Tulalip Coast Adaptation

and

Managed Retreat Strategies

Prepared by the Tulalip Tribes

Treaty Rights and Government Affairs

And

Natural and Cultural Resources

with assistance from

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Executive Summary

Along the Tulalip Reservation shore over 600 homes, Tulalip Tribal facilities and reservation infrastructure line much of the beaches and shoreline bluffs. While these water front homes and facilities provide a preferred location for living, over time they are in harm's way from storm surge, rising sea level and accelerated erosion. Efforts to mitigate these risks leads to habitat degradation along the shoreline. To better understand who will be affected and how to make informed decisions about the trade-offs between protecting our built environment and restoring natural resources along the shore we completed this analysis of the Tulalip Tribes' options for responding to sea level rise and increased storm intensity associated with climate change.

Over the last several decades, the Tulalip Reservation coastline has eroded an average of 0.5 feet (ft) per year, ranging from near zero to 3.4 ft at different locations (MacLennan et al., 2019). The rate of erosion is expected to increase over the next several decades. When there is no human intervention the shoreline is dynamic, meaning that it is slowly but constantly changing. Sand and gravel falls from "feeder bluffs" to the beach where it feeds essential habitat for species important to our people and for the Salish Sea Ecosystem. Several species of clams make the beach their home, as do spawning forage fish such as sand lance and surf smelt. Crab larvae settling from their planktonic life stage, and juvenile salmon seeking refuge from predators inhabit the shallow waters. These are all residents of the Tulalip Reservation beaches for all or some portion of their lifetimes. Sand and gravel moves or "drifts" along the beaches until it reaches a point where the force of the water carries it offshore to deeper water. Each section of shoreline where these processes are completed are called "drift cells". Functioning drift cells are important elements of the Salish Sea ecosystem.

In 2017 and 2018 the shellfish program at Tulalip inventoried the intertidal biota of reservation beaches, completed a "structure from motion" (SFM) survey of the beach and bluff, and characterized the intertidal substrate and vegetation[1]. The SFM survey allowed the staff to create a detailed three-dimensional model of the beach and bluff. A report on this survey was completed as part of this project. The information will be further used to apply the CoSMoS model to quantify changes to beach habitat and bluff erosion due to sea level rise and increased storm intensity currently being experienced as a result of climate change.

However, much of the Tulalip Reservation shoreline has received intervention to stop erosion and protect housing and infrastructure[2]. The typical method involves hardening of the shoreline with seawalls or riprap. Approximately 44% of the feeder bluffs and 38% of the marine shoreline of the reservation are lined with seawalls or riprap that stops erosion. These methods can be effective at protecting buildings and infrastructure, but they come with more than just an economic cost. Shoreline hardening diverts wave energy down into the beach, pushing beach material lower into the intertidal, deepening the beach and eliminating a diversity of habitat during high water periods, and it diverts energy to the sides where is accelerates erosion of the adjacent bluff, worsening the situation for neighboring land owners and inducing additional efforts to harden the shore.

There are also methods for "soft shore" restoration that are effective where there is space. These are typically locations where buildings have not been placed below the level of storm surge. In that case the restored beach

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[1] See Appendix A for a summary of Tulalip Tribes' survey of intertidal habitat. The full report is available on request from the Tulalip Shellfish Program.

[2] See Appendix B for Tulalip Tribes' survey of shoreline parcels and infrastructure, as well as shoreline hardening and as assessment of near-term actions that could be taken. The full report is available on request from the Tulalip Treaty Rights and Government Affairs Department.

will absorb wave energy. There may also be methods of reducing wave energy by absorbing some of it before the wave reaches the beach. Such methods may enhance habitat value and, as an added benefit provide food production and income for tribal members. Finally, before the forests along our rivers were cut and trees removed from the river, the tops of our beaches were lined with large logs at the base of the bluff. Replacing the logs may help to absorb wave energy and slow bluff erosion without compromising the ecological function of drift cells. Tulalip is currently testing the efficacy of all these methods in cooperation with the United States Geological Survey (USGS).

In neighborhoods built where sand dune (Tulare, Tulalip Shores, Sunny Shores) or sand spit (Priest Point) systems existed at the base of the bluff many of the homes are built on the upper portion of the beach[3]. Because of the history of this development, specifically that occupation of the buildings was initially periodic and casual, there are very poor records documenting the type of septic systems associated with each site, or if there are septic systems at all. Tulalip has documented high levels of fecal coliform bacteria within reservation shoreline beaches at some of these sites[4]. Shellfish harvesting is closed along much of the reservation shore because of the risk and uncertainty that poor control of septic systems on the shoreline poses to human health.

Mixed jurisdiction on the reservation between Snohomish County and Tulalip Tribes has resulted in inconsistent application of regulatory requirements for septic systems for Tribal households and non-tribal households. Estimates from the Tulalip Tribes Enrollment Department for 2020 indicate that approximately 27.8% of individuals that live on the Reservation are Tribal members while 72.2% are non-Tribal[5], but we don't have information on how this translates to shoreline ownership. The demographics and inconsistent regulatory environment results in confusion and neglect of this issue.

Sea level rise and increased storm intensity, that we have been experiencing and is expected to accelerate over the next several decades, will result in additional flooding and wave damage, and erosion for individual homes on beaches and along the top of the bluff, as well as to tribal facilities and infrastructure along the shore of Tulalip Bay. The threat includes damage to buildings, erosion of the ground upon which buildings sit and damage to septic systems, furthering contamination of shellfish populations.

As part of our effort to understand the current and future dynamics of our shore the USGS developed the Coastal Storm Modeling System (CoSMoS) for the reservation coast[6]. Flood maps were created for 8 flood recurrence intervals[7] for each of nine sea level rise scenarios projected by the State of Washington (Miller et al. 2018) and considered plausible between the years 2023 and 2150. Each of these scenarios was mapped for flood extent. Between 2.75 km^2 (1.06 $miles^2$) and 3.25 km^2 (1.25 $miles^2$) of additional flooding is expected between the extremes of the modeling. The Tulalip GIS department create a dashboard so that these data can be visualized[8].

Using the CoSMoS results and the parcel by parcel assessment we Identified and mapped the risk posed to each neighborhood on the reservation coast. Potential risks include erosion, inundation and periodic flooding. Table

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3 See Appendix C for a Tulalip resercation shoreline septic system assessment.
4 See Append D for water quality sampling data from selectedTulalip Reservation beaches.
5 See Appendix E for Reservation-wide demographics data.
6 See Appendix F for the complete report.
7 The number of times a flood is expected in a given period of time.
8 See Appendix G for a guide to the dashboard.

1 in the report below lists our assessment of risk to neighborhoods for existing and mid- to late- century coastal hazard based on flood modeling completed by the USGS using the CoSMoS model. Priest Point is assessed to be at high risk currently and extreme risk mid- to- late century. Tulare Beach is medium and high to extreme, Tulalip Shores is medium to high, Tulalip Bay and Mission Beach are low to medium and high, Sunny Shores is low and medium to high, finally Spee-BI-Dah is low and low because all structures are set back from the beach and located at a high elevation.

This report evaluates a variety of adaptation strategies. The strategies range from those that allow buildings and infrastructure to remain in place and live with the water, to managed retreat from the flooding and eroding shoreline. Each strategy has costs, benefits, risks and degree of efficacy. Alternatives such as retaining and expanding hard armoring will result in additional habitat degradation on reservation beaches. Hard armoring also has a limited lifetime because beach erosion in front of seawall and riprap continues such that the structure will eventually fail. Soft armoring, such as beach restoration, beach nourishment and placement of large woody degree may be of limited applicability along much of Tulalip's steep shoreline and be more expensive to implement than is feasible. Tulalip is also exploring the feasibility of other soft alternatives such as clam gardens, oyster reefs and hanging aquaculture.

Pollution from beach front septic systems can and should be addressed independently from the questions about sea level rise and increased storm intensity. Local, state and federal government agencies have a trust responsibility to the Tulalip Tribes and must control pollution from septic systems. They have a moral and legal responsibility to do so, but have so far failed to meet their responsibility in spite of the technology of doing so being well developed and applied in most other locations.

It may be in the interest of Tulalip Tribes of acquire interest in shoreline properties on the reservation. In this report we have outlined multiple avenues to do so[9]. Even without acquisition of these parcels, some of these strategies could facilitate managed retreat from the shoreline over time. Each method is described in detail with real life examples described in some cases.

The concept of managed retreat can be controversial and lead to polarized opinions before any planning efforts are even discussed or considered. Accordingly, it can be challenging to know when to first discuss the concept and how to present it to community members. However, it is recommended that managed retreat options be considered at the same time that other more traditional and/or near-term adaptation and management options, such as hard and soft armoring, are presented to communities.

We recommend near-terms actions such as collecting more specific demographic information about who is living on the Tulalip Reservation shoreline and how they use their property. This could inform the Tribes on the interest there might be among the residents for relinquishing ownership in the short and long term. The Tribes could develop key messages about reducing the stress on coastal system and limiting the need for emergency repairs by proactively responding to a growing threat. An outreach plan targeting Tribal staff, County staff and residents about managed retreat would enable more informed dialogue about options. Long term actions should be captured in planning documents to address the known threats that we have described in this report. Some high-risk areas such as Priest Point, Tulare Beach and Tulalip Shores may require plans for action that occurs over the next decade or so. This will require implementing a targeted outreach strategy and working with government partners (Snohomish County, BIA) to address the tendency to expand hard armoring, which in turn continues to harm Tulalip's shoreline resources.

[9] See Appendix G for methods on acquiring interest in land for purposes of adaptation and managed retreat from sea level rise.

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Introduction

The Tulalip Reservation encompasses around 14 miles of marine and estuarine coastline in Puget Sound. Over the last several decades, the coastline has eroded an average of 0.5 feet (ft) per year, ranging from near zero to 3.4 ft at different locations (MacLennan et al., 2019). When there is no human intervention the shoreline is dynamic, meaning that it is slowly but constantly changing. Material falls from “feeder bluffs” to the beach where it feeds essential habitat for species important to our people and for the Salish Sea Ecosystem. Several species of clams make the beach their home, as do spawning forage fish such as sand lance and surf smelt, crab larvae settling from their planktonic life stage, and juvenile salmon seeking refuge from predators. These are all residents of the Tulalip Reservation beaches for all or some portion of their lifetimes. Material eroding from the source bluffs moves or “drifts” along the beaches until it is carried offshore to deeper water. Sections of shoreline where these processes are completed are called “drift cells”.

Just above the higher-high-water line of the tide on the reservation and, above that, along the crest of the shoreline bluff, are the homes for over 600 tribal and non-tribal waterfront households. These people value the beach and marine waters beyond for the quality of life and mental health benefits provided by open views and access to the beach and water. However, proximity to the dynamic shoreline puts these homes in harms way from flooding and wave energy from storms, and erosion of the lands on which they stand. Efforts to protect buildings along the shoreline have typically included the construction of seawalls near the high tide line, such that nearly 38% of the shoreline is hardened with seawalls. Hardening the shoreline is in conflict with the natural processes that maintain beach habitat.

Furthermore, the origins of many of these structures was as informal vacation dwellings with minimal need for sewage treatment. As the dwellings were improved, to what are now large houses with full time residents, consideration for the disposal of sewage was often neglected, the existence or nature of sewage treatment is unknown at most sites. It is highly probable that little to no sewage treatment occurs at many of these sites. So, to protect human health, shellfish harvesting is curtailed along the Tulalip Reservation shoreline, preventing tribal members from accessing a traditional source of food.

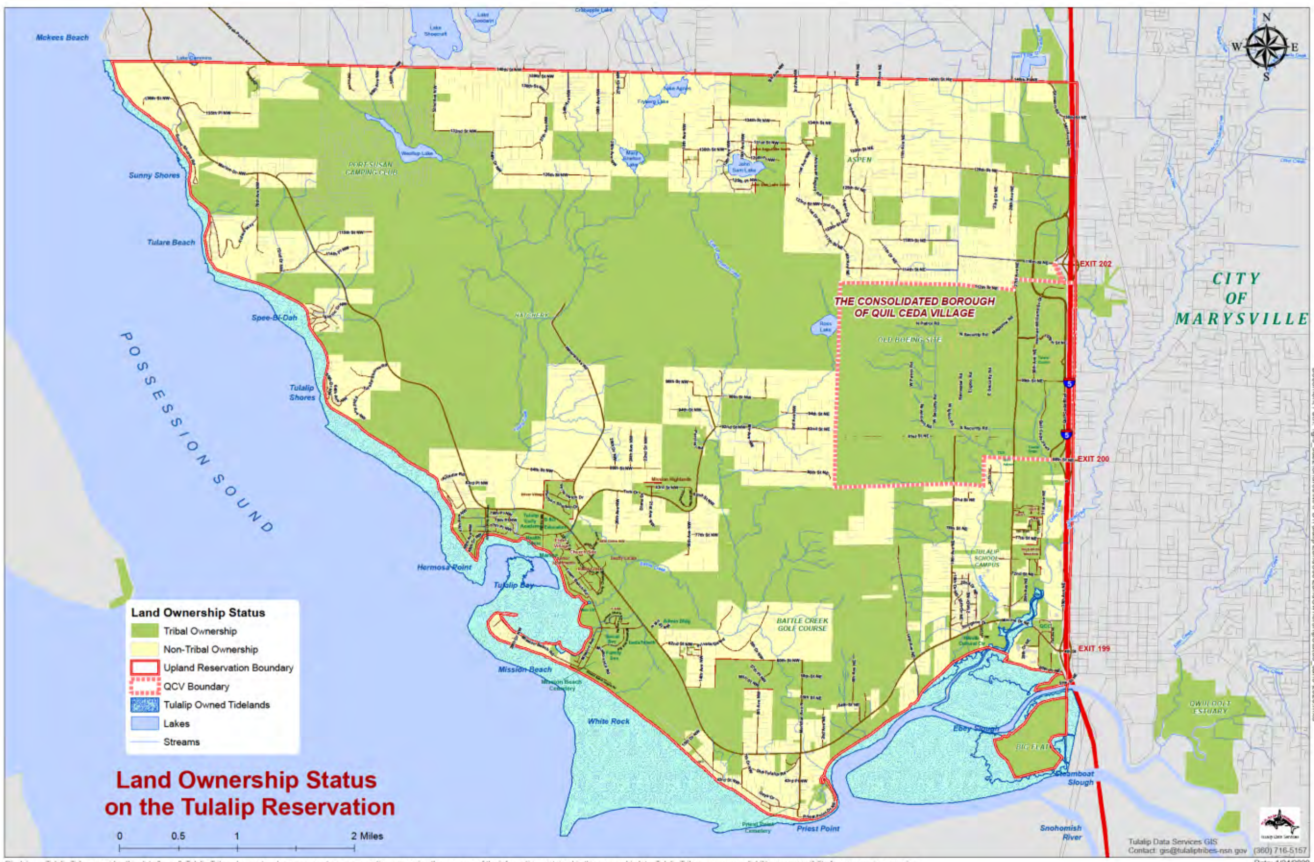
In a changing climate, shoreline erosion has been magnified as sea level rises and winter storms intensify. Sea level rise and increasing coastal storm inundation are requiring decision-makers to reevaluate existing shoreline policies and devise adaptation strategies, ranging from engineered nature-based and structural approaches, to revised policy and regulatory measures. Structural options may only prove to be both effective and feasible for a limited time before managed retreat will be required. This Coastal Adaptation and Managed Retreat Assessment evaluates the potential impacts of sea level rise and coastal erosion on infrastructure, housing, and habitats in densely populated shoreline neighborhoods along the Tulalip Reservation coastline and provides a set of options for addressing these long-term issues.

A Changing Coastline

Current conditions

The Tulalip Reservation shoreline is currently a dynamic ecosystem affected by the mix of human priorities of both Tribal and non-Tribal residents of the reservation. Much of the bluff is actively eroding and drift cells are functioning, though likely in a diminished manner due to extensive seawalls. The Tulalip shoreline consists of two “drift cells”. One drift cell moves material beginning at Hormosa Point to the north, while the other moves material from Mission Point southward to Priest Point. We have no way to know how much their function is diminished by sea walls preventing sediment contributions to the beach, nor how much habitat has changed, because we have no data from before sea walls were constructed. About 38 percent of the shoreline has been hardened to prevent erosion.

Estimates from the Tulalip Tribes Enrollment Department for 2020 indicate that approximately 27.8% of individuals that live on the Reservation are Tribal members while 72.2% are non-Tribal (see Appendix A for Reservation-wide demographics data). Of the nearly 22,500 acres of uplands and tidelands within the Reservation, approximately 62% is owned by the Tribe or individual Tribal members, with the remaining acreage in non-Tribal ownership (Figure 1). These statistics have implications for how Tulalip responds to sea level rise and storm intensification because tribal and non-tribal households are subject to different regulatory jurisdictions, each requiring different authorities in any given solution.

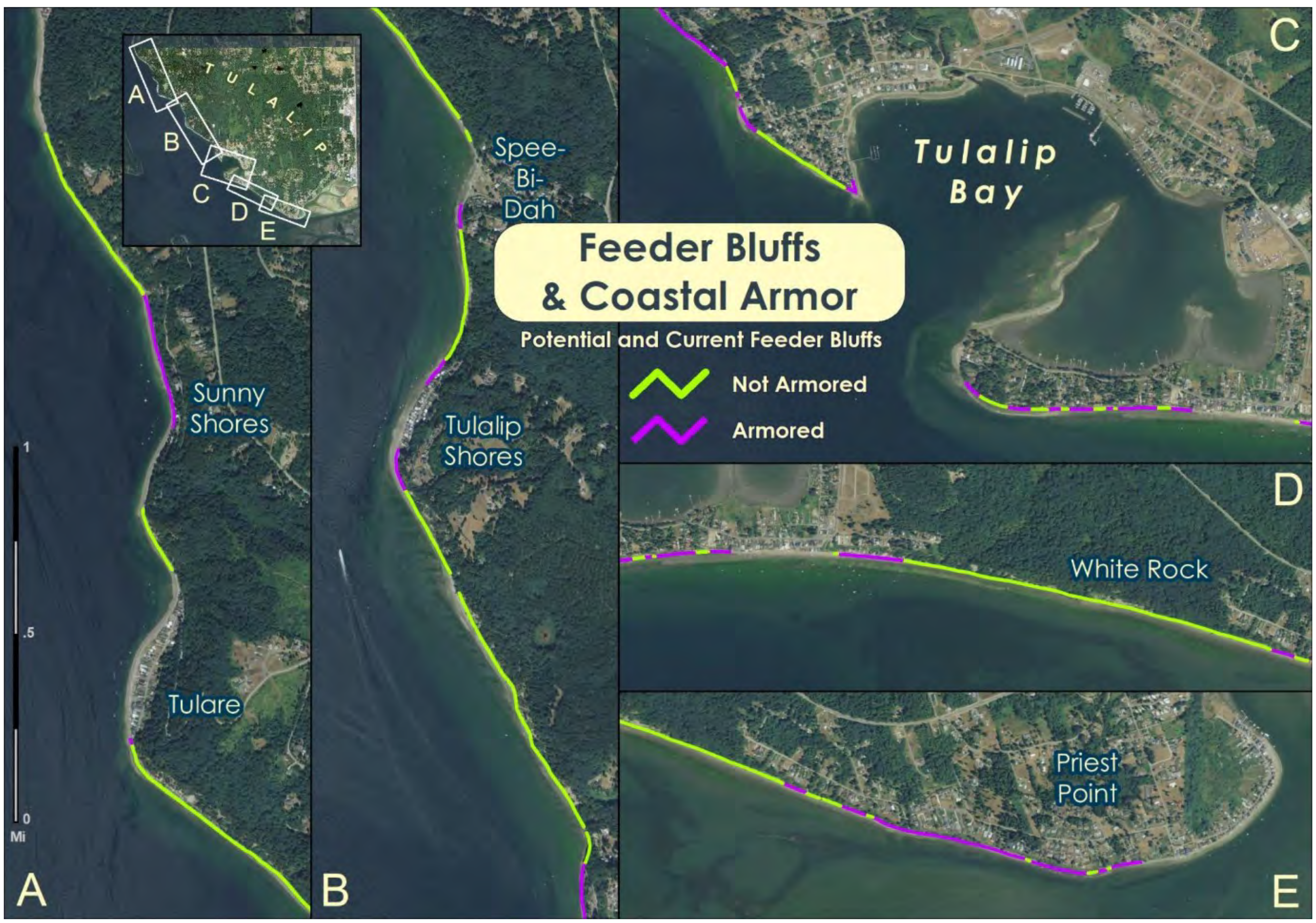


SOURCE: Tulalip Tribes 2020

Figure 1. Land Ownership Status on the Tulalip Reservation.

More than half of the marine shoreline has homes or Tribal facilities either on the beach or within a short distance of the top of the coastal bluff. This includes the entire perimeter of Tulalip Bay where the Longhouse, Gathering Hall, Elder Center, clinic, marina, and other Tribal facilities are located at or near the water's edge (Tulalip Tribes 2010a). There are over 600 waterfront residential parcels mostly owned or occupied by non-Tribal residents in neighborhoods such as Sunny Shores, Tulare Beach, Spee-Bi-Dah, Tulalip Shores, Tulalip Bay, Mission Beach, and Priest Point (Snohomish County Assessor's Office n.d.). These homes are built on fee simple lands or on trust lands under term-limited lease conditions.

To protect coastal neighborhoods, approximately 44% of the feeder bluffs and 38% of the entire marine shoreline of the Reservation has been armored to prevent erosion (Figure 2). In their natural state, coastal habitats provide a buffer to wave energy at most tide stages, slowing the rate of erosion and moving sediment down the beach (Johannessen et al. 2014). Hard armoring can provide flood protection to infrastructure but also redirects the erosive energy of waves onto the beach and to adjacent beaches and bluffs accelerating erosion at these locations. Beach sediment from an armored bluff that would usually feed the shoreline intertidal areas is blocked due to shoreline armoring, and the sediment that would normally move along the shore is instead moved further out into the inter- and sub-tidal area leaving deeper water at most tides. This results in a loss of upper beach habitat for forage fish, shellfish, juvenile salmon and other treaty reserved resources. The increased rates of erosion in adjacent locations induces further armoring by property owners. Without the ample sediment supply provided by feeder bluffs to drift cells, beaches are more likely to narrow, steepen, and coarsen over time, degrading habitat (Clancy et al. 2009) and accelerating nearby erosion.



SOURCE: Rabins 2022a (locations obtained from MacLennan et al. 2013)

Figure 2. Location of current (unarmored) and potential (armored) feeder bluffs.

The Tulalip Reservation marine shoreline includes various habitats including bays, spits, beaches, and bluffs. Recent intertidal biotic surveys conducted by the Tulalip Tribes Shellfish Department in 2005 and 2017-2018 documented shellfish species presence, habitat conditions (e.g., armoring presence and elevation), and habitat change between the two survey periods (Rabins 2022a; Appendix B). Shellfish beds are important cultural, ecological, and economic resources and provide important indicators of the ecological impacts of infrastructure such as hard armoring and pollution (e.g., septic system discharge) on intertidal habitats. Areas that are heavily armored experience scouring of the critical fine-grained sediments that form intertidal habitats and are associated with low shellfish counts in the intertidal biotic survey (e.g., Hermosa Point, Mission Beach, and Priest Point) (Rabins 2022a).

Finally, current flooding of shoreline septic systems and drainfields (collectively known as on-site sewage systems (OSS)) during king tides and storm surge, increases the risk of their failure and exacerbates pollution problems by reducing their ability to treat sewage (Hoghooghi et al. 2021; Miami-Dade County 2018; Mihaly 2018). High fecal coliform and E. coli levels have been detected on beaches in neighborhoods that rely on septic systems for sewage treatment along the Tulalip Reservation coast. Such bacteria present a health issue for humans and fish and wildlife. Septic system discharge is one of the main limiting factors affecting safe shellfish harvest along the coast. There are many undocumented and therefore unpermitted OSS (40-60%) present in densely populated shoreline neighborhoods, and septic permitting and management in the area is complicated by jurisdictional issues and willingness of agencies to spend resources on this issue.

The shoreline of the Tulalip Reservation is under mixed jurisdiction by the Tribe and Snohomish County for land use, enforcement, and regulation of sewage treatment. Non-Tribal fee landowners go to Snohomish County for land development and septic permits. Tribal members, other Natives, and Lessees go to Tulalip Tribes for development and septic permits. Indian Health Service (IHS) will install septic systems for qualified Tribal members. This situation creates regulatory gaps that have been evident in the evaluation of septic systems, particularly along the shoreline. There are several densely populated shoreline neighborhoods (e.g., Sunny Shores, Tulare Beach, Spee-Bi-Dah, Tulalip Shores, and Priest Point), where small parcels are owned by non-Tribal people. These houses are presumed to be served by OSS, because there is no centralized sewage collection system in these neighborhoods. A review of available County documents regarding OSS in these shoreline communities showed that very little information is available on sewage treatment for these homes. Wherever there are residences in shoreline neighborhoods without a connection to a centralized wastewater treatment plant and without a documented septic system, it is assumed, without evidence, that the house has an OSS.

Future conditions

Sea level rise and increased coastal storms will accelerate the processes and problems described above under Current Conditions, including coastal erosion, flooding, septic system malfunctions or failures, and habitat degradation and loss. The Washington Coastal Resilience Project (WRCP) developed local projections for sea level rise along Washington's shorelines (Miller et al. 2018). Along the Tulalip coast, WRCP estimates there is a 50% likelihood that at least 0.2 m (0.7 ft or 8 inches) of sea level rise will occur by 2050[10], and that there is a 50% likelihood that 0.67 m (2.2 ft or 26 inches) of rise will occur by 2100. These estimates assume a high greenhouse gas emissions scenario (RCP 8.5). Miller et al. (2018) project a low probability (1% chance) that sea level rise will reach much higher levels of up to 0.45 m (1.5 ft) by 2050 and 1.5 m (5 ft) by 2100. Higher rates of sea level rise are theoretically possible as well and it is important to keep in mind that knowledge about the mechanisms of sea level rise and ice cap melting (which in part drives sea level rise) is constantly being revised,

[10] That is 8 inches of sea level rise in 27 years compared to 9 inches documented in the prior 100 years.

usually predicting more rapid rise. Under a low emissions scenario (RCP 4.5), the 50% likelihood estimates at 2050 and 2100 are 0.2 m (0.7 ft) and 0.5 m (1.7 ft), respectively. To complement this analysis, the Tulalip Tribes used results from the Puget Sound Coastal Storm Modeling System (PS-CoSMoS) developed by the U.S. Geological Survey, which provides storm-induced coastal flood hazard maps under current and projected future conditions (Appendix D). The model outputs cover the mainland shoreline from the Snohomish River Estuary north to the Stillaguamish River Estuary, examining both sea level rise (e.g., 0-2 m) and storm scenarios (e.g., king tide, 1-year, 20-year, 50-year, and 100-year storm events). The Tulalip GIS Department created a dashboard, available on the Tulalip GIS system, that shows the level of flooding on the reservation given different combinations of sea level rise and storm surge. A guide to use the dashboard is available in Appendix E.

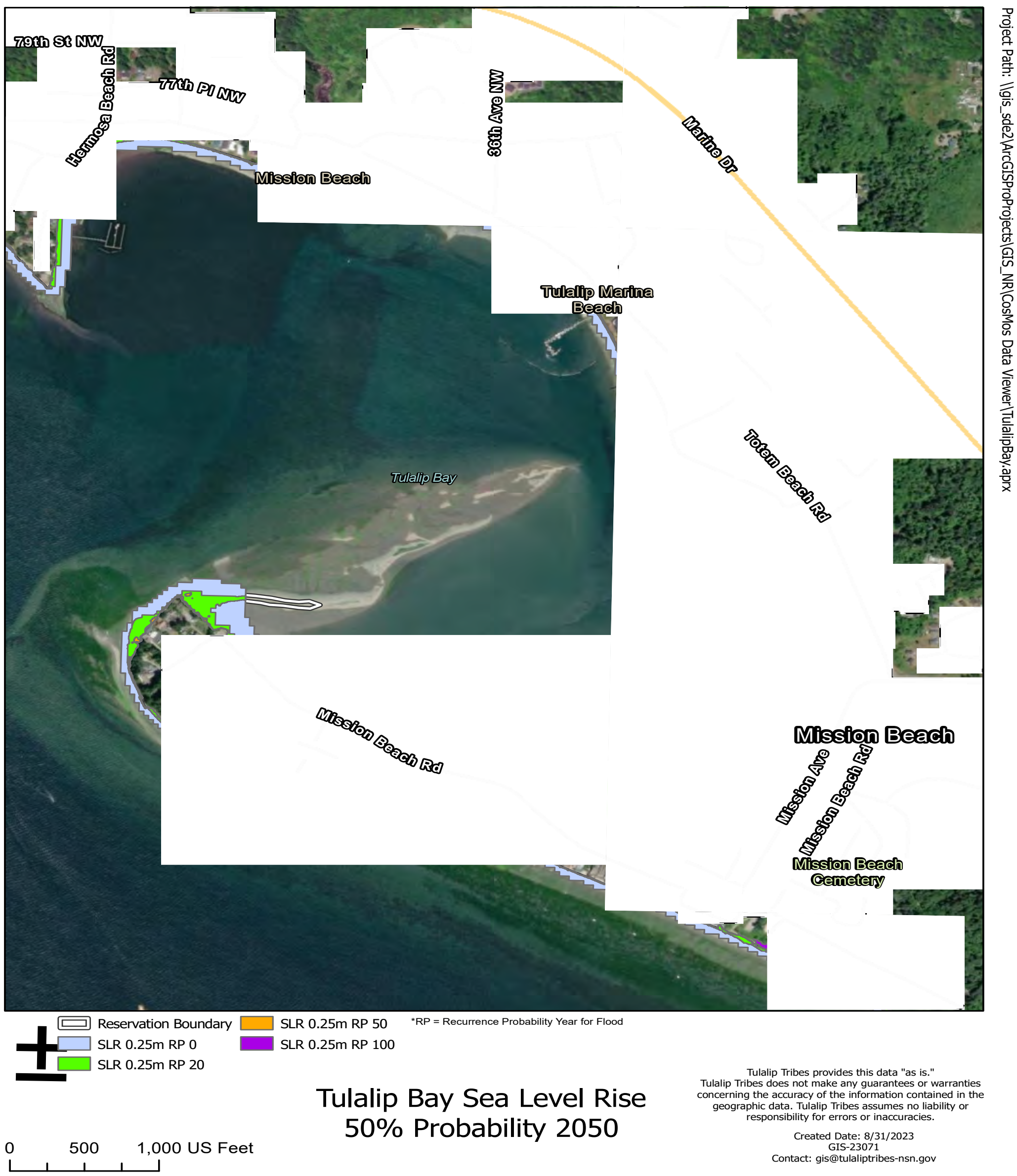


Figure 3. Coastal Storm Modeling System flood prediction for 50% probably in any year by 2050. Fifty percent means that this level of flooding is can be expected to occur once every two years.

As can be seen in the figure above flooding will reach some housing and reach higher on the shoreline bluffs. Adding storm surge to the flood level may result in significant damage to buildings and rapid erosion. Even without storms higher water levels will leach saltwater into septic systems, upsetting the chemical properties and biological communities that are essential to treating sewage (Cooper et al. 2016; Habel et al. 2020; Vorhees et al. 2022). Inundation is also likely to spread untreated pathogens from drainfields and tanks into the nearshore. Infrequent saltwater contact can corrode pipes and other metallic components inside septic tanks. Older septic systems may have fractures in pipe and tank components that make the system more vulnerable to damage from saltwater leaching and more likely to release pathogens. For systems located closest to the shoreline, there is increased risk of physical damage to tanks and drainfields (Hoghooghi et al. 2021; Mihaly 2018). Direct wave action can physically erode drainfields and/or affect soil composition within the drainfields that can exacerbate future erosion. Waves can launch debris such as driftwood and gravel that can damage inspection pipes, access points, and other aboveground septic appurtenances. Access covers and lids may be washed away by waves and inundation, further subjecting the tank to chemical and biological damage. Older systems are likely to be more vulnerable to physical damage. While septic systems and drainfields may be able to withstand infrequent flooding associated with rare and extreme storm events such as the 100-year coastal flood, as flooding increases, the physical, chemical, and biological stress on these systems increases. The degree of exposure at which an individual septic system can no longer reliably function is highly variable (e.g., will a system continue to be functional if it floods once every 5 years? Once a year? (Galbraith et al. 2007; Hoghooghi et al. 2021; Mihaly 2018). However, by the time that a septic system is inundated multiple times per year (e.g., during king tides), it is highly likely that it will no longer effectively function.

Furthermore, as sea levels rise, the brackish coastal groundwater also rises (Miller et al. 2018; Mihaly 2018). In low-lying neighborhoods within the coastal floodplain, depth to groundwater can be very shallow. Minor increases in groundwater levels can dramatically affect the physical, chemical, and biological functioning of septic tanks and drainfields (Cooper et al. 2016), and the effect of rising groundwater may be more harmful to septic systems than periodic overland inundation.

Coastal Neighborhoods and Assets at Risk

Six densely populated shoreline neighborhoods along the Tulalip Reservation coastline were selected for more detailed evaluation of coastal hazard risk. Rankings considered existing risk, future risk with 0.25 m and 1 m of sea level rise, groundwater levels, and the type and quantity of nearshore infrastructure.[11]

[11] For the purposes of this evaluation, the 10% likelihood estimates from Miller et al. (2018) were considered when assessing projected future sea level rise. For consistency with the CoSMoS mapping, the 0.25 m (0.82 ft) and the 1 m (3.3 ft) scenarios were selected to represent 2050 and 2100, respectively. No additional modeling, mapping, or calculations were performed. Instead, the team assessed relative coastal hazards based on simulated inundation, neighborhood topography, shoreline assets, and neighborhood demographics.

Table 1. Coastal Hazard Ranking by Neighborhood.

Neighborhood	Est. Number of Residences[1]	Est. Number of Septic Systems	Existing Conditions Coastal Hazard[2]	Mid- to Late-Century Coastal Hazard	Coastal Hazard Ranking
Priest Point	47	14 documented, 47 assumed	High	Extreme	1
Tulare Beach	54	37 documented, 54 assumed	Medium	High to Extreme	2
Tulalip Shores	23	6 documented, 23 assumed	Medium	High	3
Tulalip Bay/Mission Beach	300	N/A	Low to Medium	High	4
Sunny Shores	18	9 documented, 18 assumed	Low	Medium to High	5
Spee-Bi-Dah	20	7 documented, 20 assumed	Low	Low	6

SOURCE: ESA 2023

[1] A complete parcel inventory was not conducted. Multiple parcels may be owned by the same property owner, which impacts the total count, particularly for Priest Point.

[2] Hazards were evaluated on a relative basis in comparison to other neighborhoods rather than against an absolute metric.

