise on shoreline stability and flooding.

Mentioned in the summary but not addressed in the results is saltwater intrusion, bluff erosion, and septic systems. Rising seas will alter the nature of water resources adjacent to the shoreline. It is recommended that COBI add sea level rise to its water resources monitoring program. Additional study of septic systems given future inundation and increased bluff erosion is also recommended.

Ultimately, community-wide retreat or redevelopment should be managed by COBI in coordination with regional, state, and federal partners. In the near-term, it is recommended that City staff meet with Climate Change Advisory Committee members to review this preliminary assessment. Ample time should also be provided for City Council to briefed and to further study the issue. And all members of the community, but especially those who presently enjoy living beside rising waters, should be engaged to determine an equitable and resilient path forward.

Sea level rise is a form of displacement. We may not be sure how quickly it will occur, but we are certain that it will occur. We must plan proactively and pursue no-regrets strategies. Rising to this challenge will cost us much less than waiting until the next flood.

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Appendix

Figure 14: Manitou Beach Drive

December 20, 2018. Water level: approximately 10 feet NAVD88

Figure 15: Point Monroe Drive

December 20, 2018. Water level: approximately 10 feet NAVD88