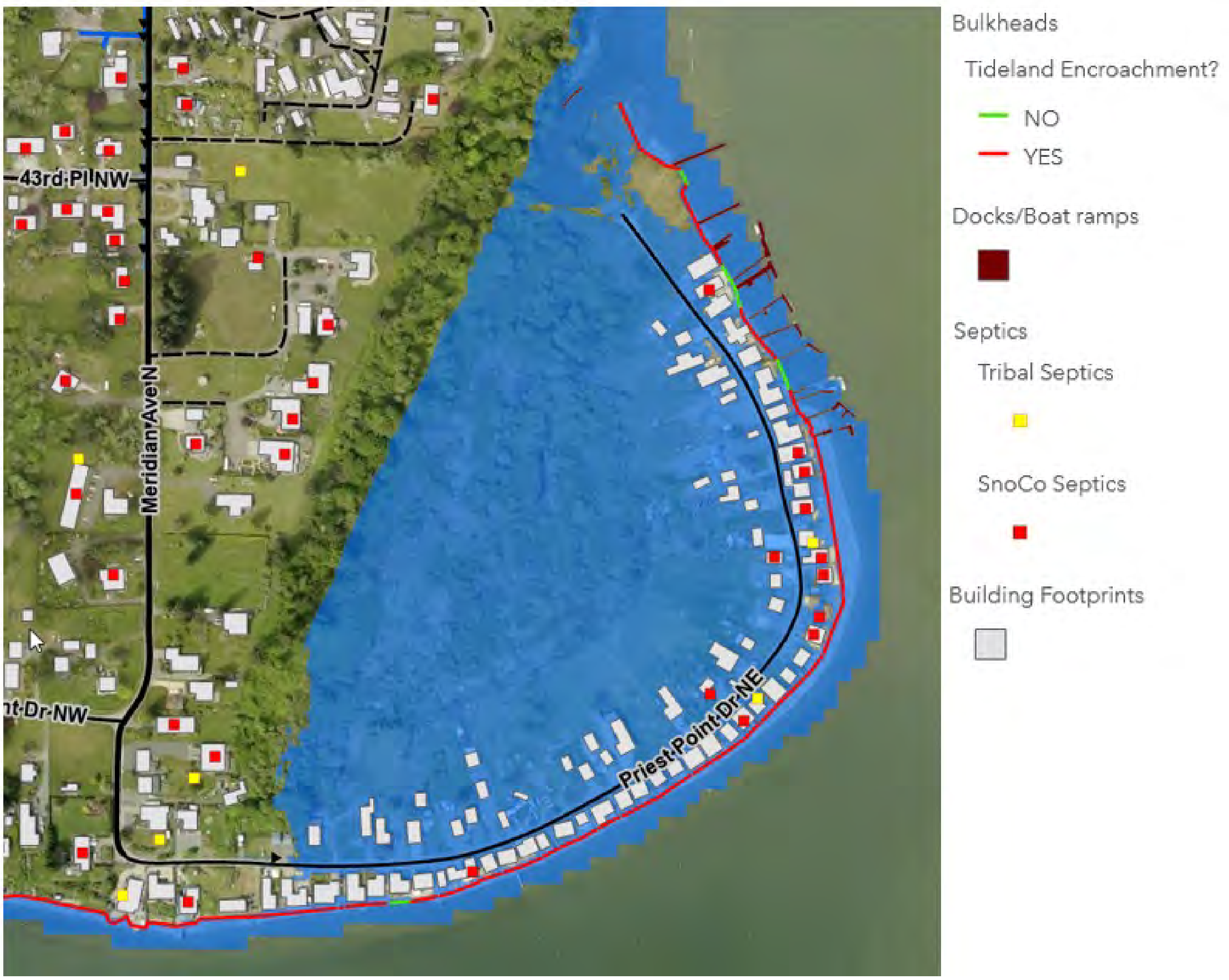
Priest Point

The Priest Point neighborhood is located on a low sandy spit enclosing a tidal wetland. The shoreline is heavily developed with numerous houses on small parcels. Priest Point Dr NE provides access to approximately 47 residences along the shore and 25 interior parcels (a number of these parcels are owned by the landowner on the shoreline side). There are 14 documented septic systems, although at least 47 are assumed to exist. All of the shoreline along Priest Point is mapped as having a bulkhead or seawall. As sea levels rise, the beach in front of the bulkhead is likely to erode, which may lead to eventual undermining of the wall. Yards and septic drainfields may be physically eroded if the wall fails.

Priest Point Dr NE is also at high risk of flooding under existing conditions. This road provides sole access to and egress from the neighborhood and is essential for emergency access and evacuation. A tide gate located at the northeast entrance to the tidal wetland is intended to prevent water from entering the wetland at high tides. This tide gate is not owned or operated by the Tulalip Tribes (Ben Lubbers, Tulalip Tribes Planning Department, personal communication). The tide gate and associated dike are reported to occasionally overtop with extreme storms and high water levels, allowing floodwaters into the site interior. The dike and/or gate may experience complete failure under extreme storms and higher sea levels. While it is likely that the CoSMoS model does not simulate the effect of the tide gate on water levels in the wetland, it can be assumed that the gate will not have a significant effect in blocking floodwaters in the future.

This neighborhood is already at elevated risk of coastal flooding under existing conditions. Most of the septic drainfields begin to flood during king tides, and under a 5-year return period event, most parcels are inundated (SOURCE: Tulalip Tribes 2023

Figure 3). With 0.25 m of sea level rise, normal tidal inundation begins to affect several septic drainfields on the seaward side of Priest Point Dr NE and most drainfields on the interior side. The entire neighborhood is inundated during king tides with 0.25 m of sea level rise. With 0.25 m of sea level rise, this neighborhood is elevated to the extreme risk category, which may occur as soon as 2050. The neighborhood likely has an extremely high groundwater table, especially considering the presence of the tidal wetland on the interior of the neighborhood. These groundwater elevations will increase with sea level rise.



SOURCE: Tulalip Tribes 2023

Figure 3. Priest Point 5-Year Storm Inundation with 0 m of Sea Level Rise (Existing Conditions).

Tulare Beach

Tulare Beach is a low-lying community of approximately 54 residences backed by a hillside and relatively unstable bluff. Thirty-seven (37) septic systems are mapped in the neighborhood, but 54 are assumed to exist. A portion of the shoreline in this neighborhood is mapped as having a bulkhead or seawall. As sea levels rise, the beach in front of the bulkhead is likely to erode, which may lead to eventual undermining of the wall. Yards and drainfields may be physically eroded if the wall fails. Portions of the shore without armoring are likely to experience shoreline retreat with sea level rise.

Tulare Way is at risk of inundation under existing conditions. This road provides sole access to and egress from the community and is essential for emergency access and evacuation. Flooding first occurs along Tulare Way and nearby lawns and drainfields. Under existing conditions, flooding begins to impact drainfields beginning at a 5-year return period storm. During a 100-year storm under existing conditions, nearly the entire community is flooded, and impacts to septic systems would be expected community-wide (Figure 4). Flooding worsens as sea levels increase. With 0.25 m of sea level rise, the interior drainfields along Tulare Way are flooded during a king tide, and there is major flooding of nearly all parcels at a 5-year event. By 1 m of sea level rise, nearly the entire community is inundated at each king tide. In addition to flooding risk, this community is at high risk of rising groundwater levels with sea level rise. Because most of the homes are located on the low-lying coastal terrace, groundwater levels are likely high and may already be negatively impacting septic drainfield function. This problem will be exacerbated in the future.

SOURCE: Tulalip Tribes 2023

Figure 4. Tulare Beach 100-Year Storm Inundation with 0 m of Sea Level Rise (Existing Conditions).

Tulalip Shores

Tulalip Shores consists of 23 houses at the base of a hillside on Port Susan Bay. There are 6 documented septic systems in the neighborhood, although 23 are assumed to exist. All of the shoreline along Tulalip Shores is mapped as having a bulkhead or seawall. As sea levels rise, the beach in front of the bulkhead is likely to erode, which may lead to eventual undermining of the wall. Yards and drainfields may be physically eroded if the wall fails. Although not subject to flooding until higher sea level rise scenarios, 66th Ave NW is also at risk in the future, and provides sole access to and egress from the homes in Tulalip Shores and is essential for emergency access and evacuation.

Under existing conditions (no sea level rise), CoSMoS data indicates that flooding of drainfields and residences begins at a 20-year return period storm (Figure 5). Approximately half of the parcels in the neighborhood would be affected under this event. With 0.25 m of sea level rise, a number of drainfields would be inundated as frequently as a 5-year return period event, with the majority being affected by a 20-year event. With 1 m of sea level rise, flooding becomes significantly more problematic with most drainfields and residences being inundated multiple times per year at a king tide. Given that many parcels are inundated during a major event under existing conditions, and that by the end of the century, much of the neighborhood could be inundated on an annual basis, this neighborhood is at high risk. Because the neighborhood is low in elevation, there is also a high risk of rising groundwater levels with sea level rise. The neighborhood is low in elevation on a coastal terrace, and thus groundwater levels are likely high and may already be negatively impacting septic drainfield function. This problem will be exacerbated in the future.

SOURCE: Tulalip Tribes 2023

Figure 5. Tulalip Shores 100-Year Storm Inundation with 0 m of Sea Level Rise (Existing Conditions).

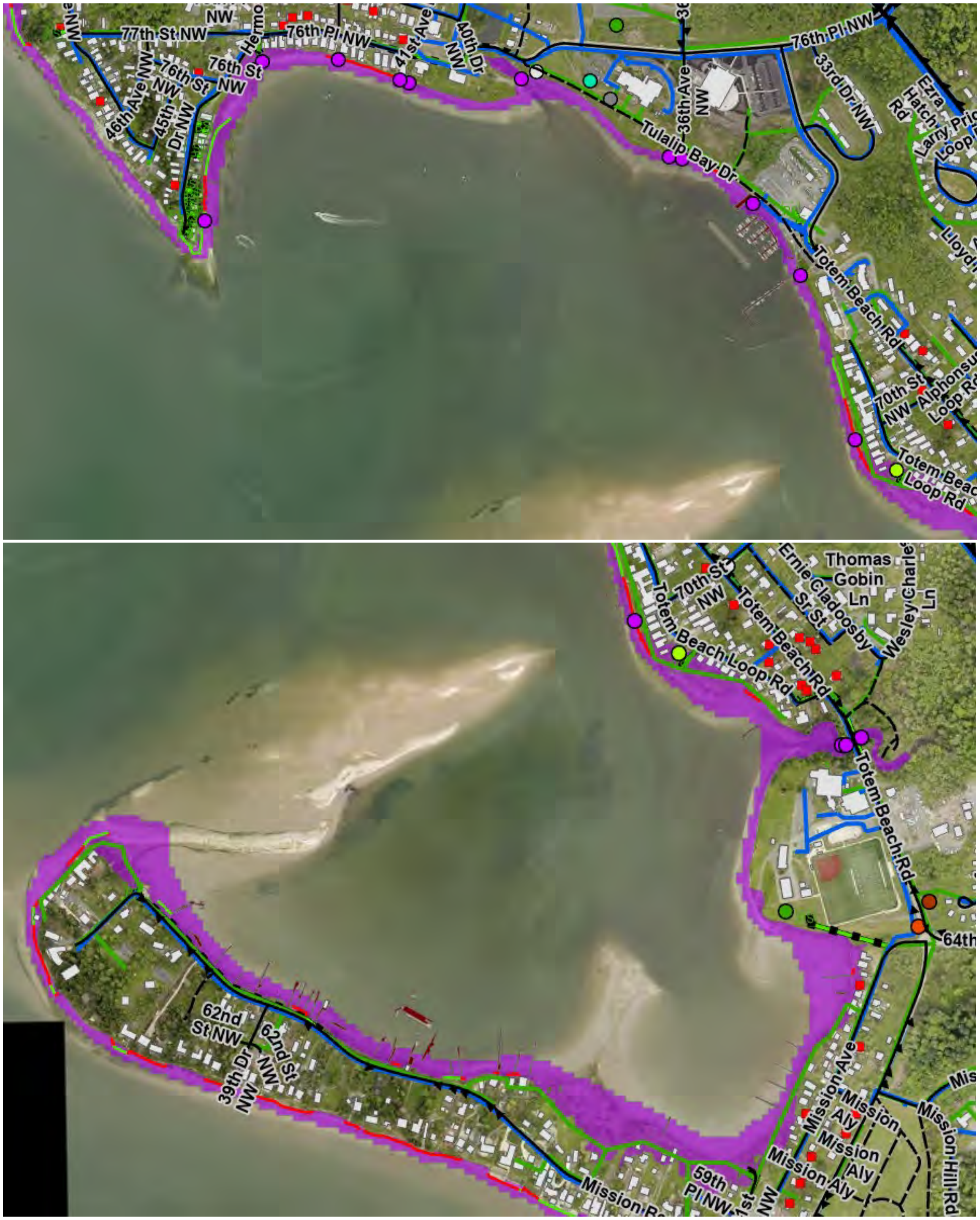
Tulalip Bay

The Tulalip Bay neighborhood (inclusive of Hermosa Point and Mission Beach) consists of ~300 homes that are supported by septic or conventional sewer systems. This neighborhood includes a number of important pieces of shoreline infrastructure including, but not limited to, marine docks and piers, buried sewer and water lines, sewage pumps, stormwater and sewer outfalls, bulkheads and seawalls, roads and bridges, the Tulalip Marina, education and recreation facilities, and Tribal buildings. A portion of the shoreline in this neighborhood is mapped as having a bulkhead or seawall. As sea levels rise, the beach in front of the bulkhead is likely to erode, which may lead to eventual undermining of the wall. Unarmored shoreline will likely experience inland migration as sea levels rise. The area has already experienced erosion, particularly in the Hermosa Point community, which is situated on an unstable bluff. The leases signed with BIA in Hermosa Point include statements that the area is hazardous and leasees are responsible for any damage (Ben Lubbers, Tulalip Tribes Planning Department, personal communication). In the Tulalip Bay neighborhood, the Tulalip Tribes Board of Directors have decided to cancel or allow leases to expire, particularly in areas where there have been requests for the repair or replacement of hard armoring structures (Ben Lubbers and Julia Gold, Tulalip Tribes Planning department, personal communication).

Under existing conditions, a small number of residences (<5) are at risk of inundation during the 100-year return period storm. Marine structures (e.g., marina, docks, boat ramps) may be damaged and/or inaccessible during significant storms under existing conditions. Stormwater and sewer outfalls may also be temporarily ineffective during major storms and could experience localized erosion. With 0.25 m of sea level rise, there is minor increase in overland flooding, although the number of affected residential parcels under a 100-year storm remains relatively low (around 8 residences). Portions of Tulalip Bay Drive and Hermosa Beach Rd NW will experience overtopping under this event. Along Totem Beach Loop Rd and Mission Beach Rd, the gravity sewer system could experience infiltration and inflow of floodwater and groundwater into the line. At least one sewer lift station off of Totem Beach Loop Rd could be affected during the 100-year event.

With 1 m of sea level rise, around 10 residential parcels will be affected by flooding during king tides. Portions of Tulalip Bay Drive and Hermosa Beach Rd NW will experience overtopping under this event. Two sewer lift stations will be inundated at the king tide, along with a portion of the gravity sewer system along Totem Beach Loop Rd and Mission Beach Rd, which could experience infiltration and inflow of floodwater and groundwater into the line. Regular groundwater or surface water inundation of the sewer lines can cause substantial strain on the sewer system. Flooding of the sewer lift stations are of particular concern and a more detailed analysis of those facilities should be conducted. At the 100-year return period event with 1 m of sea level rise, approximately 20 private residences will experience some level of flooding (Figure 6). Four sewer lift stations will be flooded, along with portions of Tulalip Bay Drive and Hermosa Beach Rd NW.

Given the extensive buried water and sewer network in the neighborhood, a more detailed evaluation of groundwater risk with sea level rise should be completed for this area of the reservation. Small levels of groundwater rise could significantly increase infiltration into sewer pipes and may increase wear on water pipes.



SOURCE: Tulalip Tribes 2023

Figure 6. Tulalip Bay/Mission Beach 100-Year Storm Inundation with 1 m of Sea Level Rise.

Sunny Shores

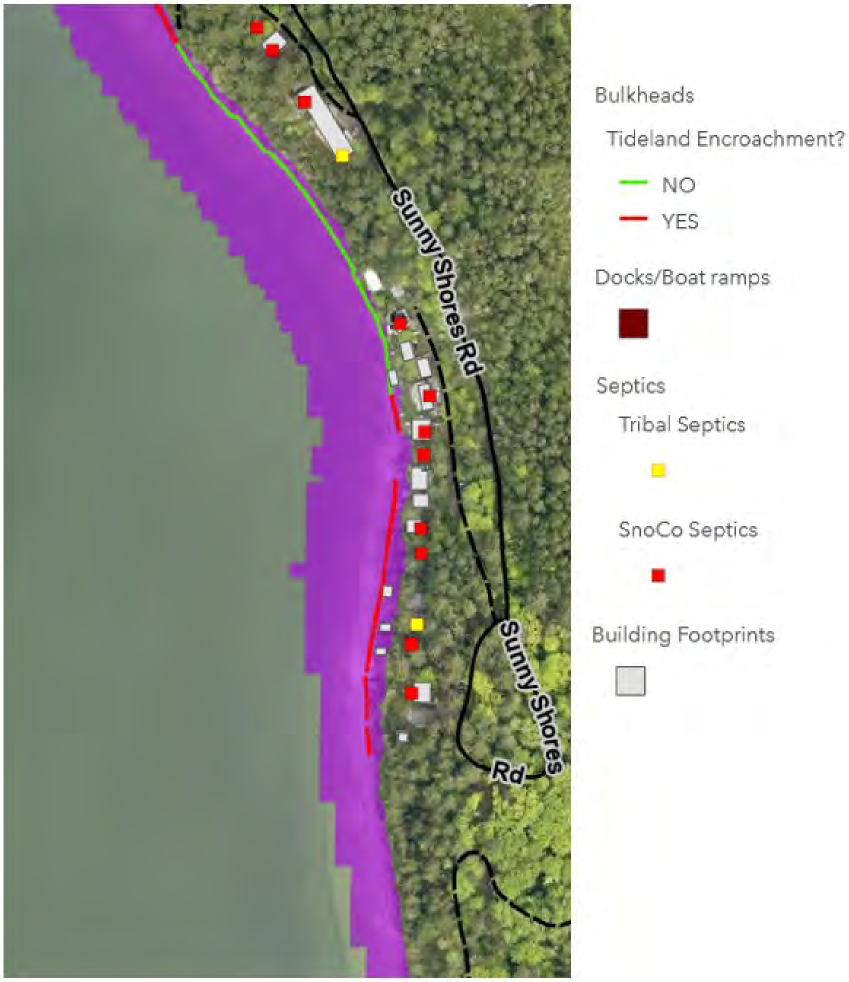
The Sunny Shores neighborhood is mostly undeveloped with 18 homes along a sloping shoreline at the side and base of a steep bluff. There are 9 documented septic systems in this community although 18 are assumed to exist. Most of the shoreline in this neighborhood is mapped as having a bulkhead or seawall. As sea levels rise, the beach in front of the bulkhead is likely to erode, which may lead to eventual undermining of the wall. Yards and drainfields may physically erode if the wall fails. The access road to this community is higher in elevation and therefore relatively unaffected by coastal flooding.

Under existing conditions, no direct inundation of septic systems is predicted even under extreme storm events. With 0.25 m of sea level rise, potential impacts to septic drainfields may occur at a 10-year return period storm, with likely impacts to most parcels occurring at a 100-year event. With 1 m of sea level rise, most septic drainfields will be impacted at a king tide event, multiple times per year.

Relative to other neighborhoods, this community has buildings that are somewhat set back from the shoreline and are located at somewhat higher elevations. There may be slightly reduced risk from groundwater-based problems for septic fields in this community.

Overall, Sunny Shores is at low risk under existing conditions and medium risk with 0.25 m of sea level rise. However, with 1 m of sea level rise, the risk increases significantly such that most parcels are affected on king tides (SOURCE: Tulalip Tribes 2023

Figure 7).



SOURCE: Tulalip Tribes 2023

Figure 7. Sunny Shores 100-Year Storm Inundation with 1 m of Sea Level Rise.

Spee-Bi-Dah

The Spee-Bi-Dah neighborhood is located within a sloping valley fronted by a 1,300 linear feet beach. Approximately 20 residences occupy the valley near the beach, with a number of homes located further up the bluffs to the north and south. Most of the homes on the valley floor are set back from the shoreline, with only 6 residences located within 100 feet of the shore. Seven (7) septic systems are documented within the valley, however 20 are assumed to exist. Most of the shoreline at Spee-Bi-Dah is mapped as having a bulkhead or seawall. As sea levels rise, the beach in front of the bulkhead is likely to erode, which may lead to eventual undermining of the wall. Several buildings south of the valley are located on a steep bluff, which is armored with a bulkhead wall. As sea levels rise, the bulkhead may become undermined and fail. Buildings upslope of the wall may be subject to increased rates of coastal bluff erosion and/or landslides.

Under existing conditions, no residences or septic drainfields are at risk of flooding even under extreme storm events (i.e. no flooding is projected for the 100-year storm). With 0.25 m of sea level rise up to 1 m of sea level rise, no substantial increase in flooding is predicted under all simulated storm events. Minor inundation on 1-3 parcels occurs at the 100-year storm event with 2 m of sea level rise. The 100-year storm inundation with 1 m of sea level rise is shown in SOURCE: Tulalip Tribes 2023

Figure 8.

The CoSMoS data shows that a portion of Park Way NW is also at risk under existing conditions under a 50-year or larger storm. However, this road is a beach access loop and does not service any residences or other critical assets along the shoreline. Because most of the residences and septic systems are located up and away from the shoreline, the risk of septic systems to elevated groundwater levels is relatively low. Overall, septic systems in this community are at low risk under existing and future conditions.

SOURCE: Tulalip Tribes 2023

Figure 8. Spee-Bi-Dah 100-Year Storm Inundation with 1 m of Sea Level Rise.

Adaptation Strategies

Increased coastal flooding and erosion will require communities and shoreline neighborhoods on the Tulalip Reservation to adapt to meet projected future conditions. Adaptation strategies can address actions that focus on protecting existing infrastructure and accommodating higher water levels as well as actions focused on managed retreat and relocation. However, coastal residents may only be able to "live with the water" for so long before moving away from the water becomes necessary. An incremental or phased approach may be best suited for the Tulalip Reservation coastline to buy time with incremental approaches as a full-scale managed retreat and planned relocation effort is put into place.

Remain in place/Live with the water

There are several approaches the Tulalip Tribes can pursue in the near-term related to reducing stress on coastal habitats, homes, and infrastructure. This includes removing hard shoreline armoring (e.g., bulkheads) and replacing with soft shoreline armoring alternatives and retrofitting existing structures to improve resilience in flood-prone areas. The Tribe may elect to pursue a number of strategies to phase out unsustainable shoreline practices (e.g., hard armoring repair and replacement, rebuilding flood-damaged homes in flood zones) while pursuing a long-term managed retreat shoreline strategy.

Hard and soft armoring

Hard shoreline armoring such as bulkheads are designed to hold land in place and prevent erosion caused by wave and tidal energy. While hard shoreline armoring can be effective in protecting the land it contains, the presence of armoring alters hydrologic conditions, resulting in increased rates of erosion on adjacent land and properties. Additionally, hard shoreline armoring prevents natural habitat-forming processes that benefit salmon, forage fish and shellfish. Soft shoreline armoring seeks to provide a similar degree of erosion protection, but in a manner that encourages natural hydrologic and habitat-forming processes. Soft shoreline armoring typically includes the installation of strategically placed large wood and other debris coupled with native plantings and beach nourishment. While soft shoreline armoring can be an effective alternative to hard shoreline armoring in limiting erosion impacts, soft shoreline armoring is less effective in preventing inundation and bulkheads may be the only viable option. The opportunity to install soft shoreline armoring may be limited where buildings are very near the higher-high water line.

Other alternatives to hard shoreline armoring include measures that reduce wave energy as it comes ashore, such as oyster reefs and clam gardens. Both clam gardens and oyster reefs have been shown to abate wave energy, stabilize sediment, and reduce erosion. Additionally, clam gardens and oyster reefs are historic features of shorelines throughout the Pacific Northwest. Like soft shoreline armoring, these measures do not prevent inundation from flood waters.

Another approach to maintaining current infrastructure involves the retrofit of existing structures and facilities to accommodate increased flooding and sea level rise. Many neighborhoods on the Tulalip Reservation have structures, including homes and garages, in close proximity to the shoreline. One potential approach to preserving the function of these structures while mitigating potential flood risk would be to elevate structures. While sea level rise-induced flooding would still occur, the associated damages and risks would be reduced.

Reducing septic pollution

Once OSS are exposed to any type of flooding, it is highly likely that they will experience reduced capacity or failure. Water quality sampling indicates that these systems are already being overwhelmed by heavy rainfall events and septic discharge is entering the nearshore and marine waters of the Tulalip coast. Collaborating with

Snohomish County, the Tribe could pursue an outreach campaign to coastal residents on the importance of septic maintenance, updates, and potential alternative technologies. For example, options exist to retrofit and upgrade septic systems to improve their adaptive capacity against future sea level rise (**Error! Reference source not found.**).

Table 2. Overview of Standard Septic Systems and Non-Traditional Alternatives.

System Name	Description	Benefits	Limitations	Recommended Inspection Frequency	Price Range[1]
Septic Systems					
Standard Gravity System	Consists of a septic tank with two compartments, distribution box and gravity distribution drainfield.	One of the least expensive options. Longer time frame in between inspections.	Slope/gravity required for operation. Lifespan (30-40 years) dependent on regular maintenance and careful use.	Every 3 years	\$5,000–\$7,000
Pressure Distribution System	Similar to standard gravity systems. Consists of a septic tank and a pumping tank.	Protects drainfield from being overused by time dosing, appropriate for areas with difficult topography.	Annual inspection required. Power for alarm system and operation required.	Annually	\$7,000–\$10,000
Sand Filter System	Consists of a septic tank, pumping tank, and sand filter for additional filtration of effluent.	Typically used where higher level of effluent treatment is needed to protect wells, surface water, or shallow ground waters. Work best in areas with high water table.	Annual inspection required. Requires additional space for the sand filter. Power for alarm system and pressure is required.	Annually	\$6,000–\$20,000
Above Ground/ Mound System	Consists of a septic tank, pumping tank, and mound located above ground level (often planted with grass).	Suitable for climates that receive high rainfall and areas with shallow soils. Planted mounds help absorb and filter nutrients.	Annual inspection required. Sand mound needs advance planning and maintenance. Power for alarm system and pressure is required.	Annually	\$10,000–\$20,000
Subsurface Drip System	Consists of a septic tank, pumping tank, and pressurized drip lines below the surface of the ground.	Used for shallow soils and takes up a smaller surface area than other systems.	Power for alarm system and pressure is required. Frequent maintenance required.	Every 6 months	\$4,000–\$25,000
Glendon Biofilter System®	Consists of a septic tank, pump tank, control panel, BioFilter and Surrounding Soil, and reserve	Used in instances of high water table or shallow soil areas. Mound can be landscaped with a	Can only be installed and maintained by persons licensed by Glendon BioFilter Technologies.	Every 6 months	\$12,000–\$18,000

System Name	Description	Benefits	Limitations	Recommended Inspection Frequency	Price Range[1]
	area. Treats effluent by with biofilter and cap sand.	normal soil load after it has compacted and solidified. Can be used in small spaces.	Inspections every 6 months.		
Aerobic Treatment Unit System (ATU)	Uses pumped oxygen to speed up the normal treatment process. May consist of trash trap, ATU, UV disinfection unit, pump tank, and drainfield. For example, Delta WhiteWater.	More efficient at treating effluent as specifically designed to reduce nutrient loading. Suitable for small lots or parcels with high water table.	Requires power and vent for ATU. Inspections every 6 months. Typically requires more frequent maintenance than traditional systems.	Every six months	$13,000–$26,000
Non-Traditional Alternatives					
Proprietary Pretreatment with Pressure Distribution Systems	Includes AdvanTex, BioRobix UV Disinfection, and BioMicrobics FAST®	Higher pretreatment levels to more effectively treat effluent. Does not require much more space.	Proprietary systems, therefore ordering replacement parts and maintenance may need to be done by people certified in the systems.	N/A	Varies
Community OSS	A decentralized wastewater treatment system under common ownership that collects wastewater from multiple buildings.	Shared treatment and drainfield. Typically used in places such as rural subdivisions. Shared maintenance costs between homeowners. Could ease transition to centralized sewer if required in the future.	May be expensive to retrofit existing systems to connect. Requires pipe infrastructure to move wastewater from businesses/homes to community septic system.	N/A	Varies[2]
Converting to centralized wastewater systems	Ties in houses to existing or new sewer lines.	Shifts responsibility of wastewater treatment from homeowners to municipalities.	Expensive. Requires political will. Requires infrastructure to move wastewater from business/homes to centralized systems.	N/A	$$$

[1] Price ranges do not include permitting, installation, or maintenance fees. In general, installations of septic tanks may cost between $2,000 and $15,000 and repairs may cost between $25 and $15,000 (This Old House 2023).
[2] Case study examples from other communities vary widely depending on if the community OSS is planned in advance or considered a retrofit.

SOURCES: EPA 2016; EPA 2022; ESA 2023; Pinkham et al. 2004; Seattle & King County Public Health n.d.; Tacoma-Pierce County Health Department n.d.; Tahja-Syrett 2017; This Old House 2023

Maintaining or updating OSS in place

As rainfall and flooding become more extreme with climate change and sea level rise, coastal homeowners will need to contend with more frequent system issues or failures. There is some guidance available to support homeowners seeking to reside in place in areas that flood (EPA 2005; NEHA 2019; WA DOH n.d.). For example, before the flood, homeowners should maintain and regularly inspect their septic systems (e.g., keep records up to date including system location and condition) and protect the drainfield (e.g., do not park on, pave over, or plant root-intensive vegetation on top of the drainfield). During flood events, homeowners should eliminate all non-essential water use and avoid using the system if the drainfield is covered with water. After flood events, systems should be inspected by a professional and water use should be limited until necessary repairs can be made.

Switching to updated system types (e.g., ATU, mounds) may improve wastewater treatment but may be cost-prohibitive or otherwise unappealing to homeowners. Whether encouraging better maintenance or updates, more stringent regulatory requirements on the operation and maintenance of OSS would likely be needed to ensure they are regularly inspected and function properly.

Offer incentives for improved individual maintenance and/or upgrades to current septic systems: For example, Rhode Island provides loans to homeowners for upgrades to advanced OSS, requires operation and maintenance contracts for those upgrades, and requires documentation in property records so that potential buyers are aware of the maintenance records and needs of the OSS for an individual home (Mihaly 2018). In Washington, the Department of Ecology teams with Craft3, a local Community Development Financial Institution, to provide low-interest rate loans for OSS upgrades.

Connecting to community OSS

Creating community OSS may be an option, particularly for those neighborhoods that already function as small, contained communities (e.g., Spee-bi-Dah). For example, the Beulah Park Plant Wastewater Treatment System on Vashon Island serves residents of the Beulah Park and Cove communities. Wastewater is pumped to the Beulah Park drainfield, which is used as a passive recreation area (Perla 2021; King County n.d.). Each home was equipped with pipes to connect houses to a vacuum chamber, which then connects to a vacuum sewer line, treatment plan, and drain field. Estimates for residents' contributions to the construction of the ~$10 million system were derived by calculating the value added to a home's assessed property value (e.g., ~$35,000), and loans and grants were acquired from the Department of Ecology and King County (Perla 2021).

Explore multiple community OSS options: For example, the Town of Brownville, Maine, developed 12 community septic systems (one large one that serves 60 homes and 11 small ones that serve between 5-15 homes each) in 1989. All 12 systems pump to a community leach field and systems are operated and maintained by the town's Water and Sewer Department. Capital investment for the systems was funded primarily through the state's Clean Water State Revolving Fund and residents all pay into a shared fund (GROWashington-Aroostook n.d.).

Abandoning OSS

Many of the coastal properties and associated OSS will be partially or completely inundated by sea level rise or flooding during coastal storms, prompting homeowners to relocate and septic systems to be abandoned. According to the Washington Administrative Code (WAC 246-272A-0300), individuals permanently abandoning septic tanks and associated infrastructure are required to have all waste removed by a licensed professional, remove or destroy the lids, and fill it with soil or gravel. Given the challenges associated with undocumented

OSS along the shoreline, the Tribe could consider establishing a program for derelict and abandoned OSS in partnership with state agencies.

Managed retreat

Adaptation options focused on infrastructure and nature-based solutions may only prove to be both effective and feasible for so long before managed retreat or planned relocation will be required. These strategies often include elements of multiple approaches that occur in phases to manage social, economic, and technical issues. While the Tribe could opt to wait out coastal residents that will likely abandon their property as coastal properties are inundated and eroded, a proactive approach to planned retreat of infrastructure and people from hazard zones is important. In addition to shoreline management efforts to disincentive building or rebuilding in flood- and erosion-prone areas, land acquisition strategies are important for the Tribe to pursue. These include:

- Buyouts
- Fee to Trust Land Acquisitions
- Conservation Easements
- Land Swaps
- Life-use Reservations
- Defeasible Estates
- Executory Interests
- Sea Level Purchase Option (SLPO)

Descriptions of each of these strategies are below and a comparison of their feasibility, benefits, limitations, and associated financial, legal, and social implications are presented in

Table *3*.

Buyouts

Buyouts involve the purchase of land from existing landowners to prevent future development in order to facilitate conversion to open space or less intensive use. This may include parcel-by-parcel buyouts or acquisitions of entire neighborhoods. Buyouts have historically occurred as part of post-storm or disaster recovery efforts rather than as proactive measures (Spidalieri and Bennett 2020; Atoba et al. 2021). Effective buyout programs should not only consider where structures and people should not be located but also where relocation and future development *should* occur. This may help alleviate some of the social and psychological burdens faced by residents being asked to leave their homes (Siders 2018). Buyouts are often expensive, and given limited resources available to support acquisition efforts, a planned and coordinated approach can help entities focus their efforts and resources on the highest priority properties. In the case of buyouts on the Tulalip Reservation, many factors and opportunities should be considered in addition to erosion and inundation risks, such where a series of acquisitions along a drift cell would restore beach processes. In addition, current federal funding focused on Tribal sovereignty, treaty rights, and nature-based climate solutions make this a unique time to pursue funding for costly buyouts.

Explore partnerships with federal agencies such as the National Oceanic and Atmospheric Administration (NOAA), National Fish and Wildlife Foundation (NFWF), and the Federal Emergency Management Agency (FEMA) to fund buyouts: NOAA's Coastal and Estuarine Land Conservation Program provides funding to support coastal acquisition of project sites included in a state's approved land conservation plan that provide public benefits and ecosystem restoration opportunities (NOAA 2003). NFWF holds a number of competitions that can be used to fund land acquisition in support of habitat conservation efforts.

FEMA's Hazard Mitigation Grant Program (HMGP) provides funding to communities after the issuance of a disaster declaration and, in some instances, for the acquisition of properties at risk of similar damages from future events. This approach is limited in that it requires the occurrence of a disaster of a magnitude that warrants a disaster declaration in order for funding to be made available. The HMGP allows for the acquisition of land, but the use of acquired land is restricted to open space, recreational uses, or wetland restoration in perpetuity (FEMA 2021). FEMA's Building Resilient Infrastructure and Communities (BRIC) program provides funds to support capacity and partnership building projects related to floods, extreme heat, wildfires, and more natural disasters.

Fee to Trust Land Acquisition

The Bureau of Indian Affairs (BIA) administers the Fee to Trust Land Acquisition program, which is used to transfer a land title to the U.S. government to be held in trust for the benefit of an individual Tribe or Tribal member. The program allows for land to be taken into trust to support historic preservation, economic development, Tribal well-being, and conservation purposes. Eligible Tribes or Tribal members provide information in a written application to the BIA for consideration. The program has been used to acquire over one million acres of land since 1934. In December 2022, the BIA initiated a proposed rulemaking process to expedite the processing of applications with less expense incurred to applicants (BIA 2022). This program could be useful for the Tulalip Tribes in acquiring parcels that become available through abandonment, or by ensuring long-term protections for land acquired by the Tribe through purchases or other agreements.

Example in Practice: In 2000, the Cher-Ae Heights Indian Community of the Trinidad Rancheria purchased 10 acres of coastal land in Trinidad, CA. In 2021, the Tribe applied to acquire the land in trust for the benefit of the Tribe. Concurrently, the Tribe granted an easement on the property to the City of Trinidad to allow public access to a pier on the property. After the Fee to Trust process was completed, the Tribe was sued by a local kayak business owner over concerns that "subjecting the property to federal trust status" would prevent public access to the pier. In February 2022, the U.S. Supreme Court declined to hear the case, upholding lower court rulings and stating that Tribal land acquisitions through the Fee to Trust program advance Congressional goals related to Tribal self-sufficiency and economic development (Waraich 2022).

Conservation Easements

Conservation easements allow for the donation or purchase of portions of land with the intention of preserving habitat, open space, and cultural and historic values. Landowners are typically either paid or given a tax incentive benefit for the donation (Siders 2013). The property remains in private ownership but the landowner agrees to limit development in accordance with the terms of the easement (e.g., prohibit shoreline armoring, vegetation removal). Easements are typically cost-effective as they do not require purchasing an entire parcel. Conservation easements may help ease the transition of coastal habitats most vulnerable to sea level rise and storm inundation.

Land Swaps

Land swaps are typically in-kind exchanges of plots of land between two or more property owners within a community (e.g., residents, businesses, governments, nonprofits). These exchanges have been used to acquire inland/upland areas to facilitate wetland migration and moving affordable housing out of flood prone areas to higher ground (Spidalieri and Bennett 2020; Spidalieri et al. 2020). Land swaps may be difficult to implement as they typically involve complex real estate transactions (particularly with existing mortgages or debts), but they can help governments save money on buyouts, and help residents relocate.

Example in Practice: In Edgemere, a small neighborhood in Queens, New York, a land swap was used to facilitate the exchange of property titles between the City of New York and private property owners in Edgemere. The resident would get the title to a city-owned property located out of the flood zone and the city would convert the resident's former property to open space (Spidalieri et al. 2020). The Quileute Tribe and the Hoh Tribe have both participated in land swaps with the National Park Service to move out of the flood zone on the Olympic Peninsula.

Life-use Reservations

Life-use reservations (or life estates) allow landowners to sell their property to a particular entity while still maintaining the right to occupy existing residences (Gross 2019). These agreements typically have a specific number of years associated with them or last for the remainder of the landowner's life. This approach would allow the Tulalip Tribes to acquire land while still allowing current owners to use the land for a certain amount of time, or until their death.

Example in Practice: Norfolk, Virginia, enacted an updated zoning ordinance that allows certain residents to remain in place with property rights terminating upon their death (City of Norfolk 2018). The Rachel Carson National Wildlife Refuge in Maine also follows this approach for acquisition of properties of interest for expansion. The Refuge contacts property owners of these lands and if the owners express interest in selling, a real estate appraiser determines the market value of the parcel. Landowners can sell the land in fee simple or sell the land but retain the right to occupy an existing residence through a life-use reservation. This can apply to the remainder of the landowner's life or for a certain number of years, after which the property reverts to the Refuge. Under this approach, the Refuge discounts the appraised value of any buildings and land value for life use, based on the age of the property owner and terms of the life-use reservation (USFWS 2007).

Defeasible Estates

A defeasible estate is a land management tool that transfers ownership of a particular parcel when specified conditions occur. For example, coastal landowners could own their land until sea levels rise a certain amount, at which point ownership of the land would transfer to the Tulalip Tribes. In this example scenario, the landowner owns a defeasible estate while the Tulalip Tribes own a future interest. This can be a useful approach for coastal protection; in a situation without a defeasible estate, a landowner would eventually need to implement shoreline protection actions (e.g., building a bulkhead) to protect their property once sea levels reach a certain point. By using a defeasible estate option, the moment at which a landowner would need to construct sea level rise protection would be the same moment the defeasible estate would initiate and the Tulalip Tribes would take over the property. Additionally, this scenario removes all incentive by the landowner to build shoreline protection infrastructure as the land ownership will eventually transfer to the Tribe (Titus 2011).

Defeasible estates can also be structured so that ownership reverts if a certain action is taken by the landowner, referred to as power of termination. For example, if a landowner constructs shoreline protection infrastructure, the owner of the future interest could go to court and demand ownership of the land. This approach has historically been more challenging to defend in the courts.

A defeasible estate approach grants time to current landowners to assist with planning and eventual relocation. Sea level rise is relatively predictable so the reversion of the land will not come as a surprise and the current owner will have time to plan and prepare. This approach minimizes harm to existing property owners, helps set expectations, and still achieves the desired acquisition and coastal protection outcomes. One potential limitation of this approach is that it is more commonly used during the initial sale of a property by a developer or similar entity.

Executory Interests

Under executory interests, a current landowner can sell or donate future interests in a property to a land trust or governmental entity (Titus 2011). This approach is somewhat related to a defeasible estate; however, it does not need to occur at the original sale of the land. Following this approach, a current landowner could enter into an agreement with the Tulalip Tribes to sell their property when a certain condition is realized (e.g., sea levels reaching a certain extent or depth). Given the existing land ownership conditions at the sites in question, this approach may be more suitable for the Tulalip Tribes.

Sea Level Purchase Option

A Sea Level Purchase Option (SLPO) is a real estate option that does not vest until sea level rise materially affects a given property (Henderson 2018). This is a similar approach to a defeasible estate and would involve a land trust or other organization purchasing a SLPO on a coastal property. When sea level rise begins to impact the property, the SLPO would vest and allow the land trust or other entity to purchase the land for a previously agreed-to price. This approach requires minimal resources until the SLPO is exercised. Additionally, it provides financial compensation to the landowners when the SLPO is purchased and when the property is purchased. Because landowners will receive the SLPO purchase payment regardless of whether or not the actual SLPO is ever exercised, high SLPO purchase prices can generate greater participation. Additionally, the SLPO purchase price can be credited towards the actual purchase of the property when the SLPO is exercised. Given the uncertain timing of when sea levels would reach an identified level, the land purchase price in the SLPO is generally set at some percentage of the property's market value at the time the SLPO is exercised. This can lower the price for the purchasing organization as the market value of the property will likely decrease as coastal flooding and erosion become a feature of the property (Henderson 2018). One potential challenge is that the purchasing organization needs sufficient funding for both the SLPO purchase and the purchase of the property. Additionally, because the SLPO is not framed around a specific date, but rather a condition (sea levels), potential legal challenges exist.

Table 3. Overview and Comparison of Land Acquisition Strategies.

Strategy	Summary	Feasibility	Benefits	Limitations	Financial Implications	Legal Implications	Social Implications
Buyouts	Direct purchase of land from owner.	Difficult	Immediate ownership of property upon completion of sale.	Expensive and requires landowner cooperation.	Requires upfront investment, challenging to coordinate grants with landowner timelines.	Straightforward, clear approach for acquisition. Limited legal obstacles and challenges.	Necessitates cooperation from landowners. Most effective when multiple landowners are onboard.
Fee to Trust Land Acquisitions	BIA program that places lands into trust held by the U.S. government for a Tribe.	Moderate	Permanent protection of acquired land and resources.	Application process through BIA. Unsure of acceptance rate.	Unclear if funding is provided through the program, requires acquisition outside of the program.	Was recently held-up by the U.S. Supreme Court against a legal challenge. Well established program/practice.	Requires acquisition and associated agreement from landowners before the program can be implemented.
Conservation Easements	Voluntary donation or purchase of portion of land for conservation purposes.	Easy to Moderate	Development is limited/restricted including activities that could exacerbate coastal vulnerability.	Only include portions of land.	Typically more cost-effective for purchaser. Landowners either paid or given tax benefit.	Typically permanent and binding to future landowners.	Voluntary landowner participation. Landowner can continue to use property.
Land Swaps	In-kind exchanges of land between property owners in a community.	Moderate to Difficult	Used to acquire inland/upland land for benefit of habitat and people.	May be difficult to implement given real estate transactions.	Can help save money on buyouts. Help resettle residents within communities and maintain tax base.	N/A	Reduced uncertainty for residents about the location of new residence.
Life-Use Reservations	Sale of a parcel while allowing landowner to occupy existing residences for a limited time.	Moderate to Difficult	Balances resource protection goals while providing landowners time and flexibility.	Benefits are not immediately realized and can take substantial amounts of time.	Requires upfront investment and a non-traditional valuation approach to discount structures.	N/A	Necessitates landowner cooperation, but provides landowners with time to remain on property.

Strategy	Summary	Feasibility	Benefits	Limitations	Financial Implications	Legal Implications	Social Implications
Defeasible Estates	Transfer of land ownership at the occurrence of a particular event. Conditions can be wide ranging.	Difficult	For sea level rise, would grant ownership to the Tulalip Tribes once a certain sea level is observed. Prevents bulkhead construction, achieves conservation purpose.	Requires landowner cooperation, and more useful during initial sale of properties by a developer or similar organization.	Requires investment to purchase future interest, and eventually purchase the land.	Legally challenging. Courts are more agreeable to situations where land reverts when certain conditions are met (sea level rise) as opposed to specific actions being taken (bulkhead construction)	Requires landowner cooperation. Provides landowners with time to coordinate and plan for transfer of property.
Executory Interests	A current landowner sells or donates a future interest in their property to another entity. Conditions can be wide ranging.	Difficult	Same as Defeasible Estates. Able to be done using current landowners, as opposed to at the first sale of a parcel by a developer.	Requires landowner cooperation and agreement on conditions.	Same as Defeasible Estates.	Same as Defeasible Estates.	Same as Defeasible Estates.
Sea Level Purchase Option (SLPO)	Purchase of a SLPO by an organization that would vest when sea levels rise to a specific level and allow the entity to purchase land for an agreed to price.	Difficult	Landowners receive a payment at the signing of the agreement, and when the property is sold. Incentivizes participation.	Purchasing organization needs funding for initial fee to landowner, and eventual sale of property. Timing is unspecific, given sea level rise rates.	Price is agreed to at signing of agreement. Typically a percentage of market rate, given that by the time the sale occurs, the value will have decreased because of flooding/erosion.	Given that the time of the SLPO execution is not specific and relies on sea level rise rates, legal challenges may arise in some jurisdictions.	Requires landowner coordination, but landowners receive payments at two times which incentivizes participation.

Putting adaptation strategies into practice

The concept of managed retreat can be controversial and lead to polarized opinions before any planning efforts are even discussed or considered. Accordingly, it can be challenging to know when to first discuss the concept and how to present it to community members. However, it is recommended that managed retreat options be considered at the same time as other more traditional and/or near-term adaptation and management options such as hard and soft armoring are presented to communities.

Near-term actions

- Collect more specific information about non-Tribal people living along the Tulalip coast and how they are using the property (e.g., primary residence or vacation/rental property). Additional research in the form of a door-to-door survey or in-person community meetings is needed to discuss risks and options, identify shared values, and identify potential leverage points based on coastal residents' perspectives.
- Develop key messages to discuss reducing stress on coastal systems and limiting the need for emergency repairs of coastal infrastructure with tailored messaging for primary and secondary homeowners. For example, some key messages that are commonly used in coastal hazards and managed retreat conversations include:
    - Flooding and erosion are already happening and only getting worse. Proactively responding to these coastal hazards is more cost-effective and efficient than waiting for post-recovery funding and response.
    - Flooding and erosion damage and permanently inundate personal property and critical infrastructure such as roads and utilities, restricting access of emergency responders, disrupting food supply chains, and cutting off access to electricity and water.
- Develop an outreach plan for engagement with Tribal staff, County staff, and residents on a phased approach to coastal managed retreat. Consider the following:
    - The vulnerability of individuals, households, and neighborhoods along the coast is influenced by demographics. Residents who live in low-lying flood zones or along eroding bluffs are more at risk from flooding, storms, and coastal erosion than those living further inland and upland. Older individuals and/or those with disabilities may have a harder time moving out of harm's way during flood events, while those with higher incomes may have an easier time affording the costs associated with evacuation, recovery, or relocation to less vulnerable locations.
    - Identify community values and goals. It is important to meet individuals where they are by first identifying their priorities. Link these to managed retreat and other coastal management efforts to demonstrate co-benefits.
    - Present alternatives, including managed retreat. There is no one-size-fits-all approach and different individuals will respond to different priorities and leverage points (e.g., public health and safety risks, protecting habitat for threatened and endangered species, buyouts).
    - Be transparent and consistent. Use clear language without jargon. Be clear about when and where community input will be solicited and how it will be used.
    - Invest in ongoing two-way communication in order to build relationships and trust. Identify trusted neighborhood leaders/property owners to engage when developing an outreach strategy.

- Diversify the means of communications and outreach. Use in-person, print, online, and other mechanisms to match residents' abilities and expectations. Primary messengers/communicators should include a mix of technical experts and others (e.g., those with "people skills," a community/neighborhood leader and fellow property owner).
- Focus on data. Who is at risk and where? What are the costs of staying versus repairing versus relocating?
- Focus on the outcomes of the process. In this way, conversations are focused on protection and reducing the threat of recurring hazards.
- Respect community members as well as their unique cultural and historical sensitivities. For example, the development of the Quinault Indian Nation's Taholah Village Relocation Master Plan was preceded by two years of well-planned and strategic community outreach in order to understand the wants and needs of community members. Tribal staff held several community events and dinners and also went door-to-door to ask additional questions and solicit feedback and comments. This engagement process was used to identify the features of the existing community that were most valued by residents in order to establish goals for the relocation plan.

Near- to long-term actions

- Investigate legal mechanisms and scenarios for pursuing managed retreat. Local governments and authorities typically have the ability to modify land use codes and regulations, however, some jurisdictions may be legally obligated to maintain existing infrastructure, which may limit the ability of a jurisdiction to phase out maintenance and operations of particular infrastructure. One potential approach to maneuver legal obligations related to infrastructure maintenance is through asset relocation and realignment of at-risk infrastructure to less vulnerable locations in order to minimize potential damages and maintenance costs.
- *For highest risk areas (e.g., Priest Point, Tulare Beach, Tulalip Shores):*
    - Implement a targeted outreach strategy designed to facilitate conversations with community members to raise awareness of coastal hazards and near-to-long-term consequences of emergency permits and repairs.
    - Work with partners (e.g., Snohomish County, BIA) to disinvest in high-risk neighborhoods (e.g., implement building/permit moratoriums, create additional steps to reduce pressure for emergency repair and replacement of coastal armoring, and cancel or halt renewal of leases).
    - Replace hard armoring with soft shore techniques and prioritize land acquisition measures. Consider allowing some existing hard armoring to remain in place while investing in soft shore restoration to create a hybrid approach to buy time and create multiple lines of defense while navigating the safe retreat of infrastructure and people.
- *For moderate to high risk areas (e.g., Tulalip Bay/Hermosa Point/Mission Beach):*
    - Address more stringent requirements for OSS inspection and maintenance and/or installation of alternatives.
    - Replace hard armoring with soft shore techniques, including potential offshore oyster reefs and intertidal clam gardens.

    - Avoid development or re-development in flood and erosion hazard zones.
    - Allow currently unarmored shorelines to adjust to rising sea levels.
    - Move critical uses to higher floors (e.g., Tulalip Health Clinic).
    - Maintain Board of Directors’ decision to cancel and/or allow Tulalip Bay leases to expire.
- *For low to moderate risk areas (e.g., Sunny Shores, Spee-Bi-Dah):*
    - Explore options for OSS alternatives, including connecting to sewer or community septic systems.
    - Allow currently unarmored shorelines to adjust to rising sea levels.
    - Install soft shore armoring techniques and remove aging bulkheads where possible. Consider strategic placement of hard armoring where necessary.
    - Consider options such as floodproofing or removal/relocation of infrastructure as they are redeveloped.

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Appendix A. Summary of the Tulalip Tribes Intertidal Monitoring Report (Rabins 2022a)

Part 1: Intertidal Biotic Inventory

Individual biotic species and total weights collected during the 2017-2018 survey are provided in Table 1.2. of the monitoring report. For each of the large bivalve species (not including horse clams), field data was interpolated for both number of individuals and weight per cubic foot over the entire Tulalip Reservation. Purple Varnish Clam (*Nuttallia obscurata*) is the dominant bivalve observed throughout the survey area. *Nuttallia obscurata* is found throughout the reservation with the highest densities north of Tulalip Bay in Tulare and Spee-Bi-Dah (Figure 1.14), which both appear to be "unclassified" shellfish growing and harvest areas (Figure 1.2). Notably both areas are documented feeder bluffs with an upward, right to left moving drift cell and have the presence of an accretion landform. They are low in density in Sunny Shores and Tulalip Bay aside from the spit berm. Butter Clam (*Saxidomus giganteus*) and Cockle (*Clinocardium nuttallii*) are both found almost exclusively directly north of Tulare starting on the tip of the residential development and extending throughout Sunny Shores to the northern survey boundary, which is an approved area for shellfish harvesting. *Saxidomus giganteus* was also dense in accretion zones and areas with no applicable moving drift cells within Tulalip Bay, which is a restricted harvest area. Eastern Softshell (*Mya arenaria*), Macoma (*Macoma inquinata*), Manilla (*Venerupis philippinarum*), and Native Littleneck (*Leukoma staminea*) are all dominant in Tulalip Bay. *Venerupis philippinarum* and *Mya arenaria* are both exclusive to Tulalip Bay. *Venerupis philippinarum* is mainly found on the eastern side of the bay close to accretion landforms and Manilla is spread out more evenly throughout the bay most dominant where there is no drift cell (Figure 1.7 and Figure 1.10). *Macoma* spp. and *Leukoma staminea* were also identified directly north of Tulare in the same zones as *Saxidomus* and *Clinocardium* spp. Areas south of Tulare and Tulalip Bay had low result totals. All area south of Tulalip Bay is a Restricted Harvest Area and north of the bay is Approved or Unclassified (Figure 1.2).

Part 2: Structure from Motion Survey and Coastal Armor Mapping

Researchers used a small helicopter and high resolution DLSR camera shot from an oblique angle to create a digital elevation model (DEM) of the 14-mile Tulalip coastline. In addition to the DEM and orthomosaic exported from this survey, researchers also digitize coastal armoring along the Tulalip Reservation using the 3D model produced through a structure from motion (SFM) software. The goal was to understand where shoreline armoring exists in relation to identified feeder bluffs on the Tulalip Reservation; understand the reduction in sediment supply to surrounding coastal habitats; and assess where local habitat loss may be occurring due to scour at the base of the armoring structures. Presence of shoreline armoring above and below MHW are displayed for each community on the Tulalip Reservation including Priest Point, Mission, Tulalip Bay, Hermosa, Tulalip Shores, Spee-Bi-Dah, Tulare, and Sunny Shores (Table 2.1, Figures 2.2-2.5). Location of current (unarmored) and potential (armored) feeder bluffs are shown in Figure 2.6 while the total length and percentages of armored feeder bluffs in each of the communities are shown in Table 2.2. Locations of active and potential feeder bluffs were obtained from (MacLennan et al. 2013). A total of 4.87 miles (37.6%) of Tulalip coastline is armored (1.25 mi below MHW, 3.63 above MHW) with the highest percentages being along Priest Point, Mission Beach, and Tulalip Bay (Table 2.1). Notable areas include shoreline armoring above MHW in the Tulare area and directly south is a documented “exceptional feeder bluff” with drift cells moving from right to left. Hermosa Point, Mission Beach, and Priest Point are all heavily armored along the shoreline and contain the majority of armoring below MHW (Figure 2.4 and Figure 2.5). These areas are also correlated to where low numbers of bivalves were identified in the intertidal biotic survey (Figures 1.3–1.15).

Part 3: Substrate and Vegetation Mapping

In 2005, the Tulalip Tribes mapped intertidal substrate and vegetation cover habitat metrics as an extension of the mapping effort described in McBride et al. (2006), using substrate and vegetation classes analogous to other regional mapping efforts. In 2017 and 2018, the Tulalip Tribes Shellfish Department repeated this survey using updated methodology and a more detailed classification system from McBride (2015). After initial collection, polygon boundaries were edited based off the SFM orthomosaic collected on July 13th, 2018. Due to improvements in technology and substrate class resolution substrate classes from the 2005 survey were re-classified and explained further in the “Substrate Class Comparison” section to demonstrate the changes more accurately over time. Changes in sediment are more drastic above subtidal elevation (Table 3.7) with all gains and losses doubling and tripling the percent cover below subtidal elevation. Vegetative cover has declined drastically and unvegetated area has increased between 2005-2018 (Table 3.8). Notable is the loss of driftwood along the spit berm and within Tulalip Bay (Figure 3.5). Fines with gravel, mixed coarse and mixed fines have been lost substantially and replaced with larger ‘gravel’ (Figures 3.6–3.9). Mud and organics are declining in Tulalip Bay and sand is increasing likely due erosion and flooding covering up critical biotic habitat throughout the bay (Figure 3.10–3.12). Sand with sand shrimp has primarily decreased in the southern portion where areas are heavily armored and has been gained further offshore in northern sections of the survey area (Figure 3.14). Green and brown algae, salt marsh, and eelgrass species are moving closer to shore indicating a shift in sea level rise and bivalve presence among other factors (Figures 3.15–3.20). The most significant eelgrass spp. loss is within Tulalip Bay and Priest Point (Figure 3.20) and the spit berm in Tulalip Bay has more than doubled in size.

Part 4: Shellfish Habitat

Researchers used habitat suitability indices to define a geographic range for the habitat of each species using data collected in the 2005-2007 and 2017-2018 surveys and mapped the changes to these ranges between these time steps. A summary of elevation and substrate ranges for each species, as well as a summary of the sources used to define these ranges are presented in Tables 4.1–4.3. All habitat suitability indices presented are constructed using the substrate classification system described in McBride et al. (2006). Elevation is increasing along much of the Tulalip coastline (Figure 4.1), particularly in areas where drift cells are moving right to left against armored structuring. Periodic high energy waves and erosional events can mobilize and deposit sediment into the intertidal zone (Johannessen and MacLennan 2007), potentially changing its composition and suitability as shellfish habitat causing an abrupt shift. This is causing low, mid, and high intertidal habitat inhabitants to shift toward the coastline and low to sub level inhabitants are decreasing overall and shifting further off the coastline (Figure 4.2–4.7). Almost all eelgrass species present in 2005 have been lost (Figure 4.8 and Figure 4.9). Juvenile Dungeness crab (*Cancer magister*) indicators have condensed landward along much of the coast and have significantly increased in the location of heavy accretion and a spit berm within Tulalip Bay (Figure 4.15).

Appendix B. Summary of Tulalip Sea Level Rise Infrastructure Response Options Report (Rabins 2022b)

This report documents all possible sea level rise response options for all coastal infrastructure on the Tulalip Tribes Reservation. The response options are displayed by parcel and represent all possible options with no determination of which option is most suitable.

Sunny Shores – Sunny Shores is a moderately armored coastline with eelgrass present in the intertidal zone, is part of a feeder bluff with drift cells moving right to left (Coastal Atlas Map 2022) and has low infrastructure present in "danger zones," with the densest infrastructure danger present from parcel 00590400001900_00000-000_L000 to 00590400000401_00000-000_L000 (Figure 12). Inundation and flood damage risk to infrastructure are low in the northern section of the coastline and there is lower erosion danger potential and higher inundation potential south of parcel 00590400001900_00000-000_ where infrastructure is denser (Figure 12). Best applicable response options include elevating, floodproofing or protecting critical building systems along the southern portion of Sunny Shores where infrastructure is densely present in the 'Periodic Building Flood Danger zone' (Figure 7) and leaving coastal armoring present or replacing with large wood placement and periodic beach nourishment considering the site is part of a feeder bluff (Coastal Atlas Map 2022). Considering there is higher erosion potential in the northern section and no coastal armoring, erosion control response methods include installing large wood, re-slope/re-vegetation or periodic beach nourishment (Figure 4) as well as the restoration or placement of artificial oyster reefs offshore as well as intertidal terraced clam gardens. Prior studies on oyster reefs have shown that these structures have the ability to abate wave energy by altering water flow patterns while trapping and stabilizing sediment. As a result, areas up shore of these reefs can experience lower wave energy and reduced erosion (Meyer et al. 1997; Peyre et al. 2015). These are more natural control methods that would benefit the coastline while providing infrastructure protection where needed.

Tulare - Infrastructure along the Tulare coastline is exclusively found in the northern section where it is heavily armored along this development patch. There is little to no erosion danger to this infrastructure, however there is very high inundation potential throughout the northern section and high periodic flood danger between parcels 00600900300002_00000-000_L000 and 00600900100402_00000-000_L000 at the northern tip and parcel 30040700401900_00000-000_L000 at the southern tip of this development (Figure 12). Considering this section is already protected by armor, applicable response options for this section include replacing hard armor with bulkhead or increasing the size of the bulkhead. Demolishing this infrastructure does not seem like an option. No action seems to be necessary south of parcel 30040700401900_00000-000_L000 considering it is unarmored and little to no infrastructure is present or in danger, however erosion potential is high due to sea level rise (Figure 12).

Spee-Bi-Dah – Infrastructure present is condensed in the north central section of the coastline (Figure 11). A majority of this infrastructure is located in erosion danger zones and is currently armored (Parcel 00582600099900_00000-000_L000_N and parcel 00582600099900_00000-000_L000_S; Figure 4). Response actions include replacing hard armoring with bulkhead or installing mixed large wood, re-slope/re-vegetation, or periodic beach nourishment. A more natural approach could be beneficial since this location is on a feeder bluff with eelgrass present in the intertidal zone (Coastal Atlas Map 2022).

Parcel 00582600099900_00000-000_L000_C is unarmored with very low infrastructure aside from some roads and an electric feature on the northern periodic flood zone boundary (Figure 11). This section is in high period flood risk due to sea level rise and has roads in an inundation risk zone as well (Figure 11). The best action may to demolish or move this infrastructure and take no other action (Figure 5 and Figure 6). No action is needed along other sections of Spee-Bi-Dah considering it is part of a feeder bluff and has no other development at risk outside of this specific area mentioned (Figure 11).

Tulalip Shores – A majority of Tulalip Shores infrastructure is threatened by inundation risk due to sea level rise (Figure 11). These features are located between parcel 00384500000700_00000-000_L000 and 00384500009900_00000-000_L000 and is currently armored. Appropriate repose options may include removing armoring and installing bulkhead (Figure 4) or removing the infrastructure where possible in this area. This area is part of a transport zone with a feeder bluff located just south of the armoring and drift cells moving left to right (Coastal Atlas Map 2022). Other infrastructure is present in the "erosion danger zone" (Parcels 00384500000600_00000-000_L000, 00384500000700_00000-000_L000, 00384500004400_00000-000_L000, 00384500009900_00000-000_L000, 00384500004203_00000-000_L000; Figure 11). Depending on the status of these structures, demolishment or relocation could be most beneficial; otherwise no action is immediately necessary.

Hermosa – Hermosa Point is densely populated along its southern portion of coastline where a majority of its infrastructure is threatened by erosion (Figure 11). The entire section of this coastline is a feeder bluff with draft cells moving right to left. Sections where roads are present in the "erosion danger zone" are armored, while the southern tip where the majority of this infrastructure is threatened is not armored. Response options include keeping armoring in the northern section where it currently is to protect erosion as well as buildings located in periodic flood and inundation danger zones (Figure 11) and adding armoring or bulkhead or beach nourishment to the southern section where infrastructure is also being threatened by erosion. No other risks are present in the southern section. –

Tulalip Bay – Tulalip Bay is situated in a low elevation making it vulnerable to inundation due to sea level rise (Coastal Atlas Map 2022); however, all infrastructure is present in the "erosion danger zone" (Figure 10) with a majority of it being unarmored (Figure 4). The armored sections also correlate with where inundation and periodic flood risk are present (Figures 4–6). Appropriate response options include replacing hard armor with bulkhead in these sections or no action and installing either bulkhead or mixed large wood in sections not currently protected. In areas where no infrastructure is threatened, installment of oyster reefs and intertidal clam gardens could be beneficial to protect intertidal organisms against inevitable erosion. Tulalip Marina (parcel 30042700100200_00000-000_L001_C) section of shoreline is heavily armored with a rock wall revetment and additional offshore breakwater. While this parcel portion is shown to contain infrastructure in danger of erosion, inundation, and periodic flooding, in reality the present coastal armoring may be sufficient to guard against these dangers.

Mission Beach – This coastline's infrastructure is dominated by homes with some sewage and water lines present on the southern end (Figure 10). This shoreline is heavily armored where infrastructure is present and would be best left intact to control erosion (Figure 4 and Figure 10). Noted in the report: Parcel: 30043500200300_T1030-000_L000: Large parcel just south of Mission Beach Heights Rd: "The only infrastructure present within this parcel is at the very northern end where a road is located within the erosion danger zone. In reality this area is largely void of infrastructure and any of the response options would only need to be applied to the extreme northern end of this parcel. For the majority of the parcel, no action is needed" (Rabbins 2022b). Response items for the very southern portion of Mission Beach include placement of large wood, beach nourishment or re-slope/re-vegetation to control erosion since it currently is not armored (Figure 4).

White Rock – No action needed as long as armoring is functioning properly.

Priest Point – A majority of this shoreline is armored along the northern section appropriately correlating to where infrastructure is present in "erosion danger zones" (Figure 4). No action seems to be necessary in this section. The very southeastern border of the Tulalip coastline is in a low elevation spot and is vulnerable to inundation due to sea level rise (parcel 00548000300101_00000-000_L000 to 00548100302700_00000-000_L000; Figure 5). Since this section is currently armored, replacing existing armoring with bulkhead or expanding the bulkhead size would be the most appropriate response action (Figure 5).

References

Washington State Department of Ecology 'Coastal Atlas Map' 2022. Available: https://apps.ecology.wa.gov/coastalatlas/tools/Map.aspx

Appendix C

Tulalip Reservation Shoreline Septic System Assessment

Prepared by Environmental Science Associates, Seattle, Washington
for Tulalip Tribes
June 30, 2023

Introduction

Sea level rise and coastal storm inundation is likely to flood onsite septic systems, increasing the risk of their failure and exacerbating existing pollution problems. High fecal coliform and E. coli levels have been detected in neighborhoods along the Tulalip Reservation coast that rely on septic systems for sewage treatment, which presents a health issue for humans and fish and wildlife species. For example, the Tulalip Tribes estimate that coastal septic system discharge is one of the main limiting factors to safe shellfish harvest along the coast. Septic system oversight (permitting and management) has gaps with uncertainty about specific locations of septic systems and their condition.

The 16-mile long shoreline of the Tulalip Reservation is under mixed jurisdiction by the Tribe and Snohomish County for land-use, enforcement, and sewage treatment. Non-tribal fee landowners go to Snohomish County for land development and septic permits. Tribal members, other Natives and Lessees go to Tulalip Tribes for development and septic permits. Indian Health Service (IHS) will install septic systems for qualified tribal members. This situation creates regulatory gaps which have been evident in the evaluation of septic systems, particularly along the shorelines. There are several densely populated shoreline neighborhoods (e.g., Sunny Shores, Tulare, Spee-Bi-Dah, Tulalip Shores, and Priest Point), where small parcels are owned by nontribal people and these houses are served by onsite septic systems. A review of available County documents regarding on-site septic systems in these shoreline communities showed that very little information is available on sewage treatment in these neighborhoods.

ESA conducted an evaluation of five coastal neighborhoods to determine the relative vulnerability of their septic systems to sea level rise and coastal storm inundation. The summary concludes with a discussion of potential individual and community-based options for management and treatment options in a changing climate.

Evaluation Methods

ESA reviewed modeling outputs from the Coastal Storm Modeling System (CoSMoS) developed by the United States Geological Survey (USGS) for the Tulalip Tribes. The CoSMoS model simulates coastal inundation caused by extreme high tidal water levels under various sea level rise (SLR) scenarios. The model outputs cover the mainland shoreline from the Snohomish River Estuary north to the Stillaguamish River Estuary. ESA's review of the CoSMoS data focused on five densely populated shoreline neighborhoods identified by the Tulalip Tribes project team that are served by onsite septic systems: Sunny Shores, Tulare Beach, Spee-Bi-Dah, Tulalip Shores, and Priest Point. ESA reviewed and interpreted the CoSMoS data and how the flooding outputs relate to septic system vulnerability, as well as general coastal hazard vulnerability in the identified neighborhoods. No additional modeling, mapping, or calculations were performed. Rather, ESA assessed relative coastal hazards based on simulated inundation, neighborhood topography, shoreline assets, and neighborhood demographics. For this assessment, it is assumed that parcels without sewer service have septic systems.

The University of Washington Climate Impacts Group (UW CIG) developed local projections for SLR along Washington's shorelines, including the effect of vertical land movement (Miller et al. 2018). Along the Tulalip coast, UW CIG estimates there is a 50% likelihood that at least 0.2 m (0.7 ft) of SLR will occur by 2050, and that there is a 50% likelihood that 0.67 m (2.2 ft) of rise will occur by 2100. These estimates assume a high greenhouse gas emissions scenario (RCP 8.5). There is a low probability (1% chance) that SLR will reach much higher levels of up to 0.45 m (1.5 ft) by 2050 and 1.5 m (5 ft) by 2100. Higher rates of SLR are theoretically possible as well. Under a low emissions scenario (RCP 4.5), the 50% likelihood estimates at 2050 and 2100 are 0.2 m (0.7 ft) and 0.5 m (1.7 ft), respectively.

For the purposes of this study, the 10% likelihood estimates was considered when assessing future conditions. The Washington Coastal Resilience Network recommends using the 0.1% to 17% likelihood estimates when evaluating hazards to residential properties. The 10% likelihood estimate was chosen for this project as it is within in the middle of the 0.1 to 17% range:

- 0.33 m (1.1 ft) of SLR by 2050
- 1 m (3.3 ft) of SLR by 2100

For consistency with the CoSMoS mapping, the 0.25 m (0.82 ft) and the 1 m (3.3 ft) scenarios were selected to represent 2050 and 2100, respectively.

Impacts on On-Site Sewage Systems

A primary assumption for this evaluation is that inundation from coastal storms will cause negative impacts to shoreline septic systems and drainfields, collectively known as on-site sewage systems (OSS) (Hoghooghi et al. 2021; Miami-Dade County 2018; Mihaly 2018). These flood events may leach saltwater into the system that will upset the chemical properties and biological communities that are essential to treating sewage (Cooper et al. 2016; Habel et al. 2020; Vorhees et al. 2022). Infrequent saltwater contact can corrode pipes and other metallic components inside septic tanks. Inundation is also likely to spread untreated pathogens from drainfields and tanks into the nearshore. Older septic systems may have fractures in pipe and tank components that make the system more vulnerable to chemical/biological damage from saltwater leaching and more likely to release pathogens. For systems located closest to the shoreline, there is increased risk of physical damage to tanks, appurtenances, and drainfields (Hoghooghi et al. 2021; Mihaly 2018). Direct wave action can physically erode drainfields and/or affect soil composition within the drainfields that can exacerbate future erosion. Waves can launch debris such as driftwood and gravel that can damage inspection pipes, access points, and other aboveground septic appurtenances. Access covers and lids may be washed away by waves and inundation, further subjecting the tank to chemical and biological damage. Older systems are likely to be more vulnerable to physical damage.

As inundation becomes more frequent and inundation depths increase with SLR, the expected impact to septic systems increases. While septic systems and drainfields may be able to withstand infrequent flooding associated with rare and extreme storm events such as the 100-year coastal flood, as flooding increases, the physical, chemical, and biological stress on these systems increases. The degree of exposure at which an individual septic system can no longer reliably function is highly variable (e.g., will a system continue to be functional if it floods once every 5 years? Once a year?; Galbraith et al. 2007; Hoghooghi et al. 2021; Mihaly 2018). However, by the time that a septic system is inundated multiple times per year (e.g., during king tides), it is highly likely that it will no longer effectively function.

Furthermore, as sea levels rise, the brackish coastal groundwater also rises (Miller et al. 2018; Mihaly 2018). In low-lying neighborhoods within the coastal floodplain, depth to groundwater can be very shallow. Minor increases in groundwater levels can dramatically affect the physical, chemical, and biological functioning of septic tanks and drainfields (Cooper et al. 2016). The effect of rising groundwater may be more harmful to septic systems than periodic overland inundation. However, groundwater modeling with SLR is complex and requires extensive data collection. For the purposes of this analysis, neighborhoods with low-lying topography were simply assumed to have an increased risk from elevated groundwater levels.

Neighborhood Evaluations

The five neighborhoods served by septic systems were ranked in order of risk relative to one another other for the purposes of planning prioritization. Rankings considered existing risk, future risk with 0.25 m and 1 m of SLR, groundwater levels, and the type and quantity of nearshore infrastructure. Table 1 presents the rankings focused on septic system risk.

Table 1. Septic system documentation and coastal hazard ranking by neighborhoods served by septic systems.

Neighborhood	Est. Number of Residences[12]	Est. Number of Septic Systems	Existing Conditions Coastal Hazard[13]	Mid- to Late-Century Coastal Hazard Coastal	Hazard Ranking
Priest Point	47	14 documented 47 assumed	High	Extreme	1
1Tulare Beach	54	37 documented 54 assumed	Medium	High to Extreme	2
Tulalip Shores	23	6 documented 23 assumed	Medium	High	3
Sunny Shores	18	9 documented 18 assumed	Low	Medium to High	4
Spee-Bi-Dah	20	7 documented 29 assumed	Low	Low	4

[12] A complete parcel inventory was not conducted. Multiple parcels may be owned by the same property owner, which impacts the total count, particularly for Priest Point.

[13] Hazards were evaluated on a relative basis in comparison to other neighborhoods rather than against an absolute metric.

Priest Point

The Priest Point neighborhood is located on a low sandy spit enclosing a tidal wetland. Priest Point Dr NE provides access to approximately 47 residences along the shore and 25 interior parcels (a number of these parcels are owned by the landowner on the shoreline side).

There are 14 documented septic systems, although at least 47 are assumed to exist.

A tide gate located at the northeast entrance to the tidal wetland is intended to prevent water from entering the wetland at high tides. However, the dike and tide gate are reported to occasionally overtop at extreme high water levels, allowing floodwaters into the site interior. It is likely that the CoSMoS model does not simulate the effect of the tide gate on water levels in the wetland. However, since overtopping of the tide gate and dike is already reported under existing conditions, it can be assumed that the gate will not have a significant effect in blocking floodwaters in the future.

This neighborhood is already at elevated risk of coastal flooding under existing conditions. Most of the septic drainfields begin to flood during a king tide, and under a 5-year return period event, most parcels are inundated (Figure 1). With 0.25 m of SLR, normal tidal inundation begins to affect several septic drainfields on the seaward side of Priest Point Dr NE and most drainfields on the interior side. The entire neighborhood is inundated during a king tide with 0.25 m of SLR. With 0.25 m of SLR, this neighborhood is elevated to the extreme risk category, which may occur as soon as 2050.

The neighborhood likely has an extremely high groundwater table, especially considering the presence of the tidal wetland on the interior of the neighborhood. These groundwater elevations will increase with SLR.

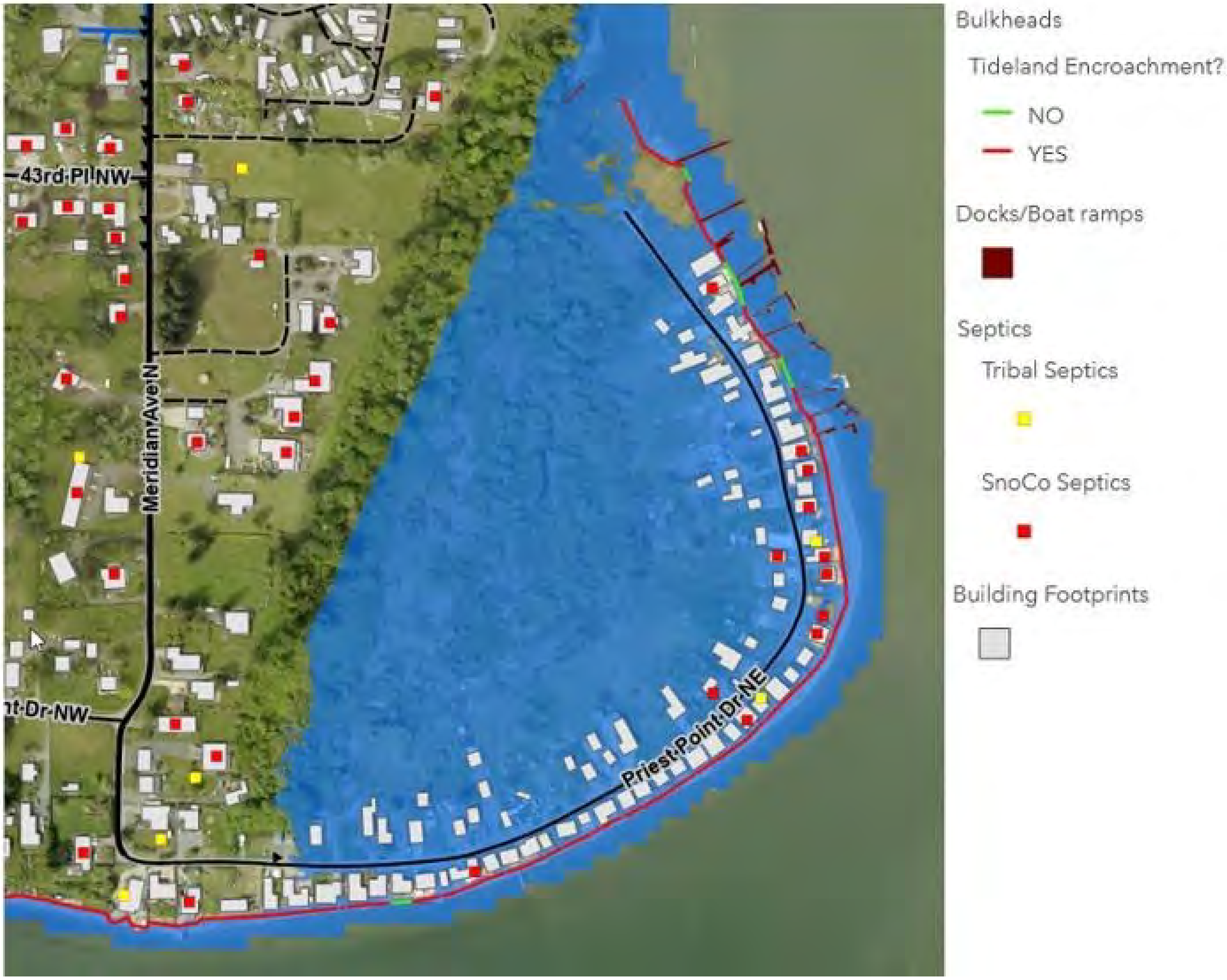

Figure 1 Priest Point5-Year Storm Inundation with 0m of SLR (Existing Conditions). Flood extents shown in blue.

Other Infrastructure The shoreline of Priest Point is heavily developed with numerous houses on small parcels, piers, and boat ramps. All of the shoreline along Priest Point is mapped as having a bulkhead or seawall. As sea levels rise, the beach in front of the bulkhead is likely to erode, which may lead to eventual undermining of the wall. Yards and drainfields may be physically eroded if the wall fails.

Priest Point Dr NE is also at high risk of flooding under existing conditions. This road provides sole access to and egress from the neighborhood and is essential for emergency access and evacuation. The tide gate and associated dike at the northeast end of the wetland is reported to fail under extreme events. The dike and/or gate is likely in poor condition, and may experience complete failure under extreme storms and higher sea levels.

Tulare Beach

Tulare Beach is a low-lying community of approximately 54 residences backed by a hillside and relatively unstable bluff (Herrera 2010).

Thirty-seven (37) septic systems are mapped in the neighborhood, but 54 are assumed to exist. Flooding first occurs along Tulare Way and nearby lawns and drainfields. Under existing conditions, flooding begins to impact drainfields beginning at a 5-year return period storm. During a 100-year storm under existing conditions, nearly the entire community is flooded, and impacts to septic systems would be expected community- wide (Figure 2). Flooding worsens as sea levels increase. With 0.25 m of SLR, the interior drainfields along Tulare Way are flooded during a king tide, and there is major flooding of nearly all parcels at a 5-year event. By 1 m of SLR, nearly the entire community is inundated at each king tide. In addition to flooding risk, this community is at high risk of rising groundwater levels with SLR. Because most of the homes are located on the low-lying coastal terrace, groundwater levels are likely high and may already be negatively impacting septic drainfield function. This problem will be exacerbated in the future.

Figure 2. Tulare Beach100-Year Storm Inundation with 0m of SLR (Existing Conditions). Flood extents shown in purple.

Other Infrastructure A portion of the shoreline in this neighborhood is mapped as having a bulkhead or seawall. As sea levels rise, the beach in front of the bulkhead is likely to erode, which may lead to eventual undermining of the wall. Yards and drainfields may be physically eroded if the wall fails. Portions of the shore without armoring are likely to experience shoreline retreat with SLR. Tulare Way is at risk of inundation under existing conditions. This road provides sole access to and egress from the community and is essential for emergency access and evacuation.

Figure 3. Tulalip Shores 100-Year Storm Inundation with 0m of SLR (Existing Conditions). Tulalip Shores consists of 23 houses at the base of a hillside on Port Susan Bay. Flood extents shown in purple.

There are 6 documented septic systems in the neighborhood, although 23 are assumed to exist.

Under existing conditions (no SLR), CoSMoS data indicates that flooding of drainfields and residences begins at a 20-year return period storm (Figure 3). Approximately half of the parcels in the neighborhood would be affected under this event. With 0.25 m of SLR, a number of drainfields would be inundation as frequently as a 5- year return period event, with the majority being affected by a 20-year event. With 1 m of SLR, flooding becomes significantly more problematic with most drainfields and residences being inundated multiple times per year at a king tide. Given that many parcels are inundated during a major event under existing conditions, and that by the end of the century, much of the neighborhood could be inundated on an annual basis, this neighborhood is at high risk.

Because the neighborhood is low in elevation, there is also a high risk of rising groundwater levels with SLR. The neighborhood is low in elevation on a coastal terrace, and thus groundwater levels are likely high and may already be negatively impacting septic drainfield function. This problem will be exacerbated in the future.

Other Infrastructure All of the shoreline along Tulalip Shores is mapped as having a bulkhead or seawall. As sea levels rise, the beach in front of the bulkhead is likely to erode, which may lead to eventual undermining of the wall. Yards and drainfields may be physically eroded if the wall fails. Although not subject to flooding until higher SLR scenarios, 66th Ave NW is also at risk in the future, and provides sole access to and egress from the homes in Tulalip Shores and is essential for emergency access and evacuation.

Sunny Shores

The Sunny Shores neighborhood is mostly undeveloped with 18 homes along a sloping shoreline.

There are 9 documented septic systems in this community although 18 are assumed to exist.

Under existing conditions, no direct inundation of septic systems is predicted even under extreme storm events. With 0.25 m of SLR, potential impacts to septic drainfields may occur at a 10-year return period storm, with likely impacts to most parcels occurring at a 100-year event. With 1 m of SLR, most septic drainfields will be impacted at a king tide event, multiple times per year.

Relative to other neighborhoods, this community has buildings which are somewhat set back from the shoreline and are located at somewhat higher elevations. There may be slightly reduced risk from groundwater-based problems for septic fields in this community.

Overall, Sunny Shores is at low risk under existing conditions and medium risk with 0.25 m of SLR. However, with 1 m of SLR the risk increases significantly such that most parcels are affected on king tides (Figure 4).

Other Infrastructure Most of the shoreline in this neighborhood is mapped as having a bulkhead or seawall. As sea levels rise, the beach in front of the bulkhead is likely to erode, which may lead to eventual undermining of the wall. Yards and drainfields may physically erode if the wall fails. The access road to this community is higher in elevation and is relatively unaffected by coastal flooding.

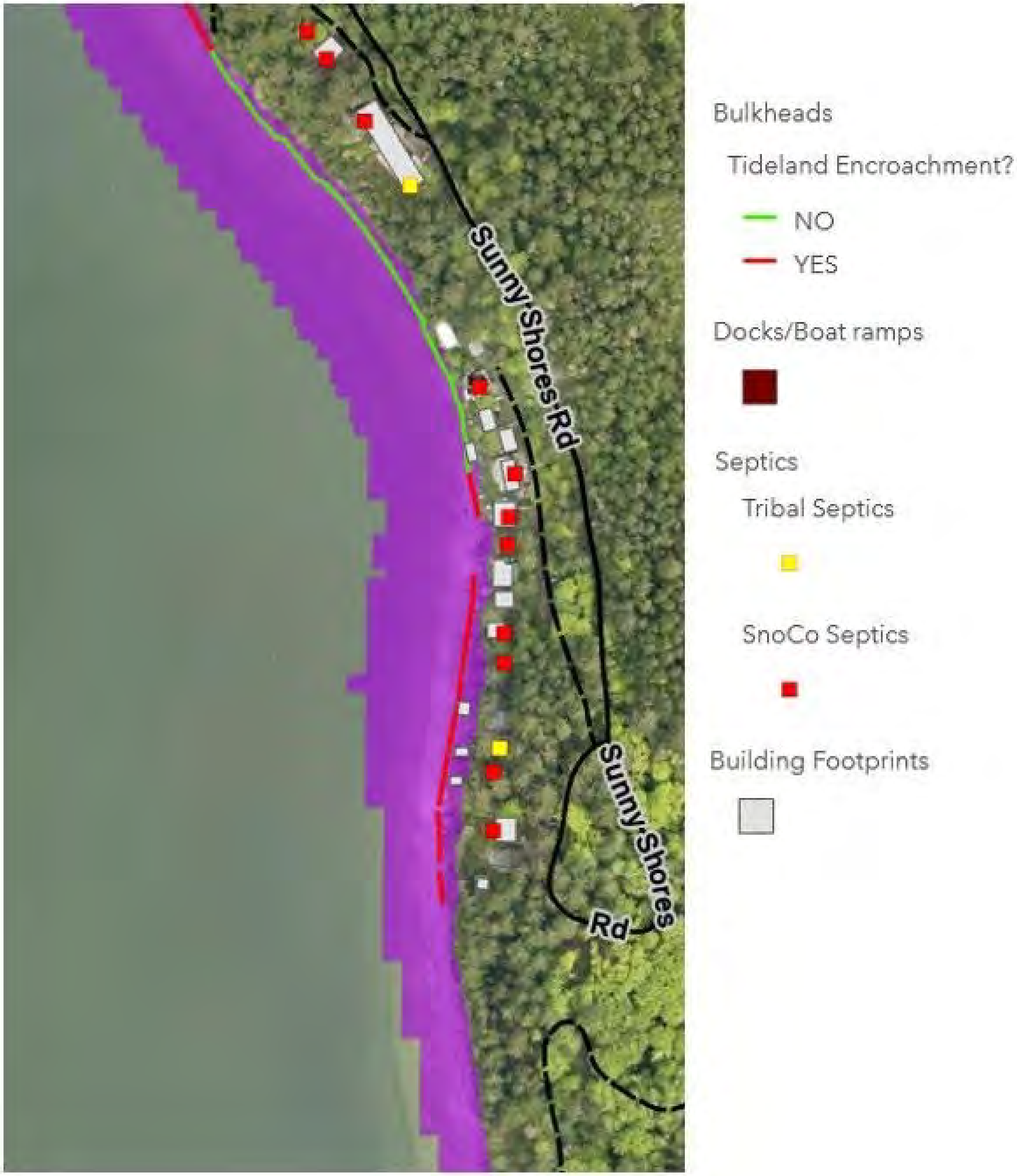

Figure 4. Sunny Shores100-Year Storm Inundation with 1m of SLR. Flood extents shown in purple

Spee-Bi-Dah

The Spee-Bi-Dah neighborhood is located within a sloping valley fronted by 1,300 linear feet beach. Approximately 20 residences occupy the valley near the beach, with a number of homes located further up the bluffs to the north and south. Most of the homes on the valley floor are set back from the shoreline, with only 6 residences located within 100 feet of the shore.

Seven (7) septic systems are documented within the valley, however, 20 are assumed to exist. Under existing conditions, no residences or septic drainfields are at risk of flooding even under extreme storm events (i.e. no flooding is projected for the 100-year storm). With 0.25 m of SLR up to 1 m of SLR, no substantial increase in flooding is predicted under all simulated storm events. Minor inundation on 1-3 parcels occurs at the 100-year storm event with 2 m of SLR. The 100-year storm inundation with 1 m of SLR is shown in Figure 5.

Figure 5. Spee-Bi-Dah100-Year Storm Inundation with 1m of SLR. Flood extents shown in purple

Because most of the residences and septic systems are located up and away from the shoreline, the risk of septic systems to elevated groundwater levels is relatively low. Overall, septic systems in this community are at low risk under existing and future conditions.

Other Infrastructure Most of the shoreline at Spee-Bi-Dah is mapped as having a bulkhead or seawall. As sea levels rise, the beach in front of the bulkhead is likely to erode, which may lead to eventual undermining of the wall. Several buildings south of the valley are located on a steep bluff, which is armored with a bulkhead wall. As sea levels rise, the bulkhead may become undermined and fail. Buildings upslope of the wall may be subject to increased rates of coastal bluff erosion and/or landslides. The CoSMoS data shows that a portion of Park Way NW is also at risk under existing conditions under a 50-year or larger storm. However, this road is a beach access loop and does not service any residences or other critical assets along the shoreline.

Tulalip Bay

The Tulalip Bay neighborhood consists of ~300 homes that are supported by septic or conventional sewer systems. This neighborhood is more developed than the other communities evaluated, and includes a number of important pieces of shoreline infrastructure including, but not limited to, marine docks and piers, buried sewer and water lines, sewage pumps, stormwater and sewer outfalls, bulkheads and seawalls, roads and bridges, marinas, education and recreation facilities, and government buildings. Under existing conditions, a small number of residences (<5) are at risk of inundation during the 100-year return period storm. Marine structures (marina, private docks, boat ramps, etc.) may be damaged and/or inaccessible during significant storms under existing conditions. Stormwater and sewer outfalls may also be temporarily ineffective during major storms and could experience localized erosion.

With 0.25 m of SLR, there is minor increase in overland flooding, although the number of affected residential parcels under a 100-year storm remains relatively low (around 8 residences). Portions of Tulalip Bay Drive and Hermosa Beach Rd NW will experience overtopping under this event. Along Totem Beach Loop Rd and Mission Beach Rd, the gravity sewer system could experience infiltration and inflow of floodwater and groundwater into the line. At least one sewer lift station off of Totem Beach Loop Rd could be affected during the 100-year event.

With 1 m of SLR, around 10 residential parcels will be affected by flooding during a king tide. Portions of Tulalip Bay Drive and Hermosa Beach Rd NW will experience overtopping under this event. Two sewer lift stations will be inundated at the king tide, along with a portion of the gravity sewer system along Totem Beach Loop Rd and Mission Beach Rd, which could experience infiltration and inflow of floodwater and groundwater into the line. Regular groundwater or surface water inundation of the sewer lines can cause substantial strain on the sewer system. Flooding of the sewer lift stations are of particular concern and a more detailed analysis of those facilities should be conducted. At the 100-year return period event with 1 m of SLR, approximately 20 private residences will experience some level of flooding (Figure 6). Four sewer lift stations will be flooded, along with portions of Tulalip Bay Drive and Hermosa Beach Rd NW.

A portion of the shoreline in this neighborhood is mapped as having a bulkhead or seawall. As sea levels rise, the beach in front of the bulkhead is likely to erode, which may lead to eventual undermining of the wall. Unarmored shoreline will likely experience inland migration as sea levels rise.

Given the extensive buried water and sewer network in the neighborhood, a more detailed evaluation of groundwater risk with SLR should be completed. Small levels of groundwater rise could significantly increase infiltration into sewer pipes and may increase wear on water pipes.

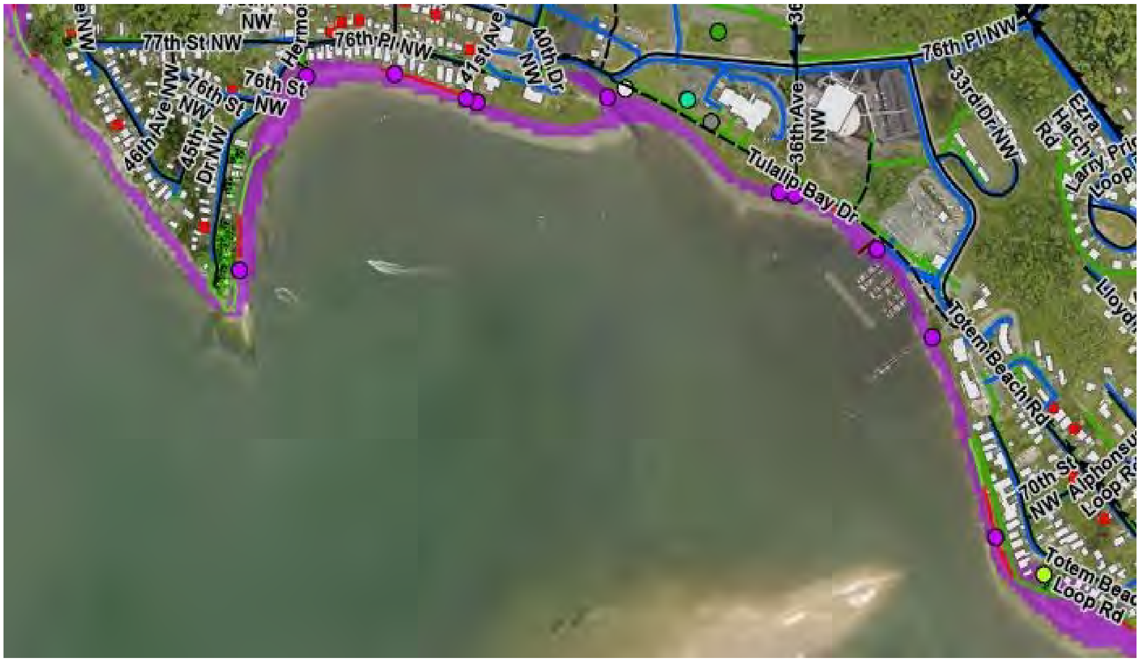

Figure 6A. Tulalip Bay100-Year Storm Inundation with 1m of SLR. Flood extents shown in purple.

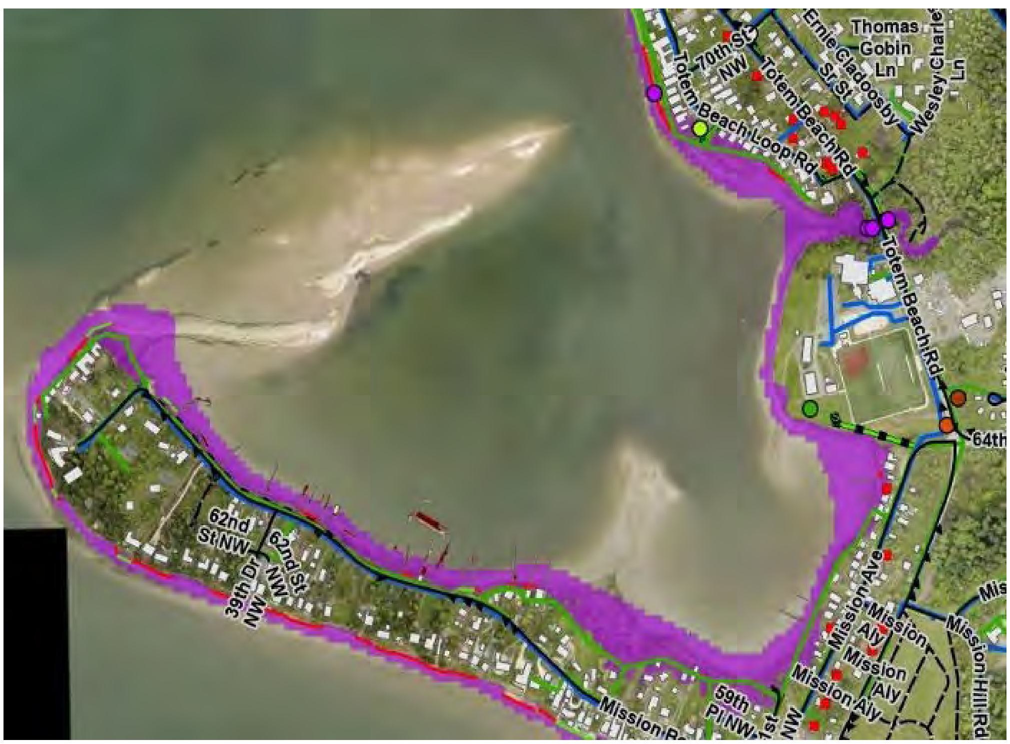

Figure 6B. Tulalip Bay100-Year Storm Inundation with 1m of SLR. Flood extents shown in purple.

Table 2. Coastal hazard ranking by neighborhood – Tulalip Bay.

Neighborhood	Est. Number of Residences[14]	Est. Number of Septic Systems	Existing Conditions Coastal Hazard[15]	Mid- to Late-Century Hazard	Coastal Hazard Ranking
Priest Point	72	14 documented 72 assumed	High	Extreme	1
Tulare Beach	54	37 documented 54 assumed	Medium	High to extreme	2
Tulalip Shores	23	6 documented 23 assumed	Medium	High	3
Tulalip Bay	300	N/A	Low to medium	High	4
Sunny Shores	18	9 documented 18 assumed	Low	Medium to high	5
Spee-Bi-Dah	20	7 documented 20 assumed	Low	Low	6

Management and Treatment Options

Once OSS are exposed to any type of flooding, it is highly likely that they will experience reduced capacity or failure. Water quality sampling indicates that these systems are already being overwhelmed by heavy rainfall events and septic discharge is entering the nearshore and marine waters of the Tulalip coast. Sea level rise and coastal storm inundation will exacerbate these issues. Table 2 presents various options, ranging from different types of OSS to non-traditional alternatives, along with benefits, limitations, inspection requirements, and price estimates.

Table 3. Overview of standard septic systems and non-traditional alternatives[16].

System Name	Description	Benefits	Limitations	Recommended Inspection Frequency	Price Range[17]
Septic Systems					
Standard Gravity System	Consists of a septic tank with two compartments, distribution box and gravity distribution drainfield.	One of the least expensive options. Longer time frame in between inspections.	Slope/gravity required for operation. Lifespan (30-40 years) dependent on regular maintenance and careful use.	Every 3 years	$5,000–$7,000
Pressure Distribution System	Similar to standard gravity systems. Consists of a septic tank and a pumping tank.	Protects drainfield from being overused by time dosing, appropriate for areas with difficult topography.	Annual inspection required. Power for alarm system and operation required.	Annually	$7,000–$10,000
Sand Filter System	Consists of a septic tank, pumping tank, and sand filter for additional filtration of effluent.	Typically used where higher level of effluent treatment is needed to protect wells, surface water, or shallow ground	Annual inspection required. Requires additional space for the sand filter.	Annually	$6,000–$20,000

14 A complete parcel owner inventory was not conducted. Multiple parcels may be owned by the same property owner, which impacts the total count, particularly for Priest Point.

15 Hazards were evaluated on a relative basis in comparison to other neighborhoods rather than against an absolute metric.

16 SOURCE: EPA 2016; EPA 2022; Pinkham et al. 2004; Seattle & King County Public Health n.d.; Tacoma-Pierce County Health Department n.d.; Tahja-Syrett 2017; This Old House 2023

17 Price ranges do not include permitting, installation, or maintenance fees. In generally, installations of septic tanks may cost between $2,000 and $15,000 and repairs may cost between $25 and $15,000 (This Old House 2023).

		waters. Work best in areas with high water table.	Power for alarm system and pressure is required.		
Above Ground/ Mound System	Consists of a septic tank, pumping tank, and mound located above ground level (often planted with grass).	Suitable for climates that receive high rainfall and areas with shallow soils. Planted mounds help absorb and filter nutrients.	Annual inspection required. Sand mound needs advance planning and maintenance. Power for alarm system and pressure is required.	Annually	\$10,000–\$20,000
Subsurface Drip System	Consists of a septic tank, pumping tank, and pressurized drip lines below the surface of the ground.	Used for shallow soils and takes up a smaller surface area than other systems.	Power for alarm system and pressure is required. Frequent maintenance required.	Every 6 months	\$4,000–\$25,000
Glendon Biofilter System® www.glendon.com	Consists of a septic tank, pump tank, control panel, biofilter and surrounding soil, and reserve area. Treats effluent with a biofilter and sand cap.	Used in instances of high water table or shallow soil areas. Mound can be landscaped with a normal soil load after it has compacted and solidified. Can be used in small spaces.	Can only be installed and maintained by persons licensed by Glendon BioFilter Technologies. Inspections every 6 months.	Every 6 months	\$12,000–\$18,000
Aerobic Treatment Unit System (ATU)	Uses pumped oxygen to speed up the normal treatment process. May consist of trash trap, ATU, UV disinfection unit, pump tank, and drainfield. For example, Delta WhiteWater.	More efficient at treating effluent as specifically designed to reduce nutrient loading. Suitable for small lots or parcels with high water table.	Requires power and vent for ATU. Inspections every 6 months. Typically requires more frequent maintenance than traditional systems.	Every 6 months	\$13,000–\$26,000
Non-Traditional Alternatives					
Proprietary Pretreatment with Pressure Distribution Systems	Includes AdvanTex, BioRobix UV Disinfection, and BioMicrobics FAST®	Higher pretreatment levels to more effectively treat effluent. Does not require much more space.	Proprietary systems, therefore ordering replacement parts and maintenance may need to be done by people certified in the systems.	N/A	Varies
Community OSS	A decentralized wastewater treatment system under common ownership that collects wastewater from multiple buildings.	Shared treatment and drainfield. Typically used in places such as rural subdivisions. Shared maintenance costs between homeowners. Could ease transition to centralized sewer if required in the future.	May be expensive to retrofit existing systems to connect. Requires pipe infrastructure to move wastewater from businesses/homes to community septic system.	N/A	Varies[18]
Converting to centralized wastewater systems	Ties in houses to existing or new sewer lines.	Shifts responsibility of wastewater treatment from homeowners to municipalities.	Expensive. Requires political will. Requires infrastructure to move wastewater from business/homes to centralized systems.	N/A	\$\$\$

Price ranges do not include permitting, installation, or maintenance fees. In generally, installations of septic tanks may cost between \$2,000 and \$15,000 and repairs may cost between \$25 and \$15,000 (This

18 Case study examples from other communities vary widely depending on if the community OSS is planned in advance or considered a retrofit.

Old House 2023). 2Case study examples from other communities vary widely depending on if the community OSS is planned in advance or considered a retrofit.

Maintaining or updating OSS in place

As rainfall and flooding become more extreme with climate change and sea level rise, coastal homeowners will need to contend with more frequent system issues or failures. There is some guidance available to support homeowners seeking to reside in place in areas that flood (EPA 2005; NEHA 2019; WA DOH n.d.). For example:

• Before the Flood

– Keep the OSS up to date on inspections and maintenance. Keep records up to date, including locations and conditions (e.g., age, materials).

– Protect the drainfield (e.g., do not park, pave over, or plant root-intensive vegetation).

• During the Flood

– Eliminate all non-essential water use.

– Do not use the system if the drainfield is covered with water.

• After the Flood

– If the tank is partially flooded or damaged, have it inspected by a trained professional.

– Reduce water use until the system is inspected and repaired.

Switching to updated system types (e.g., ATU, mounds) may also improve wastewater treatment but may be cost- prohibitive or otherwise unappealing to homeowners. Whether encouraging better maintenance or updates, more stringent regulatory requirements on the operation and maintenance of OSS would likely be needed to ensure they are regularly inspected and function properly. For example, Barnstable County (Massachusetts) requires that treatment performance for nitrogen be monitored quarterly and Rhode Island requires that high-risk properties (i.e. those most vulnerable to sea level rise and flooding) use more advanced OSS such as sand filters (Mihaly 2018). Other states and municipalities have begun offering incentives for improved individual maintenance and/or upgrades to current septic systems; for example, Rhode Island provides loans to homeowners for upgrades to advanced OSS, requires operation and maintenance contracts for those upgrades, and requires documentation in property records so that potential buyers are aware of the maintenance records and needs of the OSS for an individual home (Mihaly 2018).

Connecting to community OSS

Creating community OSS may be an option, particularly for those neighborhoods that already function as small, contained communities (e.g., Spee-bi-Dah). For example, the Beulah Park Plant Wastewater Treatment System on Vashon Island serves residents of the Beulah Park and Cove communities. Wastewater is pumped to the Beulah Park drainfield, which is used as a passive recreation area (Perla 2021; King County n.d.). Each home was equipped with pipes to connect houses to a vacuum chamber, which then connects to a vacuum sewer line, treatment plan, and drain field. Estimates for residents' contributions to the construction of the ~$10 million system were derived by calculating the value added to a home's assessed property value (e.g., ~$35,000), and loans and grants were acquired from the Department of Ecology and King County (Perla 2021).

Other communities have implemented networks of septic systems. For example, the Town of Brownville, Maine, developed 12 community septic systems (one large one that serves 60 homes and 11 small ones that serve between 5-15 homes each) in 1989. All 12 systems pump to a community leach field and systems are operated and maintained by the town's Water and Sewer Department. Capital investment for the systems was funded primarily through the state's Clean Water State Revolving Fund and residents all pay into a shared fund (GROWashington-Aroostook n.d.).

Abandoning OSS

Many of the coastal properties and associated OSS will be partially or completely inundated by sea level rise or flooding during coastal storms, prompting homeowners to relocate and septic systems to be abandoned. According to the Washington Administrative Code (WAC 246-272A-0300), individuals permanently abandoning septic tanks and associated infrastructure are required to have all waste removed by a licensed professional, remove or destroy the lids, and fill it with soil or gravel.

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Appendix D

Tulalip Shoreline Water Quality Assessment

The Tulalip Tribes of Washington
Cultural & Natural Resources Department
Environmental Division
6406 Marine Dr.
Tulalip, WA 98271

Executive Summary

Untreated septic discharge from shoreline communities are degrading potential shellfish habitat along the Tulalip shoreline as well as marine water quality in Port Susan. Over the past two years, Tulalip Natural Resource staff have been collecting water samples along the Tulalip shoreline. This project focused on four densely developed residential communities, Tulare, SpeeBiDah, Sunny Shores, and Tulalip Shores, that are served by onsite septic systems and included four reference sites (with no upland development).

Since it is likely that during high tide marine water pushes into the interstitial beach spaces and acts as a dam to prevent freshwater from leaching to the marine environment, the sampling strategy focused on collecting water samples from shallow wells dug into the beach sand at high tide to see if untreated wastewater effluent is being released from the beach communities. The strategy also included concurrent nearshore water sampling. Collected parameters included fecal coliform, E. coli, salinity, and temperature.

Analytical results of the shallow groundwater showed the usual variability of bacterial counts. Two beaches, SpeeBiDah and Tulare, had occurrences of high bacteria throughout all sampling locations, whereas the two other beaches (Sunny Shores and Tulalip Shores) had hot spots of high bacteria in one or two locations. There was a close correlation between fecal coliform and E. coli results, which indicates that most of fecal coliform found was E. coli. The highest counts of bacteria were found at Sunny Shores SS1 site (1200 cfu/100mL/1100 mpn) and Tulalip Shore TS3 site (1800 cfu/100mL).

The four densely populated beach communities showed much higher levels of bacteria in their shallow groundwater as compared to the reference sites. To date, the Snohomish Health District has resisted investigations of the onsite septic systems in these communities by citing a lack of data. Tulalip Tribes Natural Resources Dept. hopes that this evidence will convince the Snohomish Health District to inquire about the location and condition of onsite septic systems in these shoreline communities and start requesting repairs as needed.

Introduction

Tulalip Tribes would like to use their tidelands for bivalve harvest (clam and oyster). Shellfish aquaculture requires clean water above and within the shellfish beds for public health protection. There are several densely developed communities along the sixteen miles of Tulalip shoreline.

These beach communities are served by onsite septic systems that are either old or unknown according to Health District records. For example, initial on-site system record review of the Tulare beach community showed a significant number of unknown onsite systems with no records on file. Sixteen of these systems have no record of an onsite system in Snohomish Health District files. For on-site system for which there are records, the average age of theses onsite septic system is about 47 years old. Neighboring beachfront communities, Tulalip Shores, SpeeBiDah, and Sunny Shores, have similar shoreline conditions, high housing densities served by onsite septic systems that are old or unknown. Record research has not yet been completed for these neighborhoods.

The porous nature of beach sand will allow for silent failures of onsite septic systems because the untreated effluent is unlikely to back up into house. Instead, the deep sand and tidal dynamics hide untreated effluent from damaged or failing septic systems and make it difficult to collect water samples that are not diluted by seawater or are too deep in the sand to collect a sample.

A recently developed sampling strategy has shown some success in evaluating bacterial levels in the interstitial water in beach sands. It appears that during high tide, marine water pushes into the interstitial beach spaces and acts as a dam to prevent freshwater from leaching to the marine environment. Sampling in shallow wells during these conditions can capture the shallow freshwater discharge from surrounding upland.

Sampling Strategy Summary

Bacterial contamination from malfunctioning septic systems can be variable and would correlate with septic system use, tank retention times, and drainfield condition. The intermittent nature of the bacterial sources may become less apparent downgradient of the beach communities, if many onsite systems are failing. This project's sampling strategy should catch cumulative failures of onsite septic systems by collecting samples in shallow wells dug into in the beach sand during high tide conditions. This strategy for assessing the quality of shallow groundwater is particularly relevant for shellfish resources because it is the location of bivalve harvest.

A detailed sampling plan with quality assurance was prepared. Since this project was funded with Tulalip money, no official agency review was required. We followed EPA Quality Assurance Project Plan requirements and sent the sampling plan to Debby Sargeant of WA Dept. of Ecology for review.

Monitoring occurred during high tidal conditions. Past monitoring was at +6 ft to +11 ft. Water samples were collected in front of the four beach communities as well as four reference sites in areas with little to no upland development. The main parameters were fecal coliform and *Escherichia Coli.* Samples were analyzed at an accredited laboratory, AmTest laboratory in Kirkland, WA. See Figure 2 for the locations of the sampling stations for this study.

Overview of Monitoring Results

Analytical results of the shallow groundwater showed the usual variability of bacterial counts. At Tulare, the highest bacterial level occurred in December 2017 (see Table 1 and Figure 1 at the back of the document) and had low levels for the next three sampling locations. Two beaches, SpeeBiDah and Tulare, had occurrences of high bacteria throughout all sampling locations, whereas the two other beaches (Sunny Shores and Tulalip Shores) had hot spots of high bacteria in one or two locations (Table 1 and Figures 1 through 4).

For many locations, there was a close correlation between fecal coliform and E. coli results, which indicates that most of fecal coliform found was E. coli. The highest counts of bacteria were found at Sunny Shores SS1 site (1200 cfu/100mL/1100 mpn) and Tulalip Shore TS3 site (1800 cfu/100mL). Shallow groundwater at the four reference sites ranged from 1.99 cfu/100mL to 36 cfu/100mL for fecal coliform and 1.99 mpn to 18 mpn for E.coli (see Figure 5).

Tulalip Shores and SpeeBiDah had the overall highest levels of bacteria according to the summary statistics (see Table 2, below). Summary statistics by beach shown the median level of bacterial counts, the arithmetic average of all data (mean), and the geometric mean (geomean) of all data. All beaches except for the reference beaches have elevated levels of fecal coliform and E.coli in shallow groundwater as compared with reference beaches.

Figure 2: Map of Sampling Sites and Six Shoreline Neighborhoods on the Tulalip Reservation

Table 2. Summary Statics by Beach

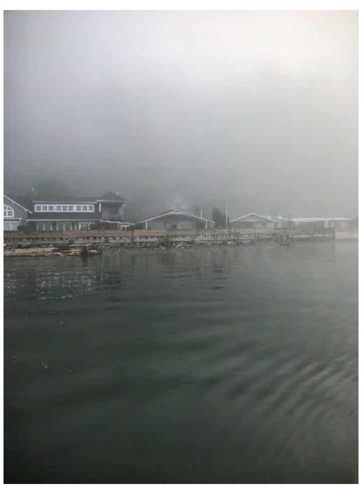
Beach	Data Overview	In Beach Fecal Coliform (cfu/100ml)	In Beach E. Coli Results (MPN)	Ambient Fecal Coliform (cfu/100ml)	Ambient E. Coli Results (MPN)
Tulare	Range	<2 - 700	<2 - 700	<2 - 18	<2 - <10
	Median	10	10	2	2
	Mean	134	134	5	5
	GeoMean	19	18	4	3
SpeeBiDah	Range	6 - 420	4 - 420	<2 - 800	<2 - 710
	Median	74	61	10	10
	Mean	118	114	130	117
	GeoMean	60	52	20	19
Sunny Shores	Range	<2 - 1200	<2 - 1100	<2 - 10	<2 - 10
	Median	7	7	9	7
	Mean	135	98	7	7
	GeoMean	11	9	6	5
Tulalip Shores	Range	<2 - 1800	<2 - 1400	<2 - 380	<2 - 340
	Median	18	80	13	10
	Mean	347	283	74	65
	GeoMean	46	42	24	21
Reference Sites	Range	<2 - 36	<2 - 18	<2 - 84	<2 - 84
	Median	6	4	8	7
	Mean	9	6	16	14
	GeoMean	6	4	8	7

Results and Summary for each Beach Community

Tulare Beach

The highest bacterial levels at Tulare beach were in December 2017. The fecal coliform and E.coli results were the same indicating that the all the fecal coliform were E.coli, which was confirmed by staff at the AmTest laboratory. All subsequent sampling events were in drier conditions with very low bacterial results. It is possible that under drier conditions, there is lower hydraulic pressure from upland areas and the shallow fresh, groundwater goes to a deeper elevation before moving into the marine environment. Another sampling event during or after a period of high rainfall (February or March) would be helpful in determining the usefulness of this conceptual framework.

Figure 2. Picture of Tulare Beach and Location of Sampling Stations



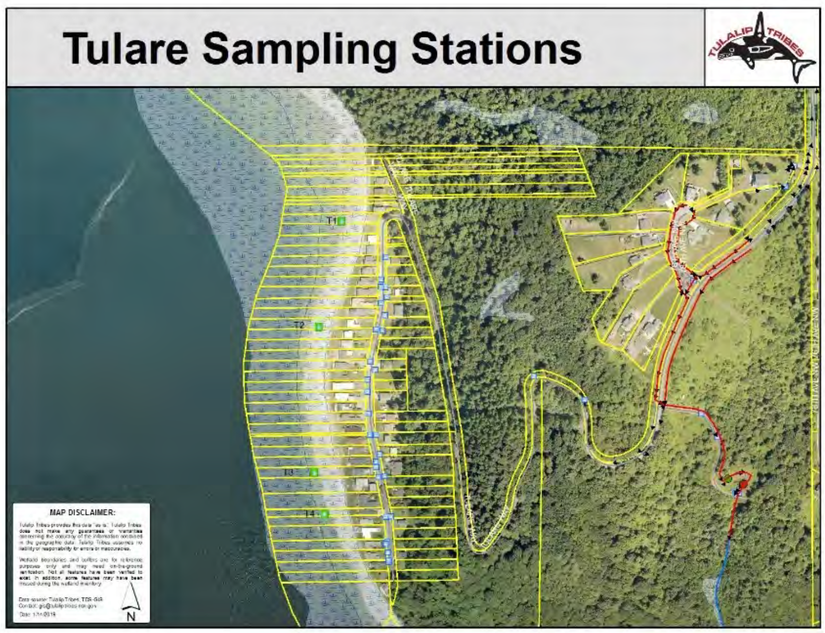


Figure 3. Bacterial Results for Tulare Beach

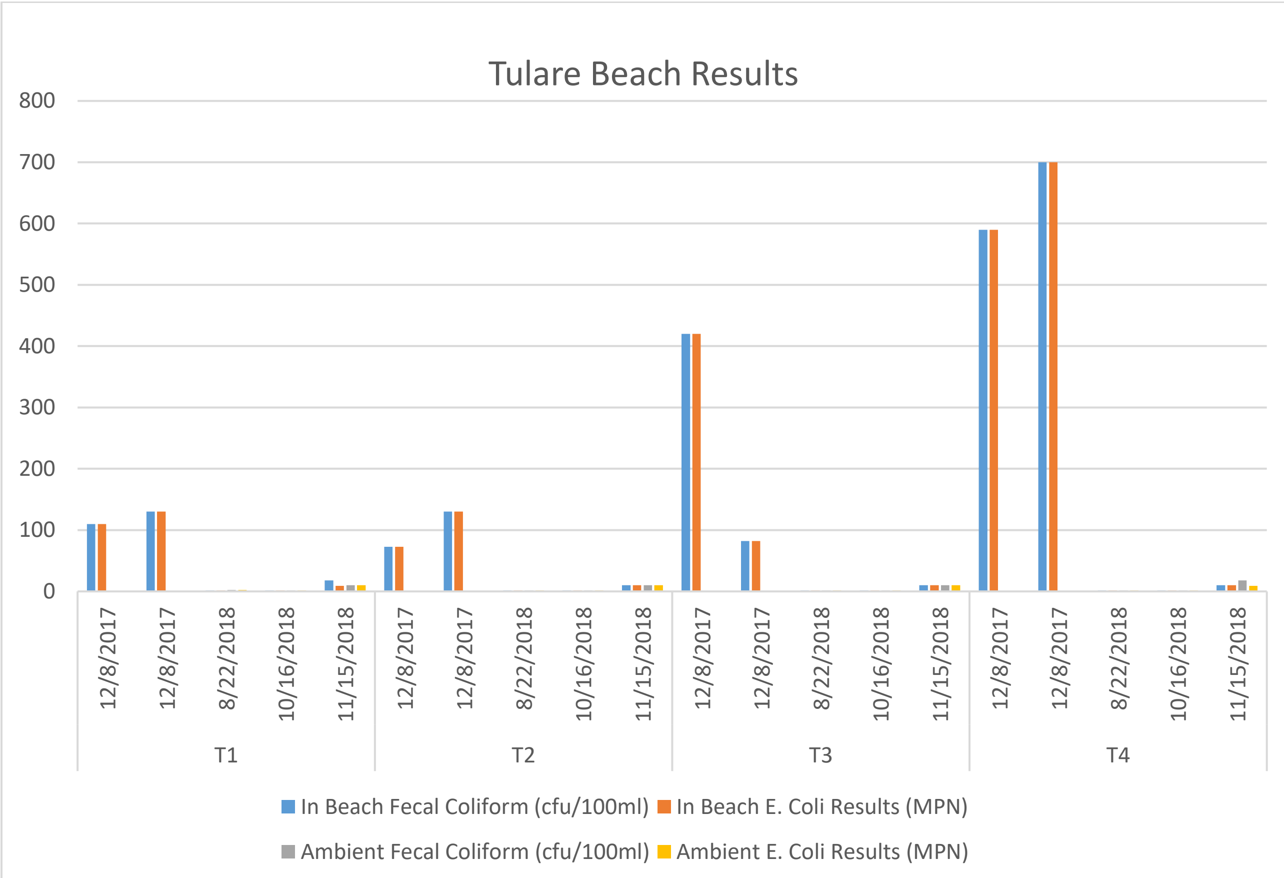


Table 3. Bacterial Results for Tulare Beach

Site Name	Date Sampled	In Beach Fecal Coliform (cfu/100ml)	In Beach E. Coli Results (MPN)	Ambient Fecal Coliform (cfu/100ml)	Ambient E. Coli Results (MPN)
T1	12/8/2017	110	110		
	12/8/2017	130	130		
	8/22/2018	1.99	1.99	2	2
	10/16/2018	1.99	1.99	1.99	1.99
	11/15/2018	18	9	10	9.99
T2	12/8/2017	73	73		
	12/8/2017	130	130		
	8/22/2018	1.99	1.99	1.99	1.99
	10/16/2018	1.99	1.99	1.99	1.99
	11/15/2018	9.99	9.99	9.99	9.99
T3	12/8/2017	420	420		
	12/8/2017	82	82		
	8/22/2018	1.99	1.99	1.99	1.99
	10/16/2018	1.99	1.99	1.99	1.99
	11/15/2018	9.99	9.99	9.99	9.99
T4	12/8/2017	590	590		
	12/8/2017	700	700		
	8/22/2018	1.99	1.99	1.99	1.99
	10/16/2018	1.99	1.99	1.99	1.99
	11/15/2018	9.99	9.99	18	9

SpeeBiDah

SpeeBiDah Beach is problematic because it had consistently high levels of bacteria throughout the beach sand. In comparing the geometric means, the fecal coliform bacterial levels at SpeeBiDah (60 cfu/100mL) are an order of magnitude above what was found at the reference beaches (6 cfu/100mL). This shoreline community has a bowl-like configuration as it is surrounded by higher elevation land, which may funnel stormwater and shallow groundwater towards the beach more efficiently than at other shoreline communities. There is high correlation between fecal coliform and E.coli levels. Failing onsite septic systems are the most likely source of bacterial pollution found in the beach sand. An assessment of the location and condition of the septic systems in this community should be verified or investigated, as it appears to be a significant source of bacteria.

Figure 4. Picture of SpeeBiDah Beach and Location of sampling stations

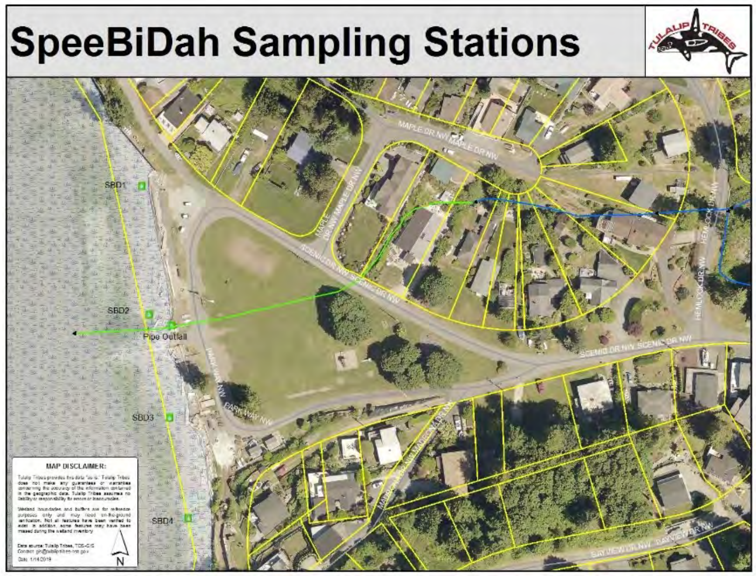


Figure 5. Bacteria Results found at SpeeBiDah Beach

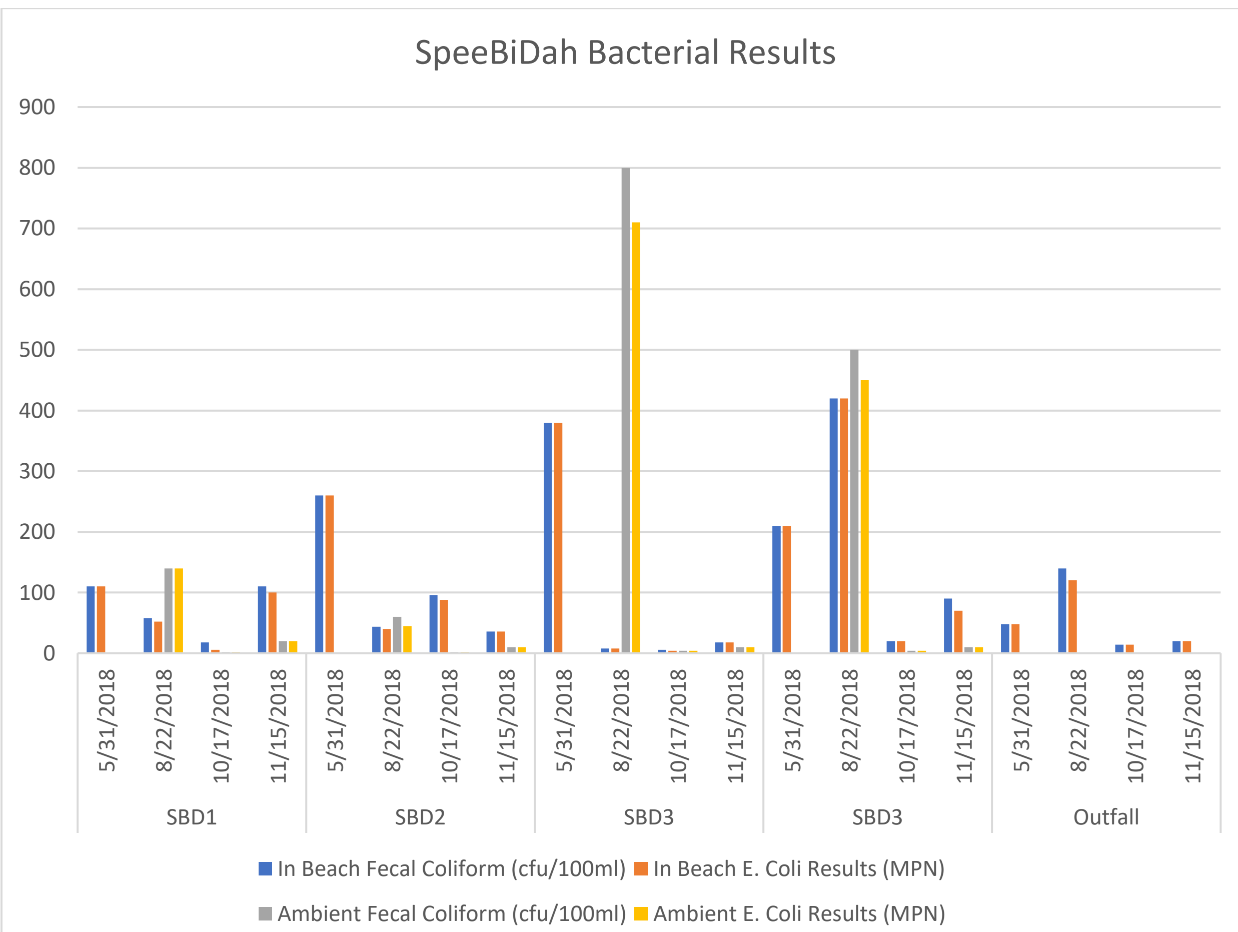


Table 4. Bacterial Results at SpeeBiDah Beach

Site Name	Date Sampled	In Beach Fecal Coliform (cfu/100ml)	In Beach E. Coli Results (MPN)	Ambient Fecal Coliform (cfu/100ml)	Ambient E. Coli Results (MPN)
SBD1	5/31/2018	110	110		
	8/22/2018	58	52	140	140
	10/17/2018	18	6	1.99	1.99
	11/15/2018	110	100	20	20
SBD2	5/31/2018	260	260		
	8/22/2018	44	40	60	45
	10/17/2018	96	88	1.99	1.99
	11/15/2018	36	36	10	10
SBD3	5/31/2018	380	380		
	8/22/2018	8	8	800	710
	10/17/2018	6	4	4	4
	11/15/2018	18	18	9.99	9.99
SBD3	5/31/2018	210	210		
	8/22/2018	420	420	500	450
	10/17/2018	20	20	4	4
	11/15/2018	90	70	10	10
Outfall	5/31/2018	48	48		
	8/22/2018	140	120		
	10/17/2018	14	14		
	11/15/2018	20	20		

Sunny Shores

Of all four beaches, Sunny Shores appeared to be cleanest in terms of bacteria levels (based on geometric means) in the beach sand and nearshore water, despite having two occurrences of high bacterial levels. Two sampling stations were only sampled once because high tide usually put them underwater. Since this beach had less samples taken, the accuracy of the monitoring results for this beach may insuffient. Future sampling efforts should be scheduled so that tidal conditions allow for sample collection.

Figure 6. Picture of Sunny Shores Beach and Locations of Sampling Stations

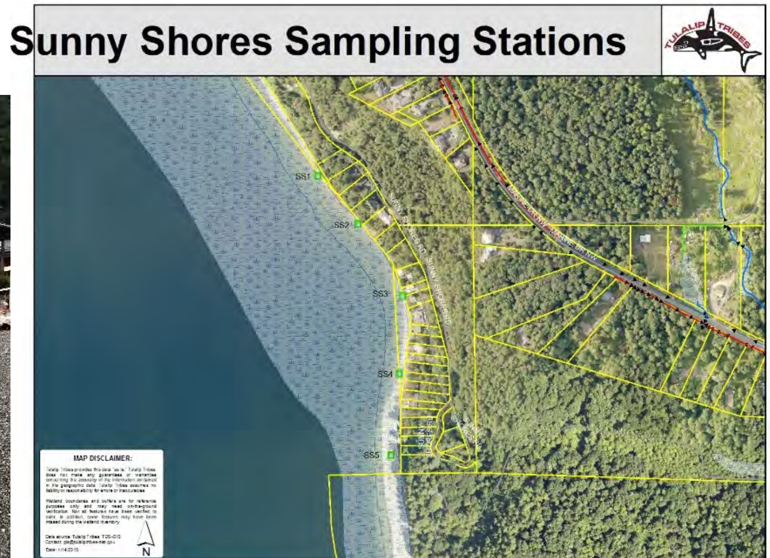


Figure 7. Bacterial Results at Sunny Shores Beach

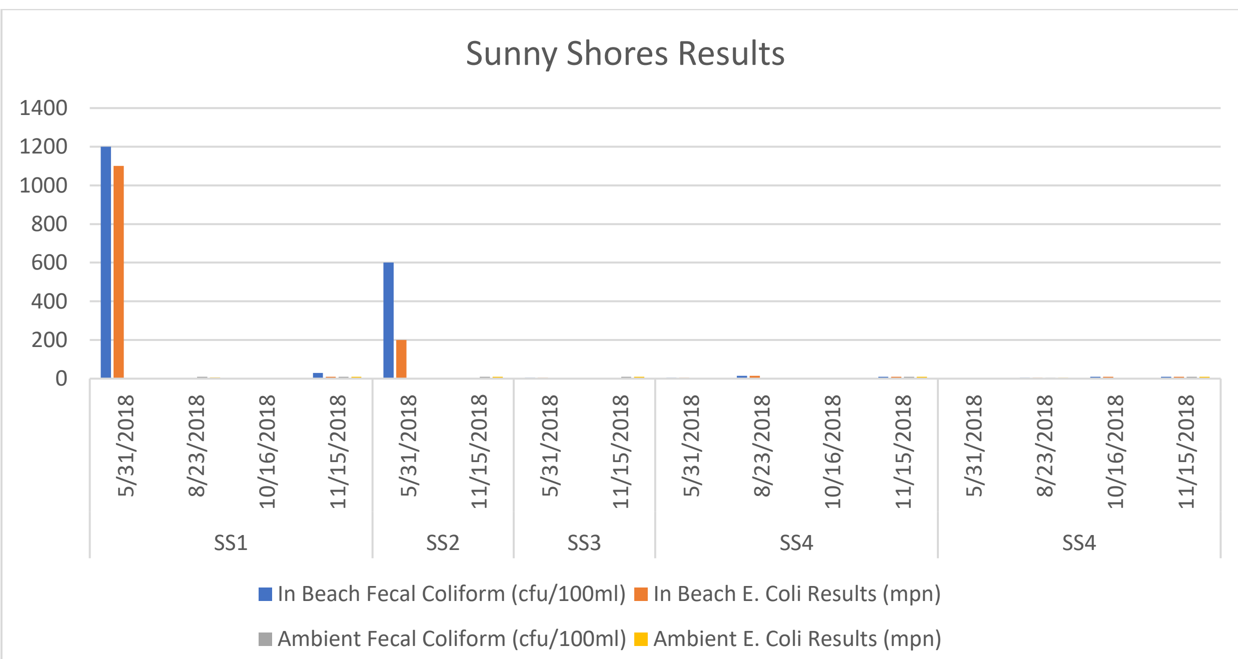


Table 5. Sunny Shores Bacterial Results

Site Name	Date	In Beach Fecal Coliform (colony forming units/100ml)	In Beach E. Coli Results (Most Probable Number)	Ambient Fecal Coliform (colony forming units/100ml)	Ambient E. Coli Results (Most Probable Number)
SS1	5/31/2018	1200	1100		
	8/23/2018	1.99	1.99	9	7
	10/16/2018	1.99	1.99	2	1.99
	11/15/2018	30	10	9.99	9.99
SS2	5/31/2018	600	200		
	11/15/2018			9.99	9.99
SS3	5/31/2018	4.99	4.99		
	11/15/2018			10	10
SS4	5/31/2018	4.99	4.99		
	8/23/2018	14	14		
	10/16/2018	1.99	1.99	1.99	1.99
	11/15/2018	9	9	10	9.99
SS4	5/31/2018	1.99	1.99		
	8/23/2018	5	5	5	5
	10/16/2018	9	9	1.99	1.99
	11/15/2018	10	10	10	9.99

Tulalip Shores

Tulalip Shores had the highest level of bacteria measured during this project. Three of the four sampling stations have had levels of bacteria that exceeded 1000 (cfu/100mL and mpn). This beach had the second highest geometric mean for bacteria. Sampling station TS3 had consistently high levels of bacteria. Onsite septic systems upgradient of this site should be investigated for failures.

Figure 8. Picture of Tulalip Shores Beach and Locations of Sampling Stations

Figure 9. Bacterial Results at Tulalip Shores Beach

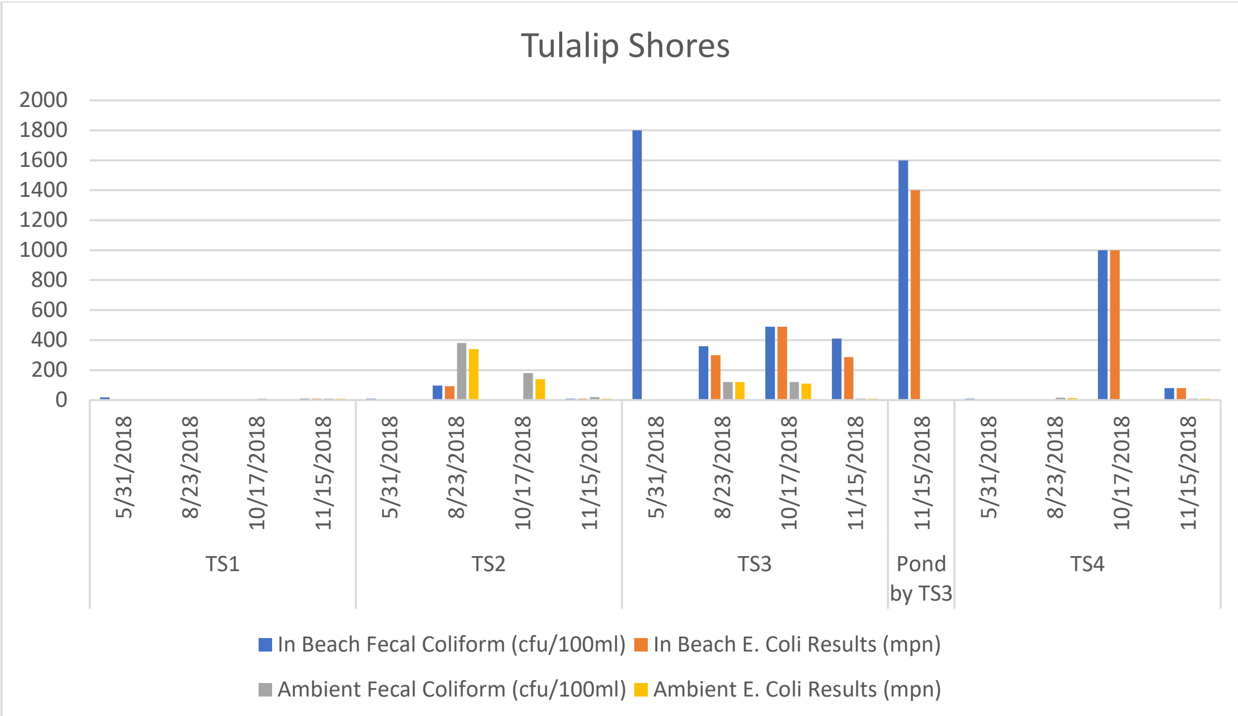


Table 6. Tulalip Shores Bacterial Results

Site Name	Date	In Beach Fecal Coliform (cfu/100ml)	In Beach E. Coli Results (mpn)	Ambient Fecal Coliform (cfu/100ml)	Ambient E. Coli Results (mpn)
TS1	5/31/2018	18			
	8/23/2018	1.99	1.99	1.99	1.99
	10/17/2018	4	1.99	10	6
	11/15/2018	10	10	10	9.99
TS2	5/31/2018	9			
	8/23/2018	98	92	380	340
	10/17/2018	4	4	180	140
	11/15/2018	10	10	20	9.99
TS3	5/31/2018	1800			
	8/23/2018	360	300	120	120
	10/17/2018	490	490	120	110
	11/15/2018	410	287	9.99	9.99
Pond by TS3	11/15/2018	1600	1400		

TS4	5/31/2018	9.99			
	8/23/2018	1.99	1.99	15	13
	10/17/2018	1000	1000	6	6
	11/15/2018	80	80	10	9.99

Reference Sites

The four reference sites showed none of the high levels of bacteria found in the beach sand as compared to the densely populated beaches. The highest level of bacteria (84 cfu/100mL and mpn) was found in the nearshore water. The beach sand concentrations did not exceeded 36 cfu/100mL for fecal coliform, of which only 4 mpn were attributed to E.coli.

Figure 10. Map of Reference Sites

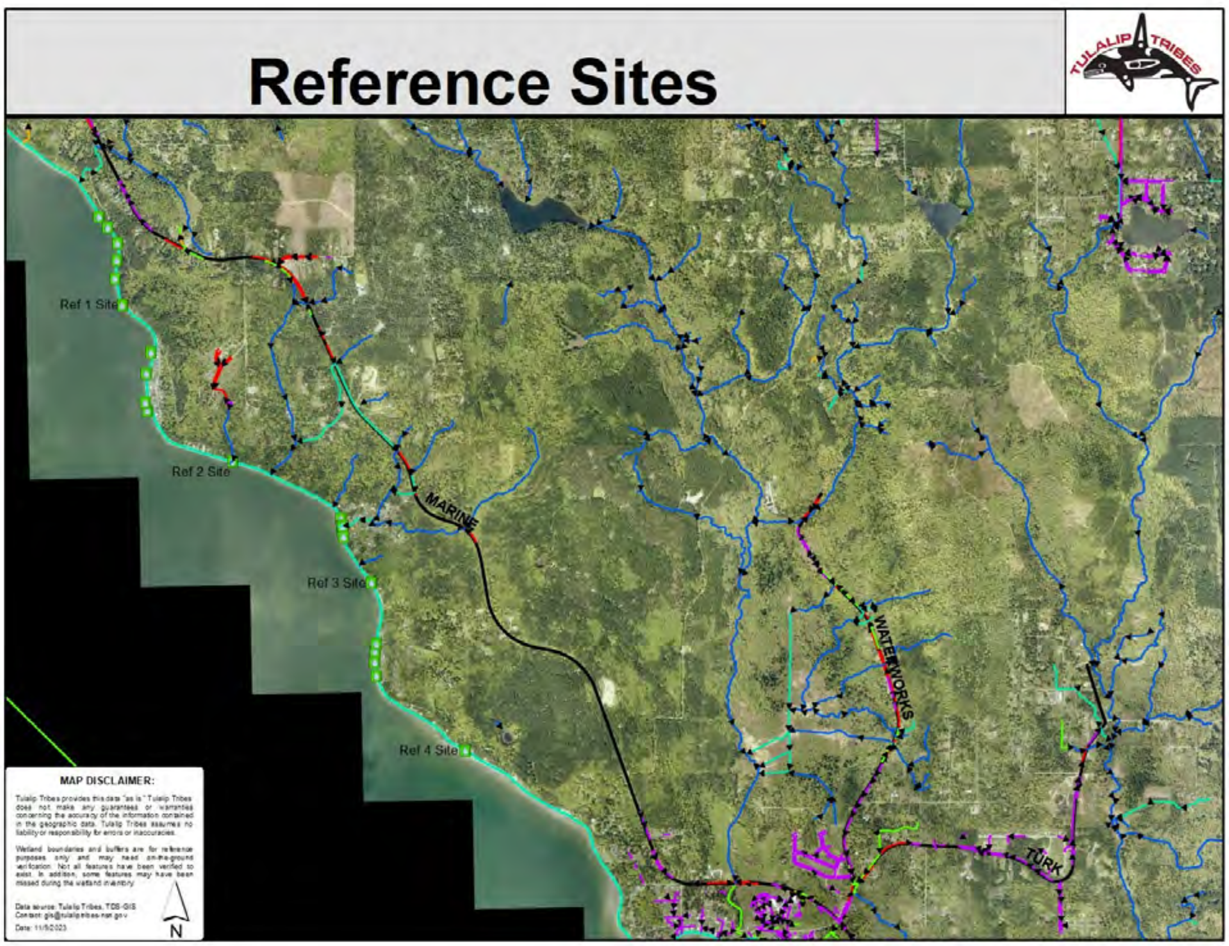


Figure 11. Bacterial Results at Four Reference Stations

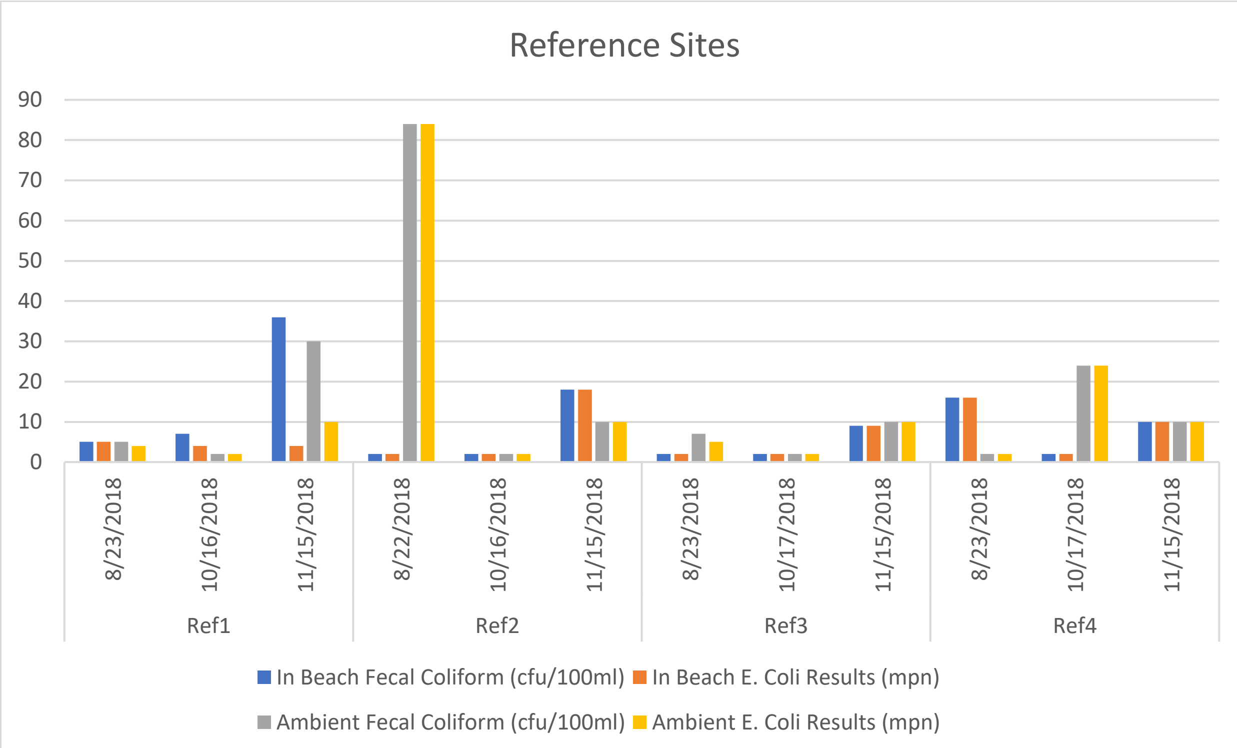


Table 7. Bacterial Results at four Reference Sites

Site Name	Date	In Beach Fecal Coliform (cfu/100ml)	In Beach E. Coli Results (mpn)	Ambient Fecal Coliform (cfu/100ml)	Ambient E. Coli Results (mpn)
Ref1	8/23/2018	5	5	5	4
	10/16/2018	7	4	2	2
	11/15/2018	36	4	30	10
Ref2	8/22/2018	2	2	84	84
	10/16/2018	1.99	1.99	2	2
	11/15/2018	18	18	10	10
Ref3	8/23/2018	1.99	1.99	7	5
	10/17/2018	2	1.99	2	2
	11/15/2018	9	9	9.99	9.99
Ref4	8/23/2018	16	16	1.99	1.99
	10/17/2018	1.99	1.99	24	24
	11/15/2018	9.99	9.99	10	9.99

Conclusions

The four densely populated beach communities showed much higher levels of bacteria in their shallow groundwater as compared to the reference sites. To date, the Snohomish Health District has resisted investigations of the onsite septic systems in these communities by citing a lack of data. Tulalip Tribes Natural Resources Dept. hopes that this evidence will convince the Snohomish Health District to inquire about the location and condition of onsite septic systems in these shoreline communities and start requesting repairs as needed.

Appendix E. Demographics Assessment

This demographics summary identifies general knowledge about residents within the Tulalip Tribes Reservation using U.S. Census data. For more specific information about non-Tribal people living along the Tulalip coast, additional research in the form of a door-to-door survey or in-person community meetings to identify shared values and discuss risks and options may be needed.

My Tribal Area provides demographic and economic statistics from the American Community Survey (ACS) on American Indian and Alaska Native (AIAN) populations. Compared to other tools that aggregate U.S. Census demographic data (e.g., EJScreen, Washington Tracking Network), My Tribal Area provides data downscaled to Tribal nations. Data presented below is from the 2017-2021 ACS 5-Year Estimates for the Tulalip Reservation and Off-Reservation Trust:

- **Total population**: 10,132
  - **Race**:
    - American Indian and Alaskan Native: 1,879 (18.5%)
    - White: 6,582 (65%)
    - Two or more races: 1,049 (10.3%)
    - Other (Black, Asian, Native Hawaiian or Other Pacific Islander, Some other race): 622 (6.13%)
  - **Age:**
    - Median age: 45.6 years
    - Of potential homeowners (18 years and older), the age distribution includes:
      - 6,050 people between 18-64 years
      - 1,950 people 65 years and over
  - **Disability**: 1,647 individuals report having a disability, of which 77 are under 18 years, 882 are between 18-64 years old, and 688 are 65 years and over.
  - **Housing Occupancy and Tenure**:
    - Total housing units: 4,163
    - 88% of these units are occupied by either owners (81%) or renters (19%). Twelve percent (12%) are vacant.
      - Occupied housing units: 3,667
        - Owner-occupied: 2,975
        - Renter-occupied: 692
      - Vacant housing units: 496
  - **Computer and Internet Use**: Of occupied housing units (3,667), approximately 97% have a computer and 91% have a broadband Internet connection.
  - **Income in 2021 inflation-adjusted dollars**: Of occupied housing units (3,667), the median household income is $93,063 and the mean household income is $108,720.
  - **Employment Status**: There are approximately 8,267 individuals of working age (classified as 16 years and over), 57% are in the labor force. Of those in the labor force, 4,397 are employed and 312 are unemployed.
  - **Educational attainment**: Of individuals 25 years and over, 89.9% have a high school degree or higher and 21.2% have a bachelor's degree or higher.

Appendix F. Project Summary: Puget Sound Coastal Storm Modeling System (CoSMoS) along Tulalip Tribes Reservation Shoreline

Project Summary:
Puget Sound Coastal Storm Modeling System (CoSMoS)
along Tulalip Tribes Reservation Shoreline

Prepared in cooperation with Tulalip Tribes

By Eric E. Grossman[1], Kai Parker [1], Kees Nederhoff[2], Liam Horner[3], Patrick L. Barnard [1]

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Acknowledgments

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• Abstract

Coastal flooding driven by storms and waves are projected to increase with accelerating sea level rise and adversely impact diverse aspects of society (Taherkhani et al., 2020; Sweet et al., 2022). The Coastal Storm Modeling System (CoSMoS) was developed by the U.S. Geological Survey (USGS) to support coastal vulnerability and climate adaptation planning for coastal hazards (Barnard et al., 2014; 2019). The Puget Sound version (PS-CoSMoS) was developed and initially implemented along the Tulalip Tribes Reservation shorelines as part of a statewide effort across coastal Washington. PS-CoSMoS accounts for sea level rise, tides, remotely-generated sea level anomalies associated with phenomena like El Niño, as well as local storm surge and wave set-up. The model produces map-based flood hazard products for a range of sea-level rise (0-5m) and storm (daily to 100-year recurrence) scenarios. This report summarizes the project, model, and results for the Tulalip shoreline. It shows that an additional area of approximately 2.75 to 3.25 km^2 across the study area is projected to become exposed to coastal flooding with anticipated sea level rise by the year 2100 accounting for coastal storms indicating the need to pursue coastal adaptation strategies.

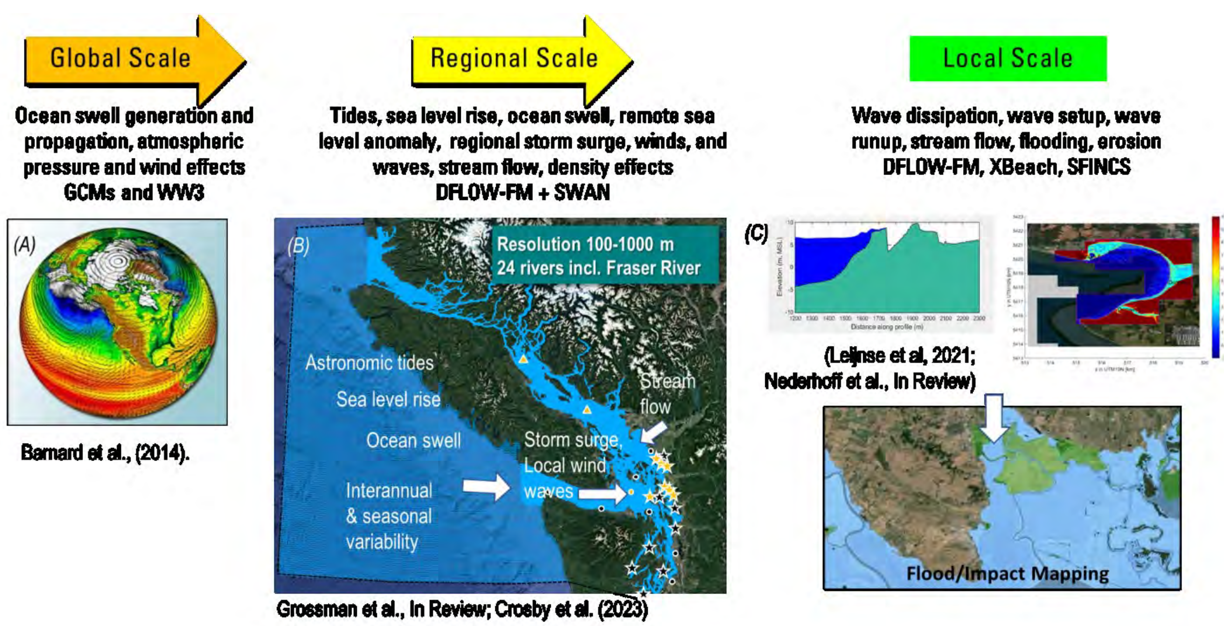
• Introduction

The USGS Puget Sound Coastal Storm Modeling System (PS-CoSMoS) was developed for the coastal waters of Washington State and initially implemented at the planning level-scale along the Tulalip Tribes reservation shoreline, Whatcom County in collaboration with the City of Bellingham, Whatcom County, the Port of Bellingham, and the City of Blaine, and reservation shorelines of Northwest Indian Fisheries Commission member coastal tribes. CoSMoS is a system of numerical models that downscale global climate and oceanographic processes to compute extreme water levels and flooding from coastal storms (Barnard et al., 2014; 2019). The modeling is validated using historical observations and model re-analyses and then uses Global Climate Models to determine future coastal flooding anticipated with sea level rise and storms across the 21st century. The models solve how atmospheric and oceanographic processes interact to generate extreme coastal water levels and waves, that cause flooding and related storm effects. PS-CoSMoS is designed to support federal, tribal, and state climate change planning guidance, vulnerability assessments, adaptation planning, and emergency response with regionally-consistent projections based on best available science and at a resolution for diverse planning needs. A strength of PS-CoSMoS is the accounting of important dynamic physical processes that lead to flooding, including local storm and wave effects, as well as remotely-generated sea level anomalies (SLA) that originate in the open ocean and penetrate into estuaries. In the Salish Sea, remote SLA can contribute 50–60% of the water level exceeding predicted tides during storms (Grossman et al., In Review).

Model outputs include flood extent, water surface elevation, water depth over land, flood velocity, flood duration, and offshore significant wave height and period. Outputs are delivered as Geographic Information System (GIS) vector shapefile and raster geotiff data sets for easy integration into common spatial analysis software and webtool frameworks used for exposure assessments, adaptation planning, and communications. Each PS-CoSMoS flood extent output also includes an associated minimum and maximum uncertainty layer accounting for the confidence of input data and model skill to enable planning for a range of risk tolerances. CoSMoS outputs these flood results as a comprehensive set of map-based products that visualize flood hazards across a range of sea level rise and storm scenarios suited for diverse short- and long-range planning needs. Here we describe the model, how it was constructed, the model outputs, and appropriate applications. A brief description of the model results along the Tulalip reservation shoreline for the range of plausible sea level rise scenarios anticipated through the year 2150 is also provided and the timing of coastal flood impacts is described by cross-walking the CoSMoS results for discrete sea level rise scenarios to downscaled sea level rise estimates for Washington State.

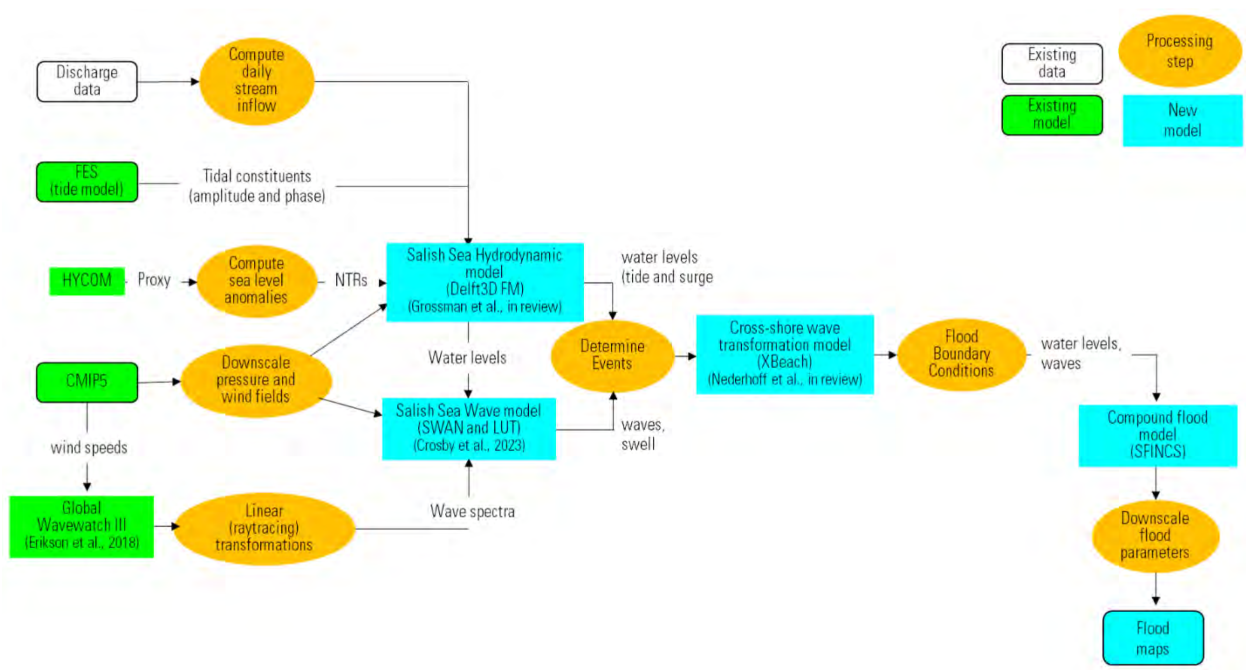
• Model Overview

PS-CoSMoS is a hydrodynamic modeling framework constructed with a system of coupled models that simulate and downscale global to regional processes (Barnard et al., 2014; 2019). These include variations in water levels and phenomena like ocean swell and remotely generated SLA associated with interannual to interdecadal processes like El Niño-Southern Oscillation that propagate across the ocean and interact with local coastlines (Error! Reference source not found.). At the regional scale, PS-CoSMoS resolves the effects of tides, sea level anomalies that penetrate into the Salish Sea, local winds and pressure effects driving storm surge, and the effects of stream runoff on water density important to calculating water levels close to shore. Because atmospheric and oceanographic processes operating in the Pacific Ocean affect flooding along Salish Sea shorelines, the regional model extends across the north and west (offshore) of Vancouver Island to ~100 km south of the entrance to the Strait of Juan de Fuca (Error! Reference source not found.**B**). At the local level, PS-CoSMoS computes wave-driven water levels in combination with tides, storms, sea level, and stream flows, to determine the extent of flooding over the land at 1 m resolution.



• Figure 9. Diagram showing the Puget Sound Coastal Storm Modeling System workflow and spatial downscaling of Global Climate Models (GCMs) using Wave Watch III (WW3) and a suite of Deltares-based open-source hydrodynamics models described in the text to compute coastal flooding.

The hydrodynamic models are constructed around a core group of models utilizing Delft3D Flexible Mesh (DFLOW-FM) (Deltares, 2020) to compute regional water levels, Simulating Waves Nearshore (SWAN) to quantify wave generation and propagation, XBeach to solve for wave transformation and dissipation, and the Super-Fast INundation of CoastS model (SFINCS) for overland flooding. PS-CoSMoS includes the best available and most current topographic and bathymetric data (Tyler et al., 2020; 2021) and parameters like land cover (Homer et al., 2020) and roughness following (Nederhoff et al. 2021) that influence the flow of water. The system of models are fed important boundary conditions and inputs including sea-level, tides, sea-surface height anomaly, atmospheric pressure and winds from global climate change models (from Coupled Model Intercomparison Project Phase 5 [CMIP5]), and downscaled ocean swell (from Global Wavewatch III) (Error! Reference source not found.). The model also includes baseflow stream discharge as it affects estuary salinity and density important to water levels. From these data and models, additional parameters are derived and sequentially fed to increasingly downscaled models including the PS-CoSMoS Salish Sea Hydrodynamic model (Grossman et al., in Review), the regional PS-CoSMoS Salish Sea Wave model (Crosby et al. (2023), and XBeach wave transformation model (Nederhoff et al., 2023).A large number of extreme events are then simulated by the SFINCS 2D flood solver with resulting water levels used to map flood extents and outputs for the defined extreme recurrence event storm scenarios (Nederhoff et al., 2023).



• Figure 10. Diagram showing models and data used as part of the Puget Sound Coastal Storm Modeling System.

Seafloor depth and land elevation data are sourced from the USGS Coastal National Elevation Dataset (CoNED) that was updated in 2020 (Tyler et al., 2020, 2021). Spatially varying roughness was evaluated and prescribed through iterative testing to identify the spatial configuration that best correlated with observed water levels at NOAA and USGS tide gage stations (Grossman et al., In Review). Atmospheric pressure and winds were prescribed from the highest resolution numerical weather and Global Climate Models available for the past to compare to observations for model validation as well as for the future to assess effects of climate change. The Canadian 2.5 km High-Resolution Deterministic Prediction System (HRDPS) (Environment Canada, 2020) and 6-km Weather Research and Forecasting (WRF) downscaling (Chen et al., 2018) of the North American Regional Reanalysis (NARR) model (Mesinger et al., 2006) were used for water level and wave model validation simulations over the period 2017-2020 and for computation of extreme event recurrence over the period 1985-2015. In addition, HRDPS was used to bias correct the 12-km WRF downscaled Coupled Model Intercomparison Project Phase 5 (CMIP5) Geophysical Fluid Dynamics Laboratory (GFDL) model (Mass et al., 2022) used to assess changes in the future. The density of water was defined based on physical measurements spanning decades by the Washington Department of Ecology (2022) and summarized by Moore et al. (2008). Baseflow stream discharge was prescribed for the 24 largest US streams (USGS, 2022) and the Fraser River (Environment Canada) in British Columbia entering the Salish Sea. The details of all model configurations can be found in Grossman et al., In Review, Crosby et al., 2023, and Nederhoff et al., 2023.

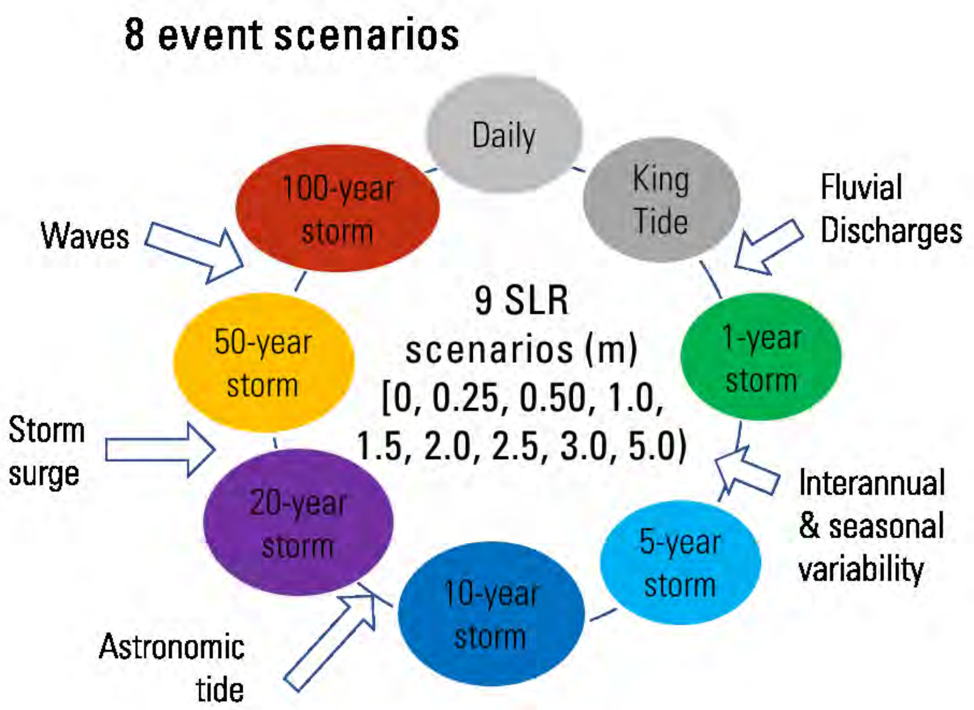
- ## Model Validation

The PS-CoSMoS model was validated through comparison of modeled and measured water levels over four years spanning 2017 to 2020. A four-year campaign led by the USGS PS-CoSMoS team measured water levels at 7 locations across Puget Sound characterized by different exposure to tides and winter storms (Nowacki et al., 2021), doubling the number of existing tide gages maintained by NOAA. Simulated water levels had excellent agreement compared to observations and were on average within 15 cm of measured water levels over the entire 2017-2020 validation period (Grossman et. al., In Review). Integrating error inherent in measured input parameters including atmospheric pressure, winds, water level, wave height and period, seafloor bathymetry, land elevations, and vertical land motion, and calculations of storm surge and wave propagation, dissipation, and wave runup across coastal lands, the overall uncertainty of modeled water levels is approximately ±0.5 m and is accounted for by changing the base water level.

- ## Model Outputs

The PS-CoSMoS model for Tulalip generated spatial projections of flood extent, flood water level (water surface elevation), flood water depth (over land), flood velocity, and flood duration for 8 storm events and 9 sea level scenarios (Error! Reference source not found.). Storm events include the daily, king tide, 1-yr, 5-yr, 10-yr, 20-yr, 50-yr, and 100-yr recurrence events. Each storm event is calculated for sea level rise scenarios of 0, 0.25, 0.50, 1.00, 1.50, 2.00, 2.50, 3.00, and 5.00 m considered plausible between 2023 and the year 2150 (Sweet et al., 2022). The King Tide scenario is the highest predicted annual astronomic tide based on the NOAA 1983–

2001 tidal epoch and included the average measured daily storm surge or non-tidal residual (NTR), the water level anomaly above predicted tide. Offshore significant wave height and period are also computed for each storm event and existing sea level scenario.



- Figure 11. Diagram showing models and data used as part of the Puget Sound Coastal Storm Modeling System. Outputs are provided for 8 storm event scenarios (daily to 100-year event) and 9 sea level rise scenarios.

Flood extents are provided as GIS polygon shapefiles. Water surface elevation, flood depth, flood velocity, and flood duration are provided as GIS raster geotiff files with a spatial (pixel) resolution of 1m. Water surface elevation represents the maximum water level computed for the corresponding recurrence storm event. Flood depth is the difference between the water surface and the land surface elevation. Flood velocity is the flow velocity of the water over land associated with the maximum flood level computed for each grid cell. Similarly, flood duration is the duration of the flood calculated for the maximum flood level at each cell. Flood velocity and duration may not be continuous from cell to cell where nearby values are derived from different storms (for example, a storm causing higher water levels at one site may have a shorter duration than at another). Additional model projections include offshore significant wave height and period for each extreme recurrence event under existing sea level position. The data are published in a USGS Data Release (Grossman et. al., 2023). Uncertainty is provided for the flood extent and flood level outputs as a minimum and maximum estimate accounting for the 0.5 m uncertainty in modeled water level.

Table 1. Puget Sound PS-CoSMoS model output product definitions, scenarios and file formats

Parameter	Definition	Units	Scenarios	File Format
Flood extent	Area of computed flooding	na	8 storm events for each of 9 sea level rise scenarios	Polygon shapefile
Flood level	Water surface elevation (maximum flood level)	meters relative to NAVD88	8 recurrence periods for each of 9 sea level rise scenarios	Raster geotiff
Flood depth	Flood depth (water over land) associated with computed maximum flood level	Meters above ground surface	8 recurrence periods for each of 9 sea level rise scenarios	Raster geotiff
Flood velocity	Flow velocities associated with computed maximum flood level	Meters per second	8 recurrence periods for each of 9 sea level rise scenarios	Raster geotiff
Flood duration	Flood duration associated with computed maximum flood level	Hours	8 recurrence periods for each of 9 sea level rise scenarios	Raster geotiff
Wave height and period	Significant wave height	Meters	8 recurrence periods for existing sea level	Raster geotiff
Wave period	Significant wave period	Seconds	8 recurrence periods for existing sea level	Raster geotiff

- **Additional Products**

Additional products that will cover the study domain but are distributed separately include a regional groundwater model and socioeconomic hazard exposure tool. Estimates of daily average groundwater levels are projected for each sea level rise scenario with a different set of models and assumptions following Befus et al. (2020). Groundwater projections represent computed groundwater depth below the land surface. The USGS Hazards Exposure and Reporting Analytics (HERA) webtool (www.usgs.gov/apps/hera) evaluates socioeconomic exposure for a Nationally-consistent set of CoSMoS model scenarios and is distributed county by county.

• Model Product Applications

The goal of CoSMoS is to provide regionally-consistent, future coastal flood hazard mapping information at a resolution useful for community resilience planning and decision-making. CoSMoS supports federal, tribal, and state-supported climate change planning guidance, local and regional-scale vulnerability assessments and adaptation plans, and emergency preparedness. For example, in California CoSMoS continues to support city and county Local Coastal Program updates, vulnerability and adaptation planning by the California Department of Transportation, and coastal development permit review by the California Coastal Commission. Additional examples of case studies can be found on the Our Coast, Our Future web tool (www.ourcoastourfuture.org). In Washington State, PS-CoSMoS is already being used to inform tribal, county, city and port vulnerability assessments and climate change adaptation plans (e.g., 2023 Whatcom County Compound Flood Vulnerability Assessment; www.whatcomcounty.us/4244/Climate-Change-Risks), and initial capital investment planning for transportation and storm/wastewater infrastructure by the City of Bellingham and Port of Bellingham).

PS-CoSMoS was designed to assess regional and community-scale vulnerabilities and as a screening tool to identify where more detailed engineering studies may be required. PS-CoSMoS was not developed to directly answer site-specific engineering issues (e.g., site design) and is not necessarily compatible with engineering design codes and guidance. Even so, numerous engineering and environmental efforts use CoSMoS as regional boundary conditions or guidance for more specific models and assessments of vulnerability and resilience planning for specific applications.

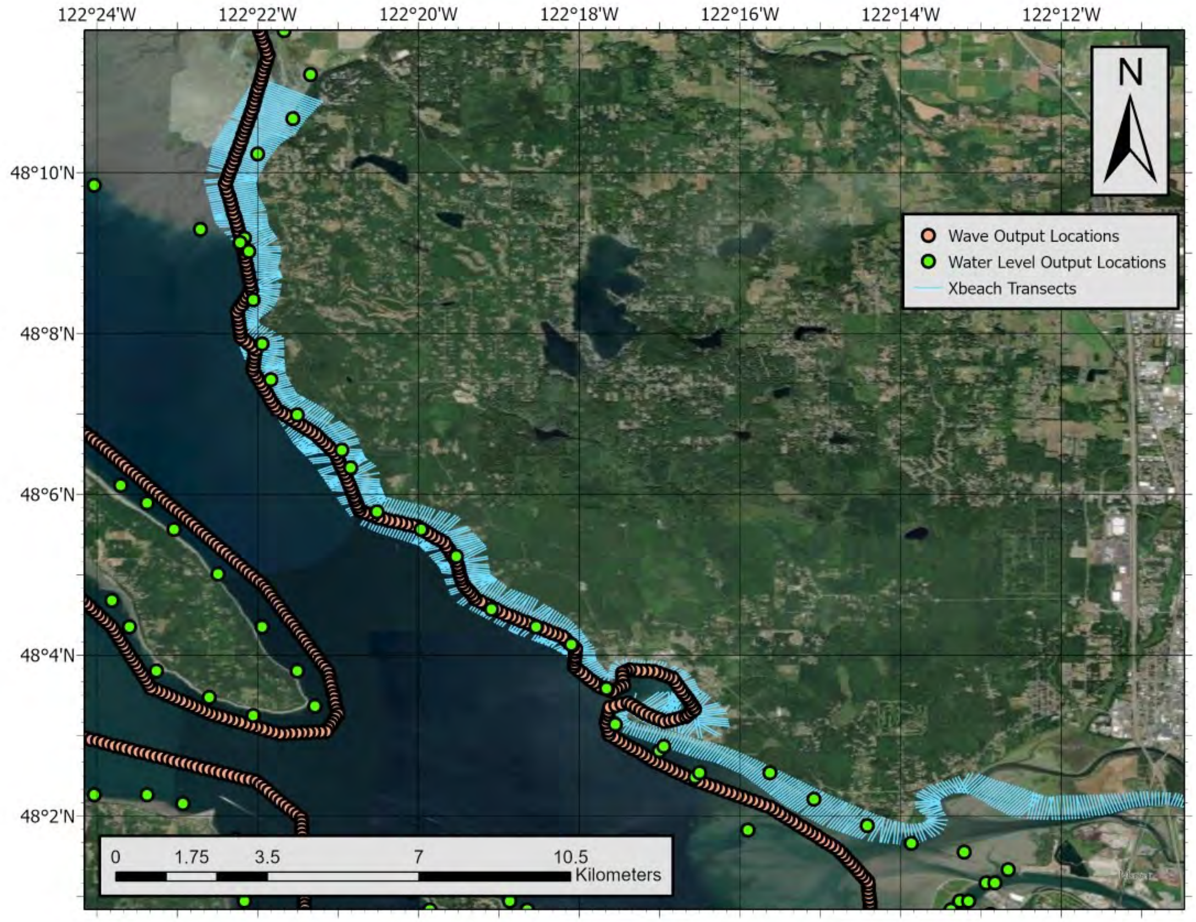
Model projections for discrete sea level scenarios enable CoSMoS results to remain relevant even as estimated rates of sea level rise continue to be periodically updated with the best available science. PS-CoSMoS storm recurrence scenarios including the daily, 1-year, 5-year, 10-year, 20-year, 50-year, and 100-year, and a King Tide scenario, provide a diverse set of extreme flood and associated wave statistics to inform a wide range of risk tolerances and time horizons for planning. Projections of less severe but increasingly disruptive hazards like the 5-, 10-, and 50-yr flood events are fundamental for informing more resilient capital infrastructure design and planning given the rapid increase in coastal flood hazard impacts observed across our nation's coasts. PS-CoSMoS projections of the daily and annual extremes for future sea level rise help communities and planners prepare for anticipated increasingly frequent nuisance and yearly flooding. In turn these outputs aid assessments of where such flooding may be accommodated (e.g., parks and public open space) or too impactful for valued land use (e.g., agricultural productivity), ecosystem functions, or habitat restoration.

A model is a representation of reality and can be a useful tool for planning, but no model perfectly accounts for every detail that leads to flooding. It is important to acknowledge and understand assumptions and limitations of models. PS-CoSMoS in its current form, projects extreme water levels calibrated for mean winter Salish Sea water density conditions and may not resolve summer water levels as effectively. Additionally, the accuracy of the modeled flood extents are only as robust as the underlying data characterizing land surface elevations. Channel depths, and narrow coastal protection structures like levees or sea dikes can be physically smaller than the model grids. Where available, sub-grid features have been integrated into the model. We therefore recommend considering the minimum and maximum uncertainty layers in planning, depending on the importance of (e.g., critical infrastructure), vulnerability, and adaptive capacity of the asset at risk.

• PS-CoSMoS for Tulalip Tribes Reservation

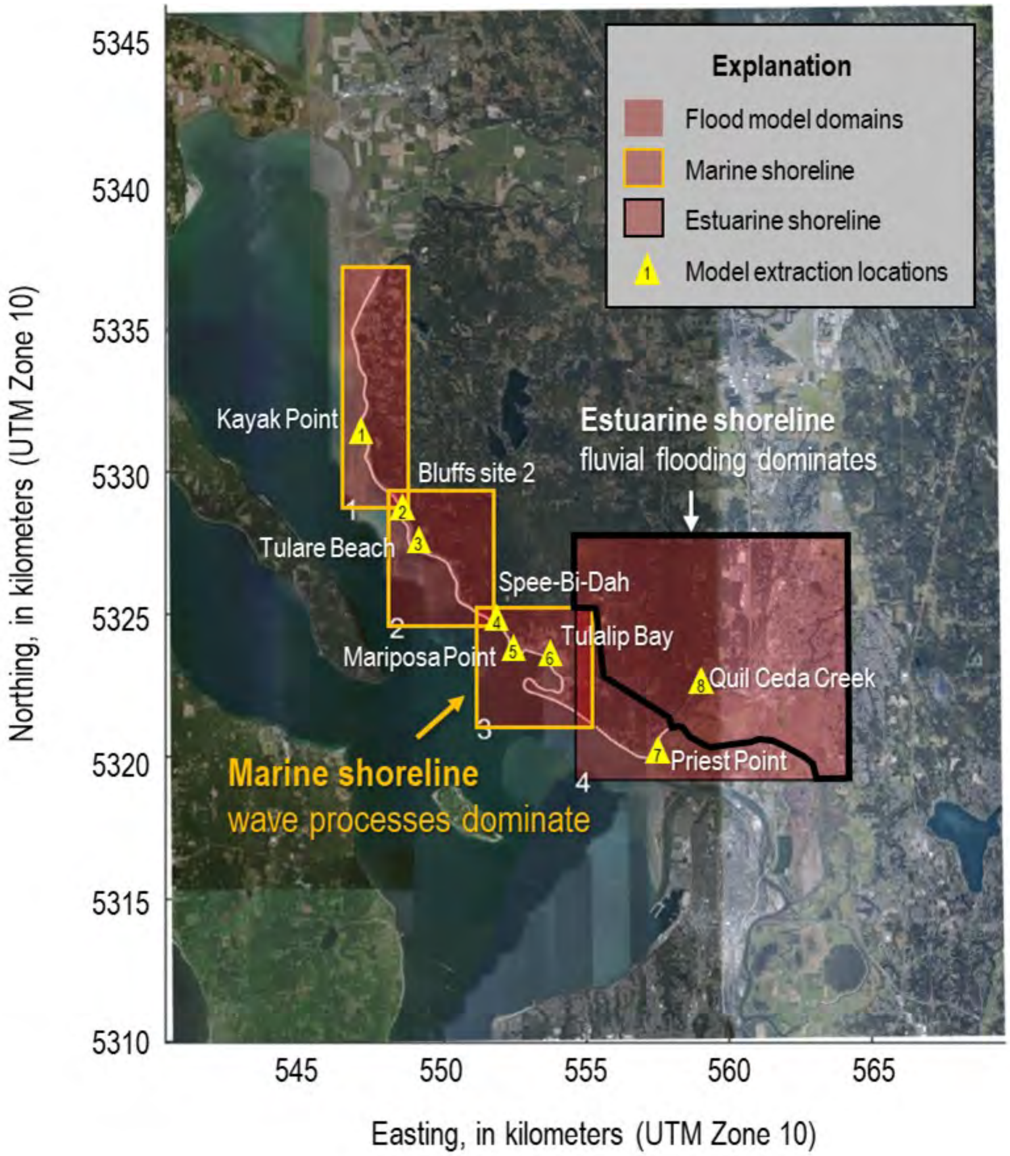
• Local Scale Model Configuration for Tulalip Reservation

The fine/local-scale PS-CoSMoS modeling of wave transformation and flooding along the Tulalip Tribes Reservation extended south from Port Susan Bay to the Snohomish River estuary. Local modeling utilized the regional water level and wave model output alongshore as boundary conditions for computing wave dissipation and the combined effects of tides, storm surge, winds and waves to flooding (Error! Reference source not found.). Wave dissipation and setup were modeled using XBeach along cross-shore transects placed every 50 m alongshore. Outputs of XBeach were used as principal inputs to the 2D SFINCS flood solver.



- Figure 12. Maps showing the regional model water level output locations (diamonds) and detailed cross-shore wave model transects spaced every 50 m alongshore.

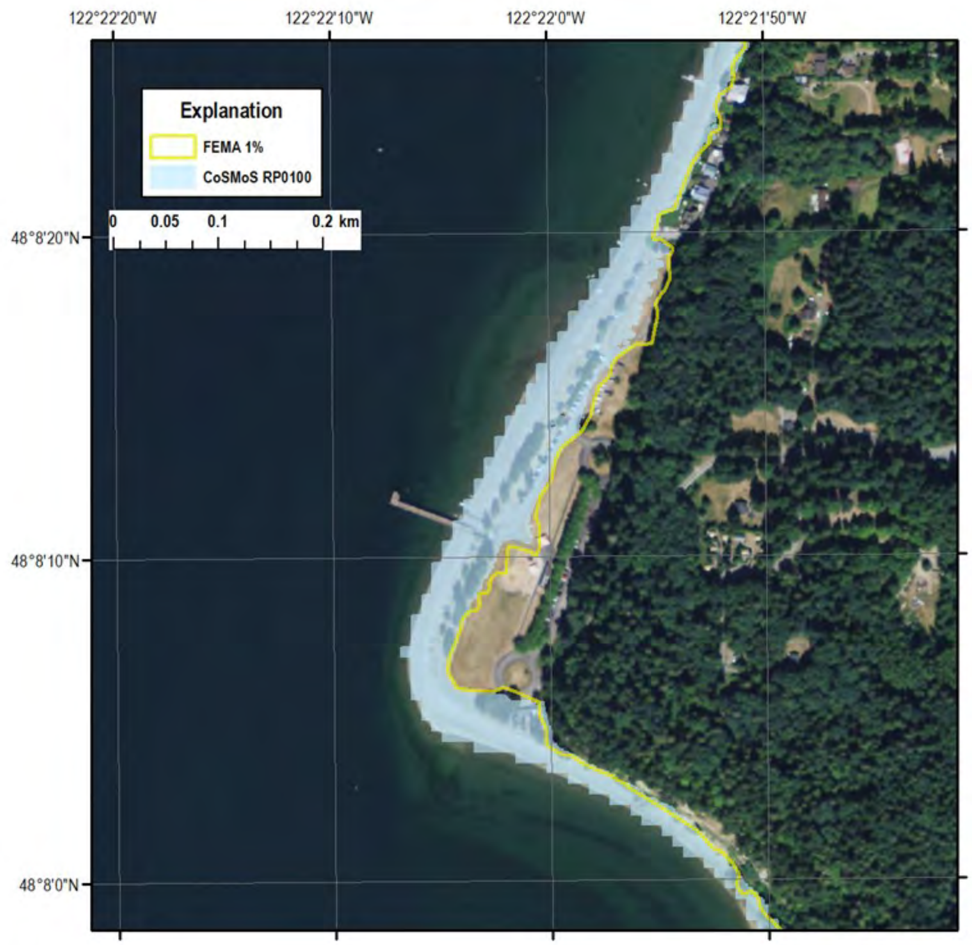
The flood model was configured with 4 subdomains that were ultimately merged into final results for the entire study area. In addition to the total area, results were summarized for the three marine shoreline domains (domains 1–3, Error! Reference source not found.) separate from the single estuary domain (domain 4) to assess the extent that flooding along narrow, steep coast is related to coastal processes including waves. The flood results were also assessed for the single estuary shoreline domain connected to the Snohomish River estuary (domain 4) to evaluate flooding where the coast is low-sloping and waves are not as important (Error! Reference source not found.). Results were also extracted at 8 site specific locations representing shore types of concern to Tulalip Tribes. These included low-lying coastal plains like Kayak Point, Tulare Way beach development, Tulalip Bay, and Priest Point (sites 1, 3, 6, 7 shown as yellow triangles in Error! Reference source not found.), steep bluff-backed beach sites experiencing some of the highest rates of recession (sites 2, 4, 5 in Error! Reference source not found.), and the low-lying urban development zone along the I-5 corridor and Quil Ceda Creek (site 8 in Error! Reference source not found.).



- Figure 13. Map showing the four flood model domains (boxes) for which results were merged then analyzed for changes along marine shorelines (gold line) where waves processes dominate, estuary shorelines (black line) where waves are largely absent, and 8 specific sites representing shore types of concern (yellow triangles).

- **Comparison to FEMA 100-year flood hazard zone**

PS-CoSMoS flood projections of the 100-yr recurrence flood compare well with the current FEMA 100-year (also referred to as the 1-percent-annual-chance flood) flood hazard zone for existing sea level position (Error! Reference source not found.). PS-CoSMoS estimates generally agree closely with FEMA but can vary slightly higher or lower in response to differences in the model formulations and uncertainty in the data used as boundary conditions for both PS-CoSMoS and FEMA models described above. In addition, actual differences on the ground related to changes in elevation and/or land cover affecting data used in the models may be responsible for slight variability between the PS-CoSMoS and FEMA results. The differences observed are well within the CoSMoS model uncertainty.



- Figure 14. Map showing the flood extent for the PS-CoSMoS 100-yr recurrence flood compared to the
FEMA 100-year flood at Kayak Point in the northern area of the study domain.

- **Results: Changes in flood exposure with sea level rise across the entire study area**

PS-CoSMoS projections indicate that the area flooded with sea level rise across the Tulalip Reservation study area (Error! Reference source not found.) will increase from an area of ~ 3 km^2 today (2023), defined as the area flooded by daily recurrence water levels (i.e., the highest daily tide, "no storm" scenario), to over 5 km^2 with 1 m of sea level rise (Error! Reference source not found.**A**). Because the topography is generally steeper along the marine shorelines, the changes in area of flooding in the future are typically smaller along the western edge of the reservation comprise of marine shorelines (Error! Reference source not found.**B**) than along the southeastern edge bordering the Snohomish River and estuary (Error! Reference source not found.**C**). Along the marine shorelines, an increase in area flooded of ~0.3 km^2 is computed for 1 m of sea level rise alone whereas an additional area of 0.5 km^2 is anticipated to flood relative to today when accounting for the 50- and 100-yr storms resolved by CoSMoS (Error! Reference source not found.**B**); the area affected is slightly less for the 10- and 20-yr storms. In contrast along the I-5 corridor and Quil Ceda Creek area where the coastal slope is lower than the marine shorelines, an additional 3 km^2 area is projected to flood due to 1 m of sea level rise by itself and ~4 km^2 accounting for storms (Error! Reference source not found.**C**). With 2 m of sea level rise, approximately 7 km^2 area is projected to flood across the study area with between 5.0 and 5.5 km^2 flooding along the low-sloping I-5 corridor and Quil Ceda Creek area.

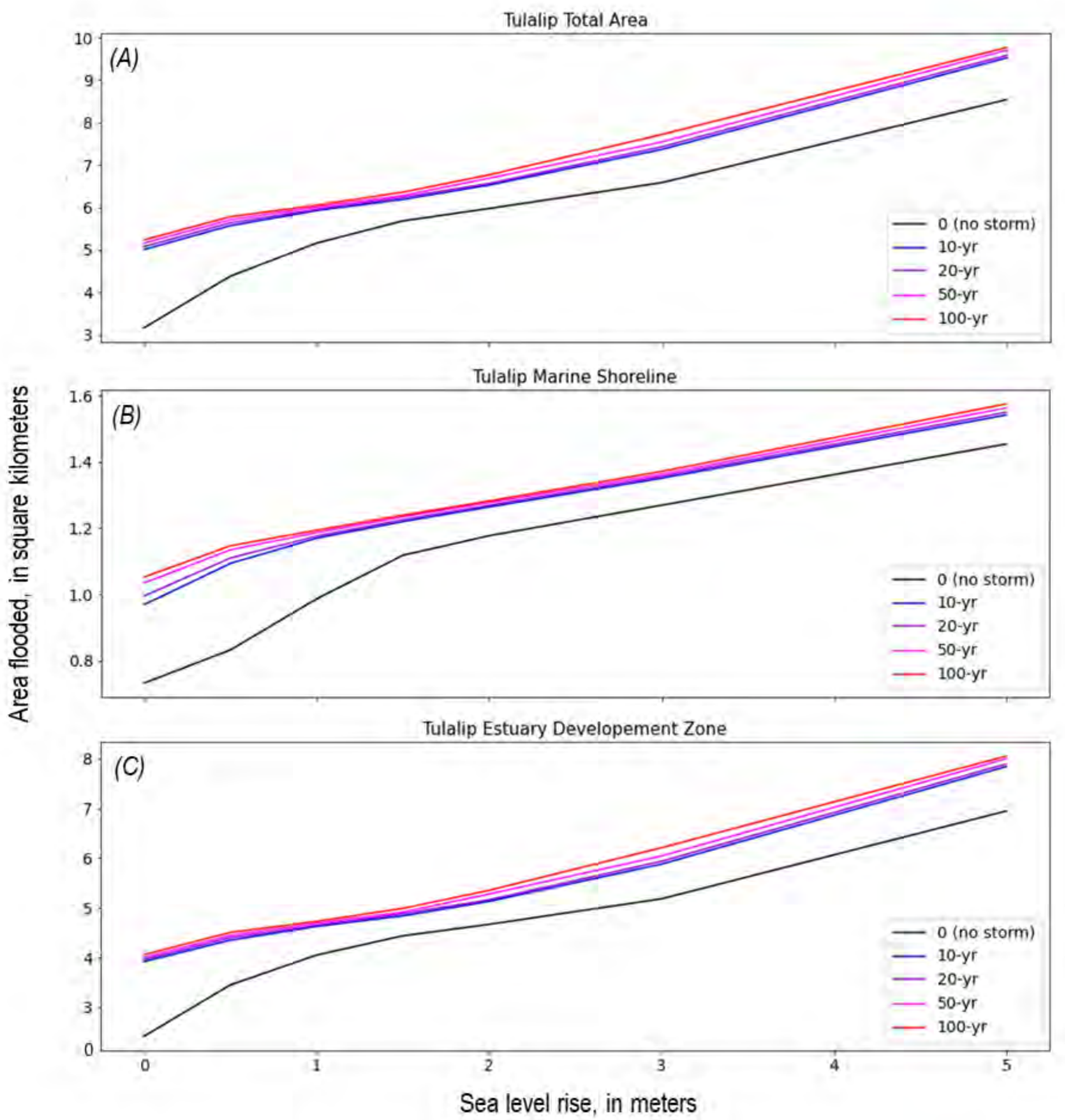


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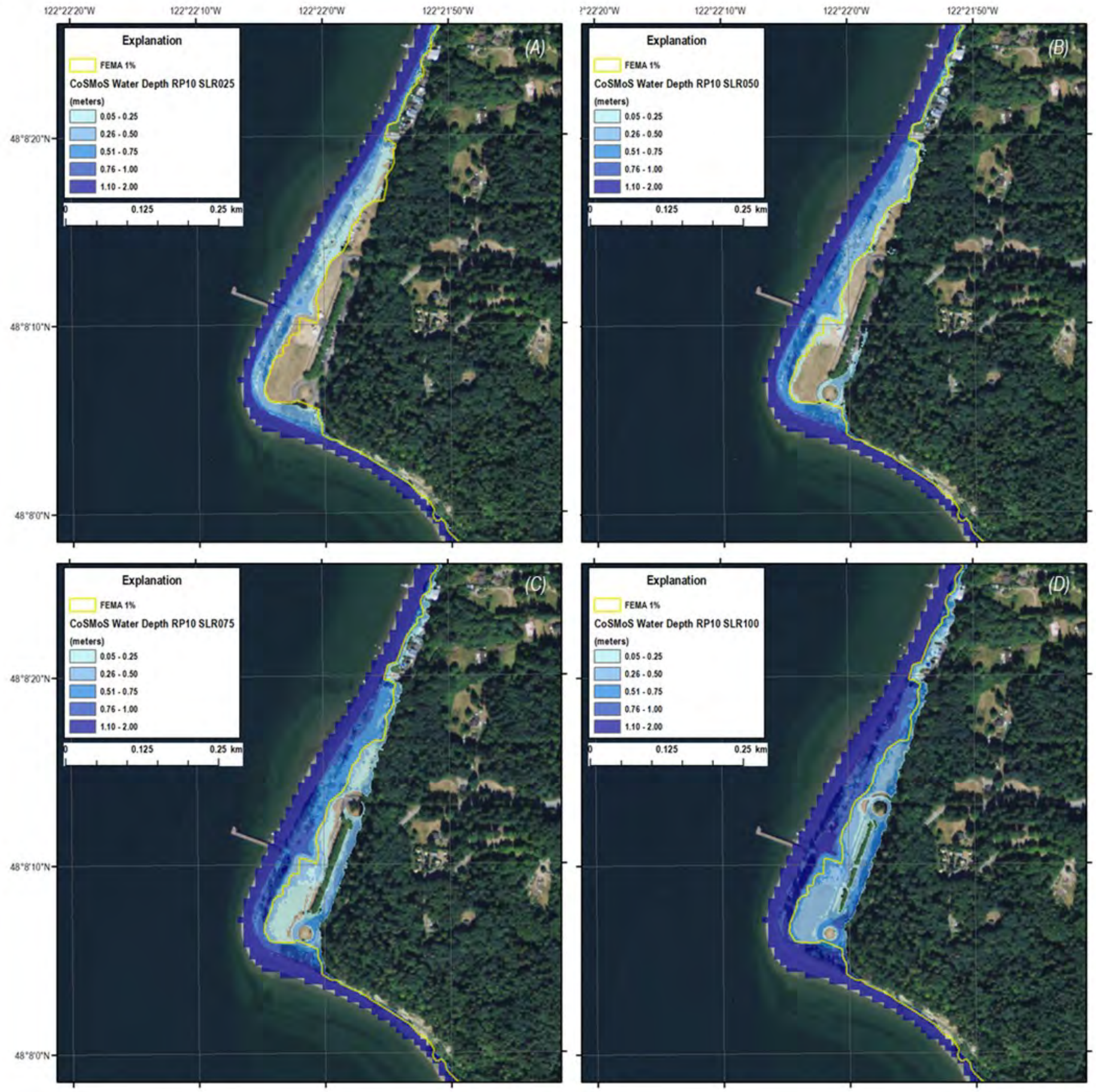
Figure 15. Plots showing the area projected to flood with sea level rise and the 10-, 20-, 50- and 100-yr flood events across the Tulalip Tribes areas of interest (A), steeper marine shorelines (B), and lower-sloping estuary development zone bordering the Snohomish estuary (C). Refer to Figure 5 for map showing marine vs. estuarine shoreline locations.

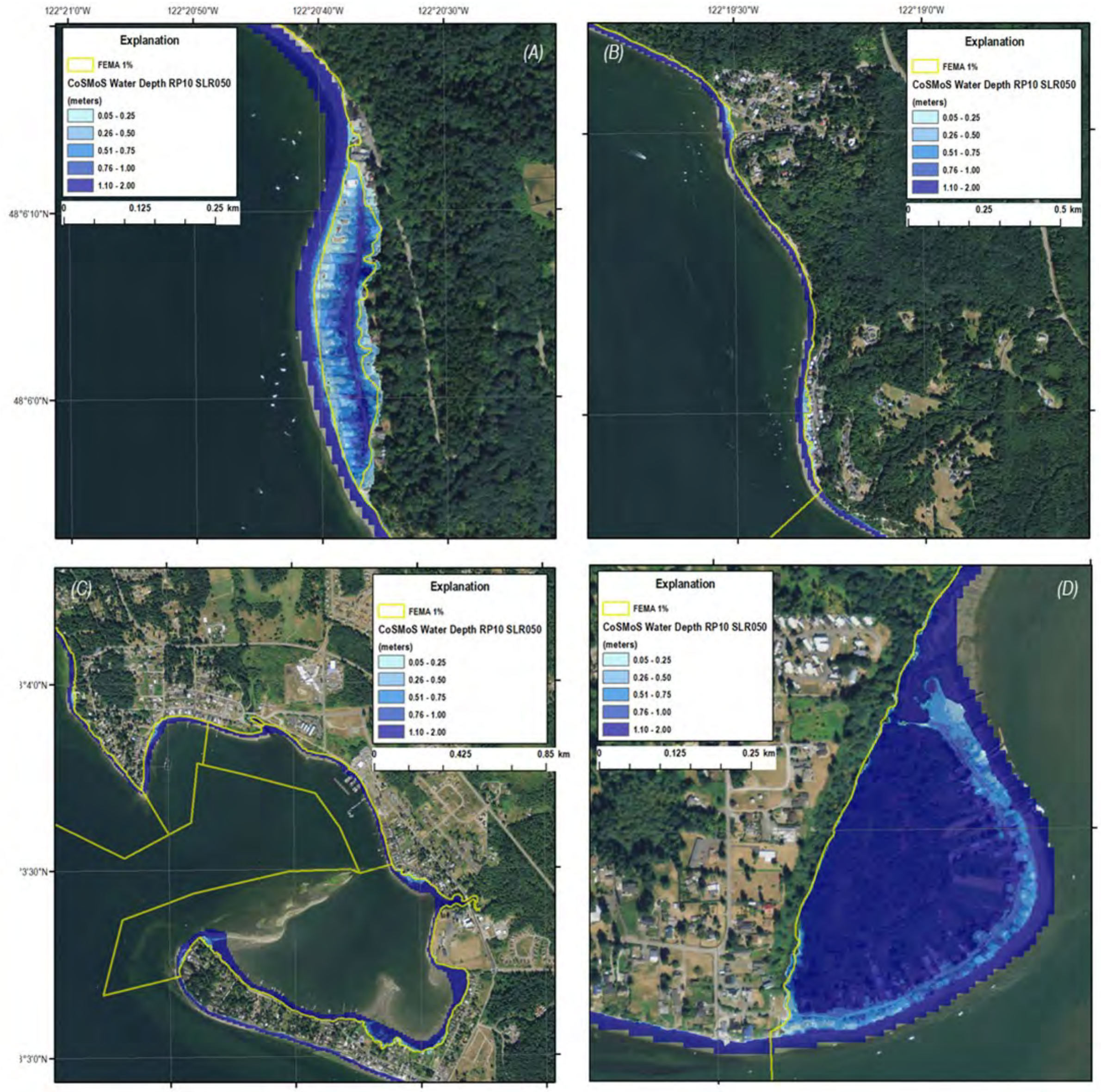
- **Results: Changes in flood exposure magnitude and frequency at specific locations of concern**

The magnitude and frequency of flood exposure is projected to be substantially greater along low elevation and low-sloping shorelines. Low coastal plain and beach developments like Kayak Point, McKees Beach, Tulare Way Beach, Spee-Bi-Dah and Tulalip Shores Beach developments, Tulalip Bay, and Priest Point are anticipated to experience rapid increases in coastal flooding with slight and near-term sea level rise. Kayak Point (Site 1, Figure 5) has a similar slope to the other beach developments listed above and is a good example. With just 0.25m of sea level rise, the flood extent associated with the 10-yr recurrence flood along Kayak Point is projected to exceed the present-day FEMA 100-year flood extent (Error! Reference source not found.). Flood extent associated with the 10-yr recurrence flood ultimately extends across these entire coastal plain settings with ~0.75 m of sea level rise. Water depths for the 10-yr recurrence flood exceed 0.50 m over more than 50% of areas like Kayak Point with ~1 m of sea level rise (Error! Reference source not found.).



• Figure 16. Maps showing the change in flood extent and water depth associated with the 10-yr recurrence flood at Kayak Point with sea level rise of 0.25 m (A), 0.50 m (B), 0.75 m (C), and 1.00 m (D). The current FEMA 100-year flood boundary is included for reference.

Similar flood exposure exists at several other low-lying coastal plains along the marine shorelines. Estimates of flood extent and water depths for the 10-yr recurrence flood with 0.5 m of sea level rise exceed the current FEMA 100-year flood at Tulare Beach, Spee-Bi-Dah, and Tulalip Shores, Tulalip Bay, and Priest Point (Error! Reference source not found.). Nearly the entire coastal plain of Tulare Beach, Spee-Bi-Dah, Tulalip Shores, and Priest Point are estimated to be flooded by the 10-yr storm when sea level rise of 0.5 m (Error! Reference source not found.**A, B, D**). In Tulalip Bay, the area exposed to the 10-yr storm when sea level rise reaches 0.5 m is restricted to the narrow intertidal bench and is anticipated to be greater in the southern portion of the bay than in the north (Error! Reference source not found.**C**).



• Figure 17. Maps showing the change in flood extent and water depth associated with the 10-yr recurrence flood with sea level rise of 0.50 m along Tulare Beach (A), Spee-Bi-Dah and Tulalip Shores (B), Tulalip Bay (C), and Priest Point (D). The current FEMA 100-year flood boundary is included for reference.

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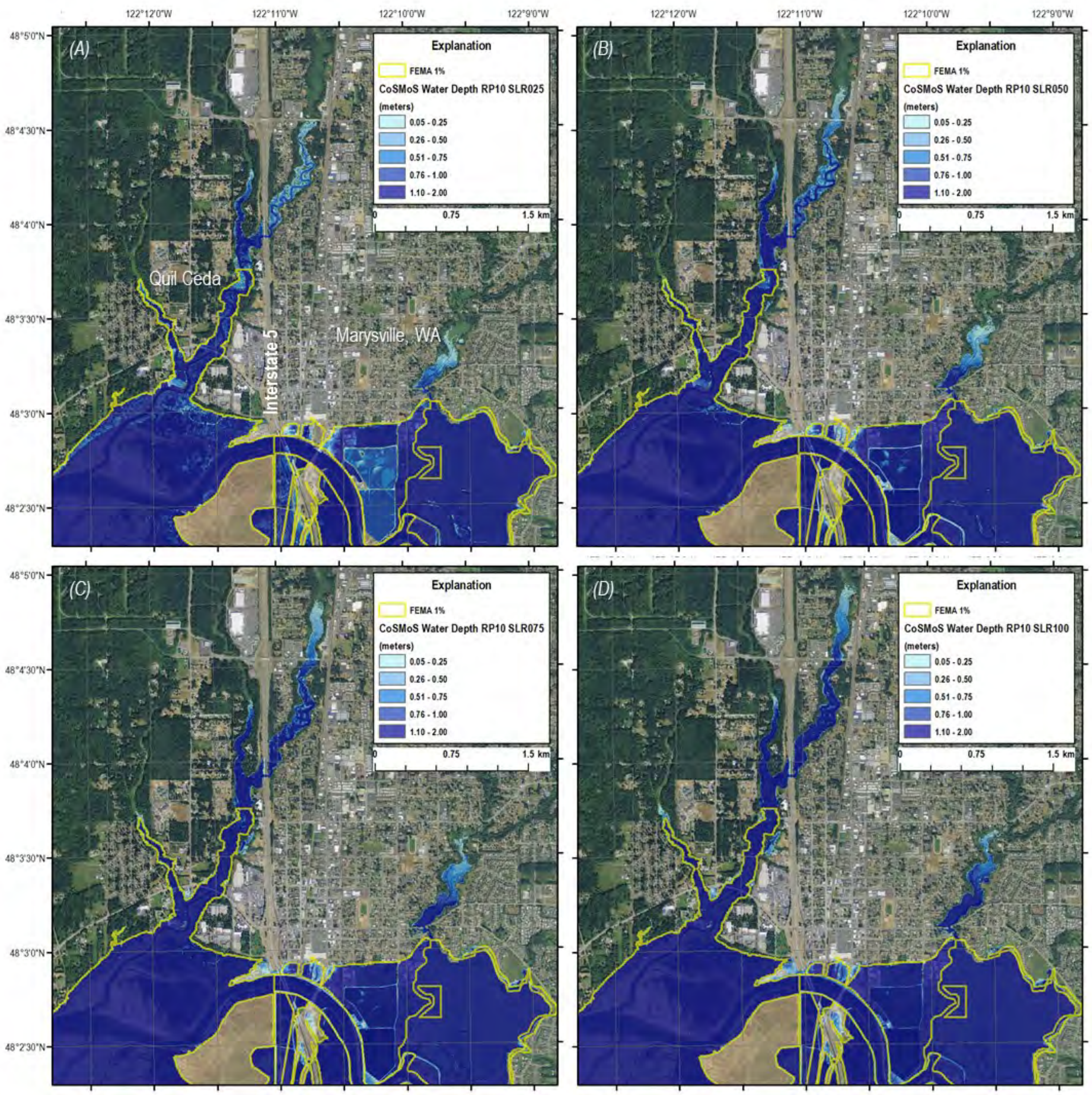
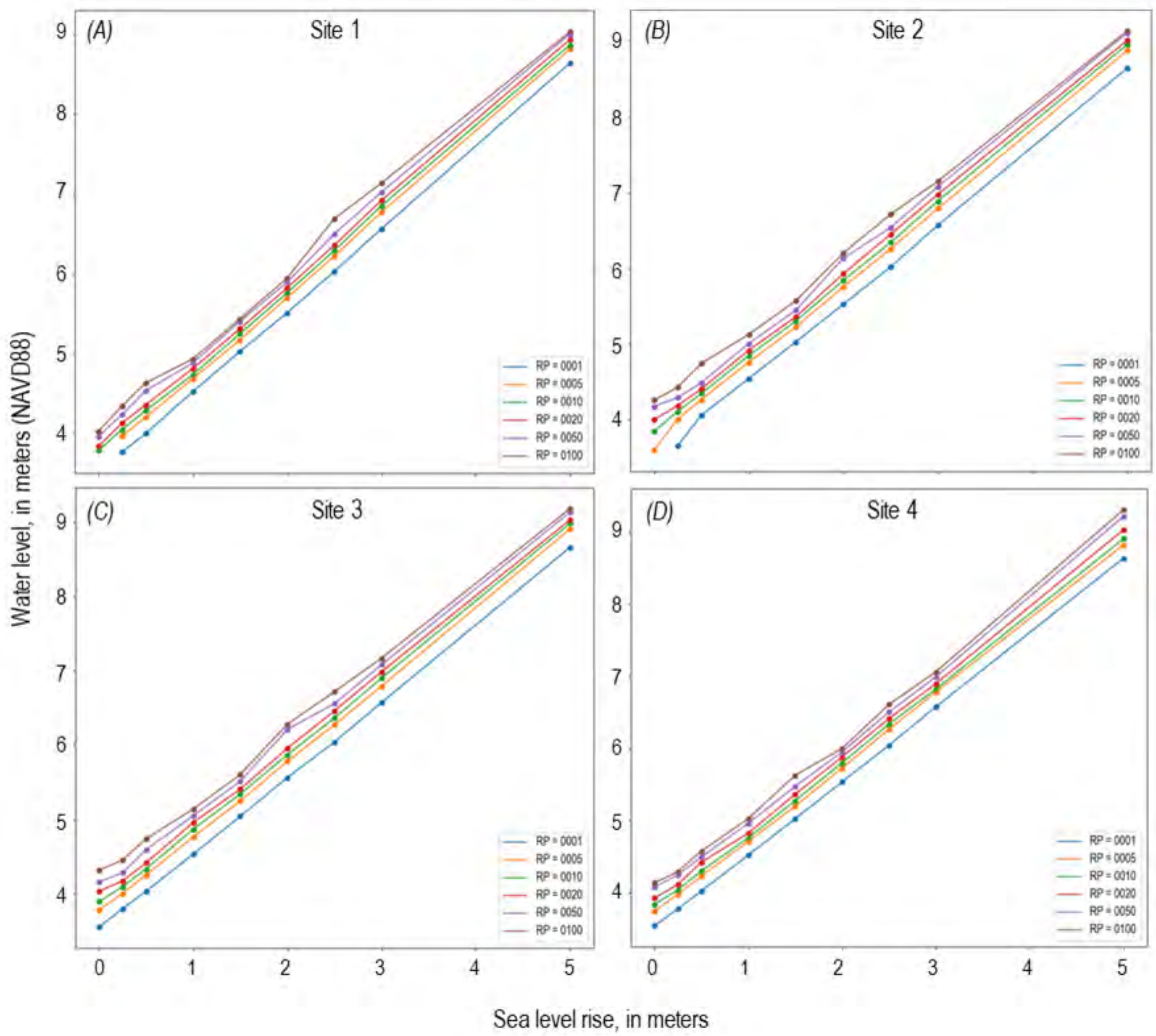
A more substantial increase in the extent of coastal flood exposure with sea level rise is projected in the southeastern portion of the study area in the vicinity of the I-5 corridor and Quil Ceda Creek that is connected to the Snohomish River estuary. **Figure 10** shows the steady progression of modeled flooding associated with the 10-yr storm under 0.25 m (A), 0.50 m, (B), 0.75 m (C) and 1.0 m (D) sea level rise. We also note that the flood estimates have greater uncertainty in the region of Quil Ceda Creek due to high uncertainty in the digital elevation data, complex morphology and roughness, and the influence of flow control structures that may not be well represented in the model. This area of concern to Tulalip Tribes warrants improvements in mapping elevations and landcover and characterizing the influence of flow control structures to water flow and water levels.



- Figure 18. Maps showing the change in flood extent and water depth associated with the 10-yr recurrence flood with sea level rise across the I-5 corridor and Quil Ceda Creek area with sea level rise of 0.25 m (A), 0.50 m (B), 0.75 m (C), and 1.00 m (D). The current FEMA 100-year flood boundary is included for reference.

- **Results: Total water level relative to sea level rise at specific locations of concern**

In general, the wave climate of the Tulalip Reservation area is relatively uniform and characterized by small to moderate wave heights ranging from 0.5 to 1.0 m height. As a result, future total water levels are anticipated to be largely driven by sea level rise in a linear manner (i.e., steadily increasing with increases in sea level). Slight non-linear responses in total water level are projected at Kayak Point when sea level reaches ~ 0.5 m and ~ 3 m and at Tulare Beach when sea level rise reaches 0.5 m and 2 m (Error! Reference source not found.**A, B**), respectively. Similar slight deviations from a linear trend just south of Spee-Bi-Dah when sea level reaches ~ 2m (Error! Reference source not found.**C),** Hermosa Point when sea level reaches ~1.5 m **(**Error! Reference source not found.**D)** and Priest Point when sea level reaches ~2.0 m (Error! Reference source not found.**G**).



• Figure 19. Plots showing projected total water level in response to sea level rise for the 10-, 20-, 50- and 100-yr recurrence storm events at Kayak Point (A), McKees Beach (B), a bluff site ~ 1 km south of McKees Beach (C), Spee-Ba-Dah bluff-backed beach (D).

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In the area of Quil Ceda Creek (Site 8) slightly higher total water level is projected for the two larger storm recurrence events (e.g., 50- and 100-yr) when sea level rises to ~ 1.50 m relative to smaller storms followed by a more linear trend after (Error! Reference source not found.**H**). The water level under a 1-yr storm does not reach the Site 8 location under current conditions, therefore the total water level curve for the 1 year storm starts once sea level reaches 0.25 m.

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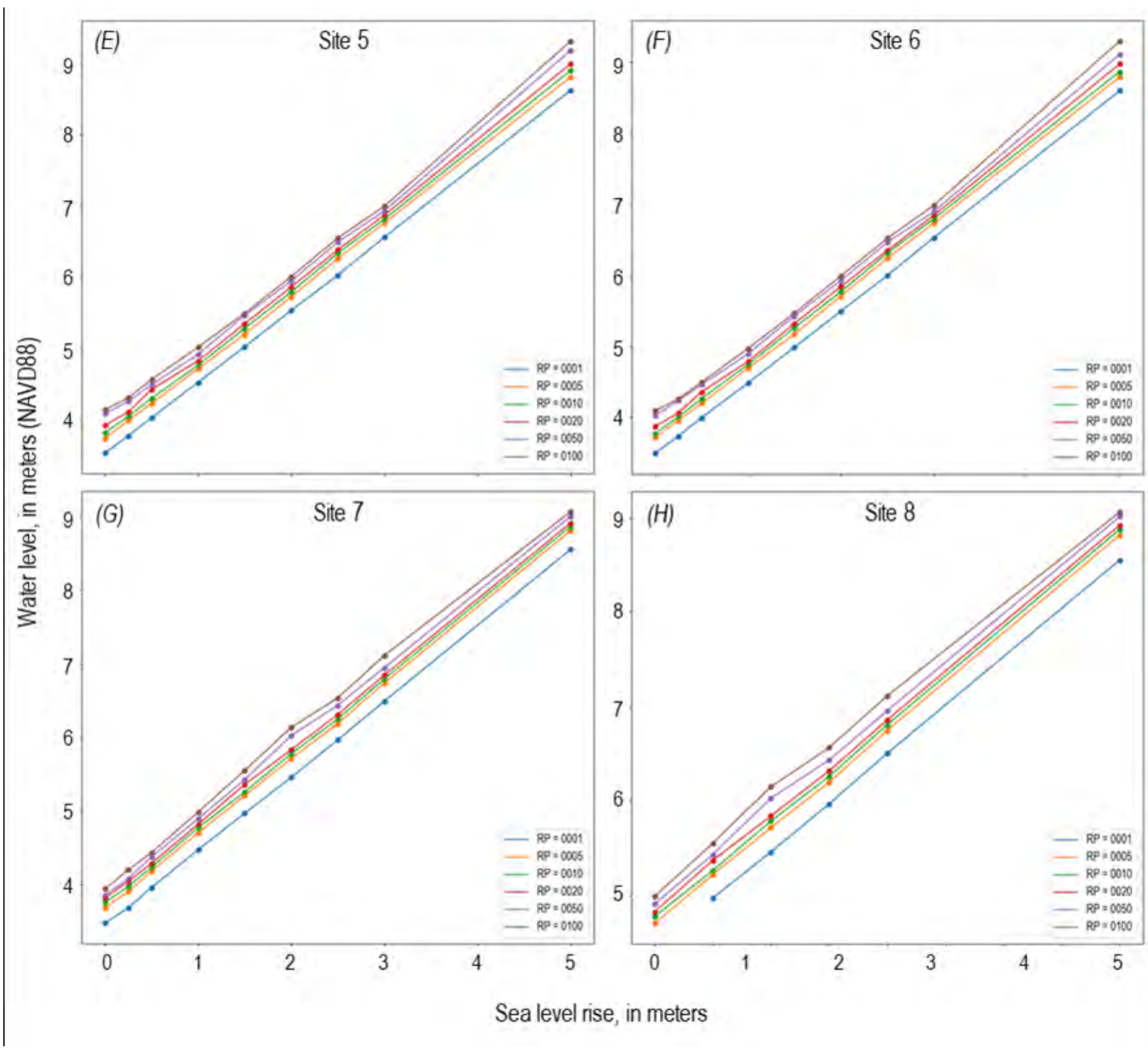
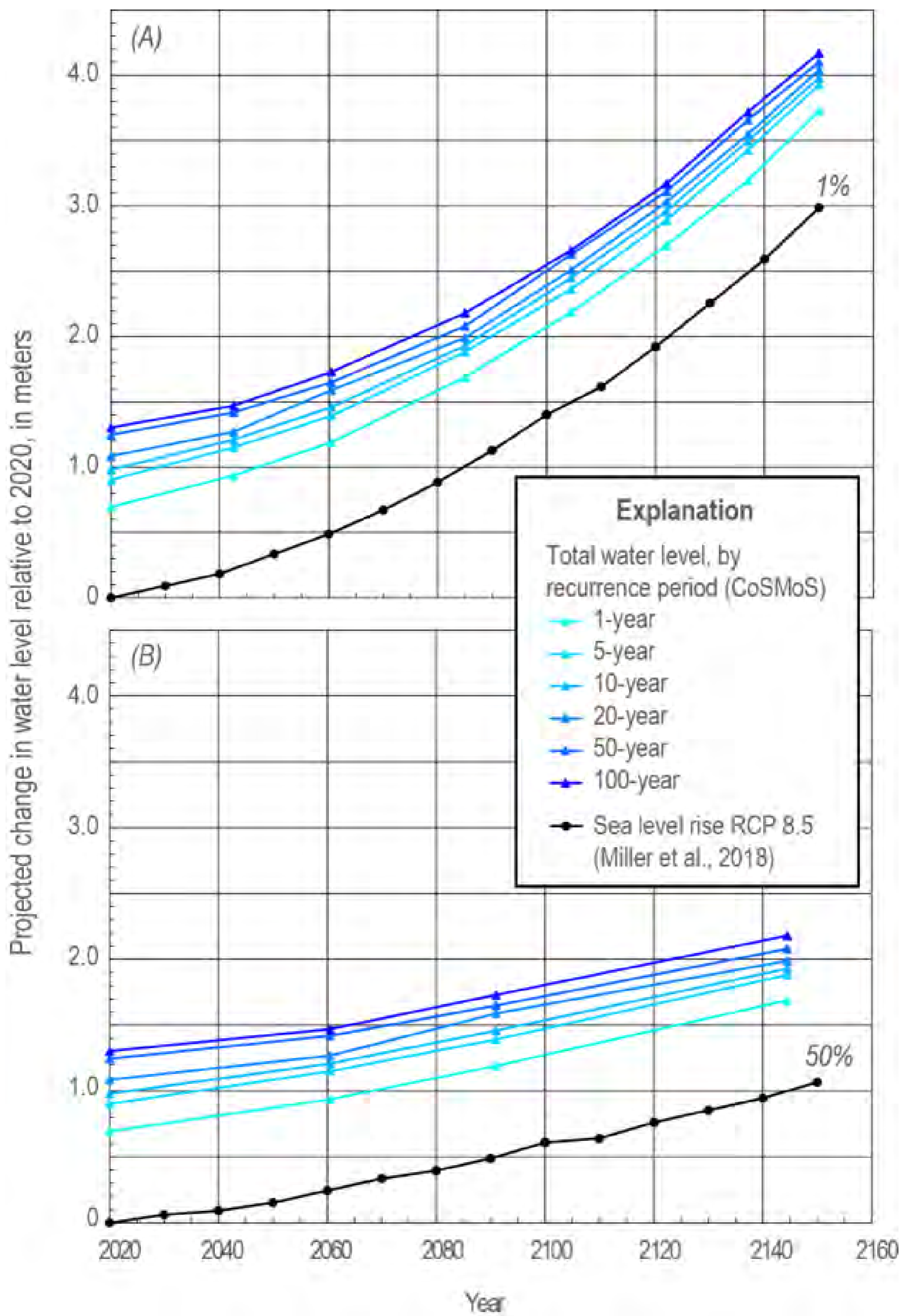


• Figure 11 (con't). Plots showing projected total water level in response to sea level rise for the 10-, 20-, 50- and 100-yr recurrence storm events at Mariposa Point I, Tulalip Bay (F), Priest Point (G) and the commercial complex at the corner of Marine Drive NE and 27th Ave NE (H). Note different y-axis in H.

-
- **Timing of projected coastal flood impacts**

The timing that coastal flooding will adversely affect people, wildlife, and habitats of concern to Tulalip Tribes is in part dependent on the timing of sea level rise and climate change. PS-CoSMoS results, based on discrete sea level scenarios to remain relevant as new sea level rise rate projections are generated, can be easily related to timing by a crosswalk with sea level rise estimates. At the time of this summary, the spatially downscaled, probabilistic sea level rise projections of Miller et al., (2018) provide the best available science of sea level rise projections for Washington State. Miller et al. (2018) estimated sea level rise to the year 2150 for two of the Inter-Governmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) Representative Carbon Pathways (RCP 4.5 and 8.5) and 10 probabilities or likelihoods of sea level rise occurrence along the entire Washington State shoreline.

An example of this crosswalk is shown in Error! Reference source not found. that overlays the CoSMoS outputs with the 1% and 50% sea level rise likelihoods of Miller et al. (2018) for Site 5 at Hermosa Point. The sea level rise projection at Hermosa Point is representative and applicable to the broader Tulalip marine shorelines. Whereas the 50% and 1% likelihood sea level rise projections increase to ~0.6 m and ~1.4 m by 2100 at Site 5, total water level accounting for the additional influence of sea level anomalies, storm surge and waves resolved by PS-CoSMoS, are computed to reach closer to 1.7 m and 2.5 m, respectively (Error! Reference source not found.). As observed in Error! Reference source not found., extreme total water levels along Tulalip marine shorelines are ~0.7 to 1.4 m higher than just the position of sea level. The combined assessment of CoSMoS storm water levels and sea level rise better resolve the total risk of coastal flooding than simple bathtub type sea level rise viewers that don't account for storm effects in a dynamic manner and that may vary locally due to fetch, wave climate, and local shoreface morphology. Comparing the estimated change in extreme water levels in Error! Reference source not found. and sea level rise in Error! Reference source not found.**A**, a projected area of between 2.75 to 3.25 km^2 across the study area is anticipated to become exposed to coastal flooding by the year 2100 for the 50% and 1% sea level rise likelihoods, respectively accounting for coastal storms.



- Figure 20. Plots showing projected total water level in response to sea level rise for the 1-, 5-, 10-, 20-, 50- and 100-yr recurrence storm events at Mariposa Point (Site 5, Error! Reference source not found.) for the 1% (A) and 50% (B) likelihood sea level rise projections of Miller et al. (2018).
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For sites like Kayak Point, where the average elevation of the coastal plain is ~3.75 to 4.25 m (NAVD88), as little as 0.25 to 0.50 m of sea level rise is projected to lead to extensive flooding by 10-yr storms (Error! Reference source not found.). The timing that flooding of the coastal plain under a 10-yr flood above the elevation zone of 3.75 to 4.25 m NAVD88 (Error! Reference source not found.**A**) and associated with 0.25 to 0.50 m of sea level rise under the 1%

likelihood of sea level rise is anticipated to occur between 2045 and 2060 (Error! Reference source not found.**A**). Similar timing for coastal flooding by the 10-yr storm is expected along Tulare Way Beach, Spee-Bi-Dah, and Tulalip Shores Beach developments of similar elevation, although McKees Beach and portions of and Priest Point which are slightly lower (~3.50 to 3.75 m) may experience impacts sooner. The area of Quil Ceda near Site 8 (Error! Reference source not found.) which is much lower-gradient than the marine shorelines and vulnerable once water levels exceed the elevation of the protective marshes, is anticipated to see substantially more flooding with sea level rise of ~ 0.5 m expected by 2060 (Error! Reference source not found.**A**) under the 1% likelihood estimate of Miller et al. (2018).

• Summary

The Puget Sound Coastal Storm Modeling System (PS-CoSMoS) was implemented along the Tulalip Tribes Reservation shorelines. Maps and plots provide estimates of the extent and frequency, that the coast is anticipated to experience vulnerability to coastal flooding and associated impacts of sea level rise accounting for tides, sea level anomaly, storm surge, and the effects of waves. Model outputs showed excellent agreement with 30 years of measured water levels and the current 100-year FEMA flood hazard zone. The additional flood outputs in the form of GIS vector shapefiles of flood extent and raster geotiffs of extreme water levels, depths, velocities, and durations of floods associated with the daily, 1-, 5-, 10-, 20-, 50- and 100-yr recurrence storm events, provide diverse information and tools to support vulnerability and adaptation planning across a wide set of concerns.

The Tulalip Tribes Reservation shorelines are anticipated to experience additional flooding across an area of 2.75 to 3.25 km^2 by the year 2100 for the 50 or 1% likelihood of sea level rise, respectively, and up to 4 km^2 with 2 m of sea level rise. Most of the increase in area flooded is projected to occur along the I-5 corridor and Quil Ceda Creek area, an important economic development zone for Tulalip Tribes. Uncertainty in land surface and estuary channel elevations, vegetation cover, and flow control structures across the Quil Ceda coastal plain are important information priorities to refine and better resolve the flood exposure of the area. Cross-walking the CoSMoS flood projections with the best available science estimating sea level rise (e.g., Miller et al., 2018) indicates that flooding associated with 10-yr coastal storms into the Quil Ceda area will likely begin with ~0.5 m of sea level rise expected by 2060. It is important to note, that this area is most exposed to riverine flooding that is not accounted for in this study but underway in a separate effort.

Less extensive flooding of <1.0 km^2 area is projected for 1-2 m of sea level rise along marine shorelines that are composed of steeper bluff-backed beaches. Even so, projections of the increase in frequency of higher water levels and wave events associated with sea level rise indicate that the low-lying beach developments of Kayak Point, McKees Beach, Tulare, Spee-Bi-Dah, Tulalip Shores, and Priest Point will be extensively flooded by 10-yr recurrence floods with 0.25 to 0.50 m of sea level rise anticipated between 2045 and 2060 under the 1% likelihood sea level rise scenario of Miller et al. (2018). Perhaps equally important and of concern are the effects of the projected sea level rise and storms to the area's coastal bluffs. Water levels reaching 0.7 to 1.4 m higher than today with as little as 0.25 to 0.50 m of sea level rise is expected to substantially increase bluff recession rates along Tulalip shorelines which is known for having some of the highest observed historical recession rates across Puget Sound. These results point to the need to better understand and predict the vulnerability of coastal bluffs and beaches to greater erosion as wave energy is translated higher in the tidal regime.

• Acknowledgments

We thank Nathan vanArendonk and Sean Crosby of the USGS for their efforts in helping to construct the models and conduct related field efforts to better understand wave runup and beach changes in response to storms and wave events. We also acknowledge the efforts of Callie Little and Bob Mitchell of Western Washington University who helped to collate and analyze available bluff recession data along the Tulalip shoreline and assess the relative contributions of factors driving bluff change. This work benefitted from the local knowledge of several Tulalip Tribes Natural Resources Department staff including Phil North, Valerie Streeter, Lucas Rabins, Todd Zackey, and Michelle Totman.

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Appendix G: User Guide for Coastal Storm Modeling System Data Viewer

Tulalip Tribes of Washington

Coastal Storm Modeling System (CoSMoS) Data Viewer………………………………………………………111

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TDS-GIS
4-4-2023

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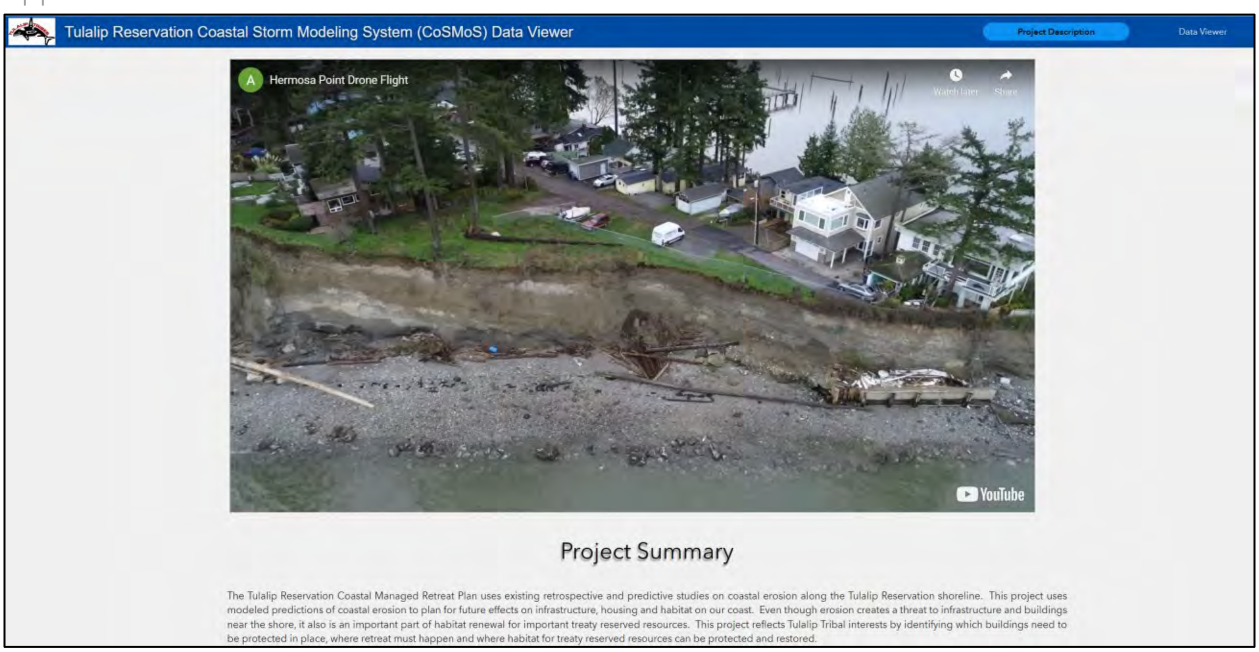
Introduction

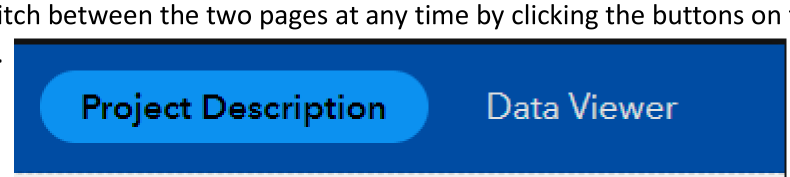
The Tulalip Tribes Coastal Storm Modeling System (CoSMoS) Data Viewer is an ArcGIS Online hosted application developed by the Tulalip Tribes/ Quil Ceda Village Geographic Information Systems (GIS) department. The application displays utilities, buildings, as well as other infrastructure of the Tulalip Reservation and surrounding areas that may be impacted by sea level rise. Data on sea level rise was obtained from the USGS as part of the Tulalip Reservation Coastal Managed Retreat project, the goal of which is to use modeled predictions of coastal inundation and erosion to plan for the future effects on infrastructure, housing, and habitats of the Tulalip Reservation's coast line. The data displayed in the application combines USGS CoSMoS sea level rise modeling with Tulalip Tribes infrastructure data to show areas of the Reservation that are vulnerable to flooding and erosion and aid the Reservation in planning for future sea level rise-related events.

The Tulalip Tribes CoSMoS Data Viewer is publicly accessible and can be reached via desktop web browser at https://experience.arcgis.com/experience/92a675a17570406ea6acfcd912f3f925/. Mobile web browsers are not recommended. Questions regarding the application can be directed to the Tulalip Tribes GIS department at gismailbox@tulaliptribes-nsn.gov. For more information regarding CoSMoS, please see the USGS website at https://www.usgs.gov/centers/pcmsc/science/coastal-storm-modeling-system-cosmos. Tulalip Tribes provides this data "as is." Tulalip Tribes does not make any guarantees or warranties concerning the accuracy of the information contained in the geographic data. Tulalip Tribes assumes no liability or responsibility for errors or inaccuracies.

Application Overview



The CoSMoS data viewer is an ArcGIS Online Experience with two pages: Project Description and Data Viewer. Users can switch between the two pages at any time by clicking the buttons on the upper-right portion of the screen.



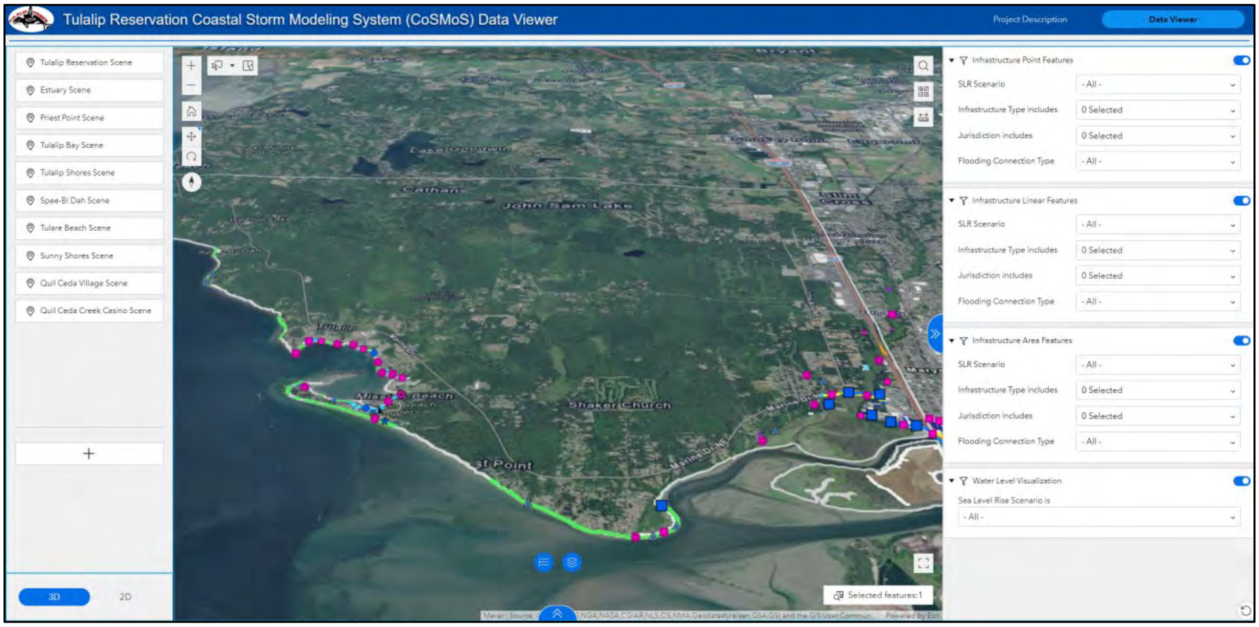
The Project Description page is the default landing page for users accessing the application for the first time. This page is vertically scrolling and offers background information for the CoSMoS Data Viewer and the Tulalip Reservation Coastal Managed Retreat project. This page is important for understanding some of the data that is presented within the Data Viewer portion of the application. The Project Description page provides the Sea Level Rise (SLR) probability matrix, which lists the probability of SLR scenarios occurring at approximate years. For instance, the matrix shows that by the year 2040 there is a ten percent chance of SLR025 (0.25-meter SLR). The matrix also shows that by 2080, there is a fifty percent chance of 0.5-meter SLR as well as several other SLR scenarios with their probability date.

The Project Description page also describes the SLR scenarios and recurrence periods that are used in the Data Viewer. These are:

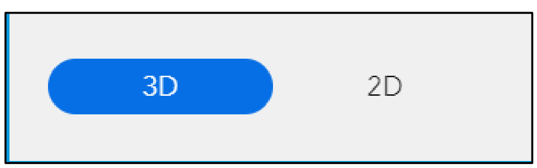
- 0.25-meter SLR, Average Daily Tide
- 0.25-meter SLR, 20-year Storm Event
- 0.25-meter SLR, 50-year Storm Event
- 0.25-meter SLR, 100-year Storm Event
- 0.25-meter SLR, Average Yearly King Tide
- 0.5-meter SLR, Average Daily Tide
- 0.5-meter SLR, 20-year Storm Event
- 0.5-meter SLR, 50-year Storm Event
- 0.5-meter SLR, 100-year Storm Event
- 0.5-meter SLR, Average Yearly King Tide
- 1-meter SLR, Average Daily Tide
- 1-meter SLR, 20-year Storm Event
- 1-meter SLR, 50-year Storm Event
- 1-meter SLR, 100-year Storm Event
- 1-meter SLR, Average Yearly King Tide
- 1.5-meter SLR, Average Daily Tide
- 1.5-meter SLR, 20-year Storm Event
- 1.5-meter SLR, 50-year Storm Event
- 1.5-meter SLR, 100-year Storm Event
- 1.5-meter SLR, Average Yearly King Tide
- 2-meter SLR, Average Daily Tide
- 2-meter SLR, 20-year Storm Event
- 2-meter SLR, 50-year Storm Event
- 2-meter SLR, 100-year Storm Event
- 2-meter SLR, Average Yearly King Tide

Data Viewer

The Data Viewer page can be accessed by clicking the Data Viewer button on the upper-right portion of the screen. The data viewer provides access for viewing SLR impacted Tulalip infrastructure as well as visualization of CoSMoS SLR scenarios.



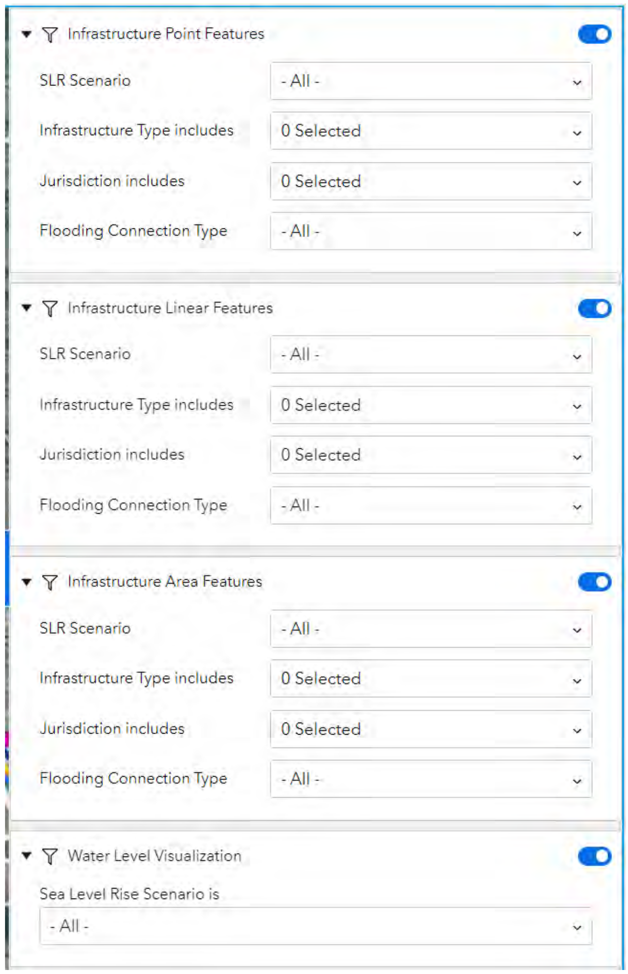
The Data Viewer allows for both 3D and 2D representations of the map and data. The default view is the 3D view, but users can switch back and forth between 3D and 2D at any time by clicking the 3D and 2D buttons on the lower-left portion of the screen.



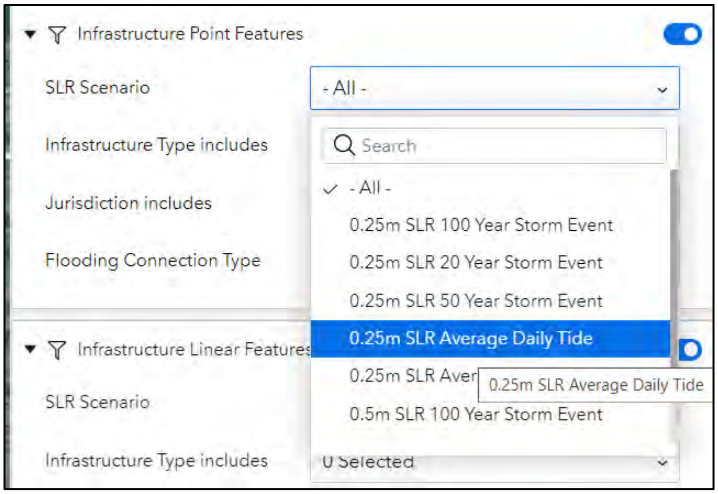
Most of the data within the Data Viewer is available in both the 3D and 2D views, however, because of performance issues with displaying large amounts of continuous data, the only visualization for USGS CoSMoS data in the 3D view is Water Level. The 2D view offers visualizations for water level, water depth, water velocity, and water duration. The information on water level, depth, velocity, and duration has been added to the infrastructure features based on their point(s) of intersection on both the 3D and 2D views. Use of either view is up to the user's personal preference.

Filters

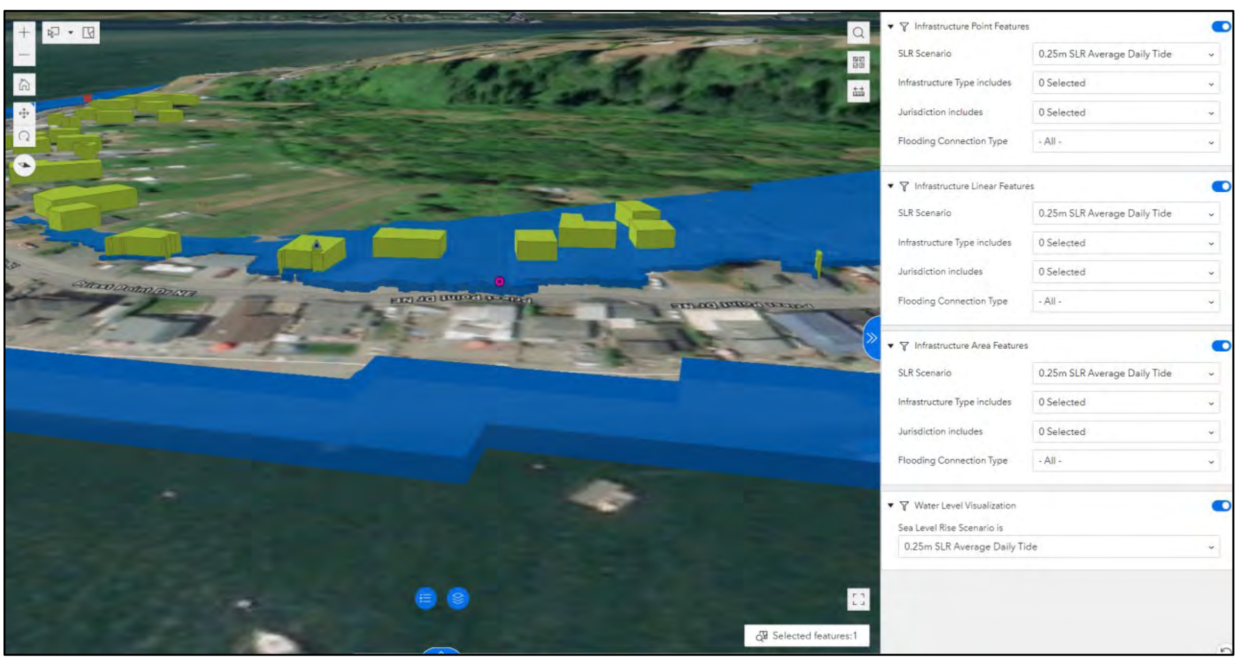
Because there is a large amount of data within the Data Viewer, the use of filters is recommended to aid in performance and understanding when using the application. Users can filter point, line, and polygon (area) features by using the pre-built filters located on the right-side of the screen.



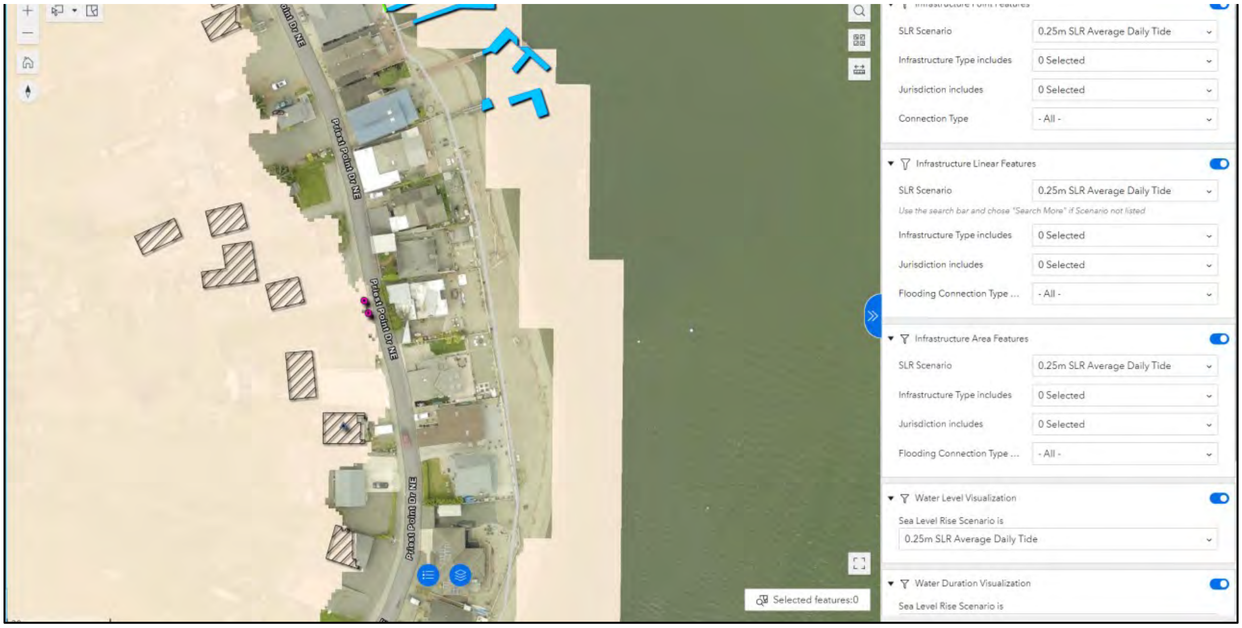
Using the filters, users can filter the infrastructure features by their SLR Scenario, Infrastructure Type, Jurisdiction, and/or Flooding Connection Type. For instance, a user only wanting to see infrastructure and visualization for 0.25-meter SLR, Average Daily Tide, would select the option shown below for all four filters. The infrastructure features can be further filtered (if desired) by selecting specific infrastructure types, jurisdictions, and connection types.



The water level visualization layer is turned off by default. To view the water level visualization, select a SLR scenario in the Water Level filter, then turn on the layer by clicking the layers button and selecting Water Level Visualization (see Legend and Layer List section). It is recommended to select a water level visualization SLR scenario before turning on the Water Visualization layer; otherwise, all water level visualization scenarios will be displayed simultaneously, affecting the performance of the application. The 2D view also offers visualizations for water depth, velocity, and duration that can be turned on in the same manner.



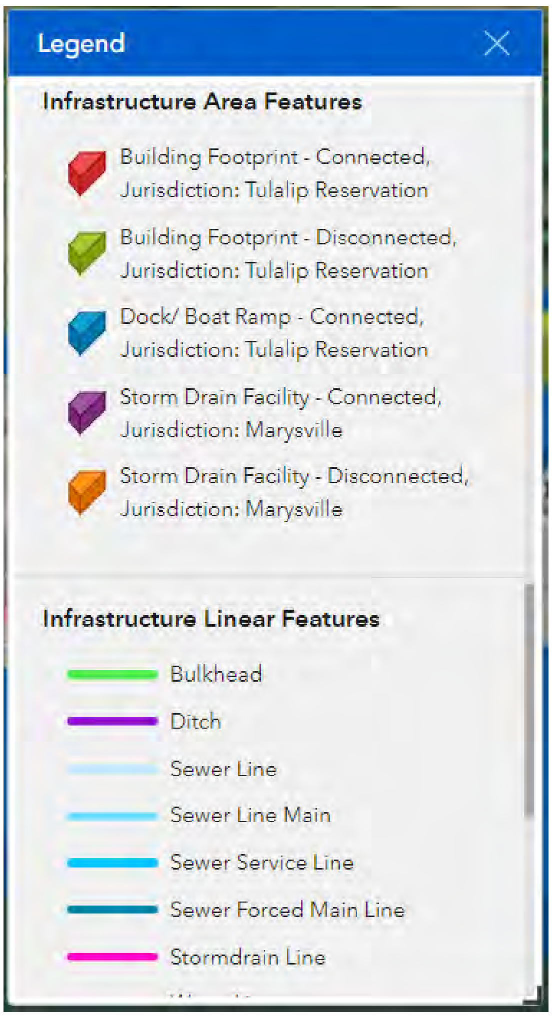
3D View of Priest Point with filters for 0.25m SLR, Average Daily Tide

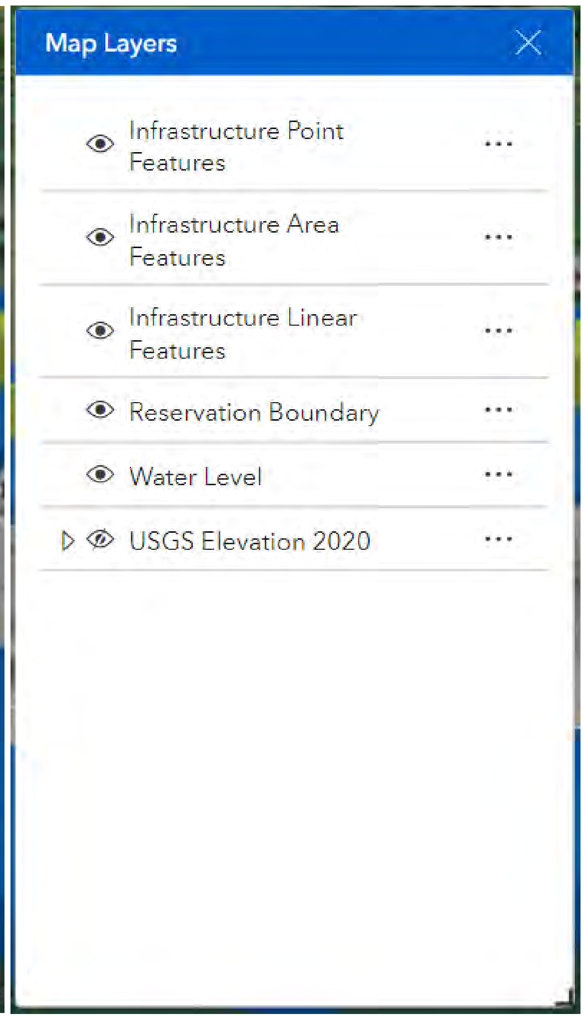


2D View of Priest Point with filters for 0.25m SLR, Average Daily Tide

Legend and Layer List

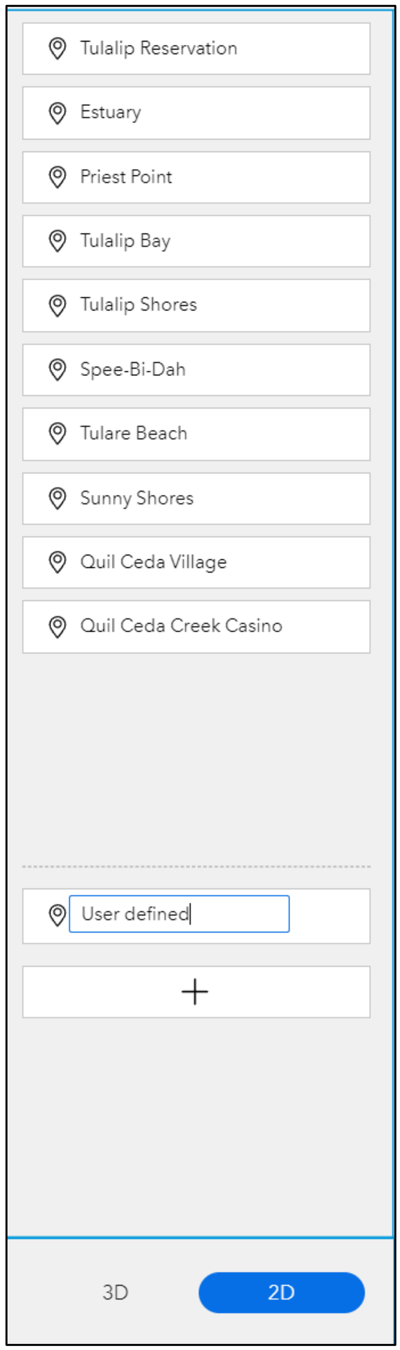
The Legend and Layer List buttons are located at the bottom-center of the screen. Clicking the Legend button will open a small expandable window that provides an explanation for all the symbols and colors displayed on the map. Clicking the Layer List button will open a small expandable window displaying all the layers in the map and allow the user to turn those layers on or off. Within the Layer List, the eye symbol indicates that the Layer is on while the crossed-out eye indicates the layer is turned off. If a blue dot is visible next to the name of the layer, it indicates that the layer is loading. This may happen with more data intensive layers, such as the water duration visualization layer in the 2D view.





Bookmarks

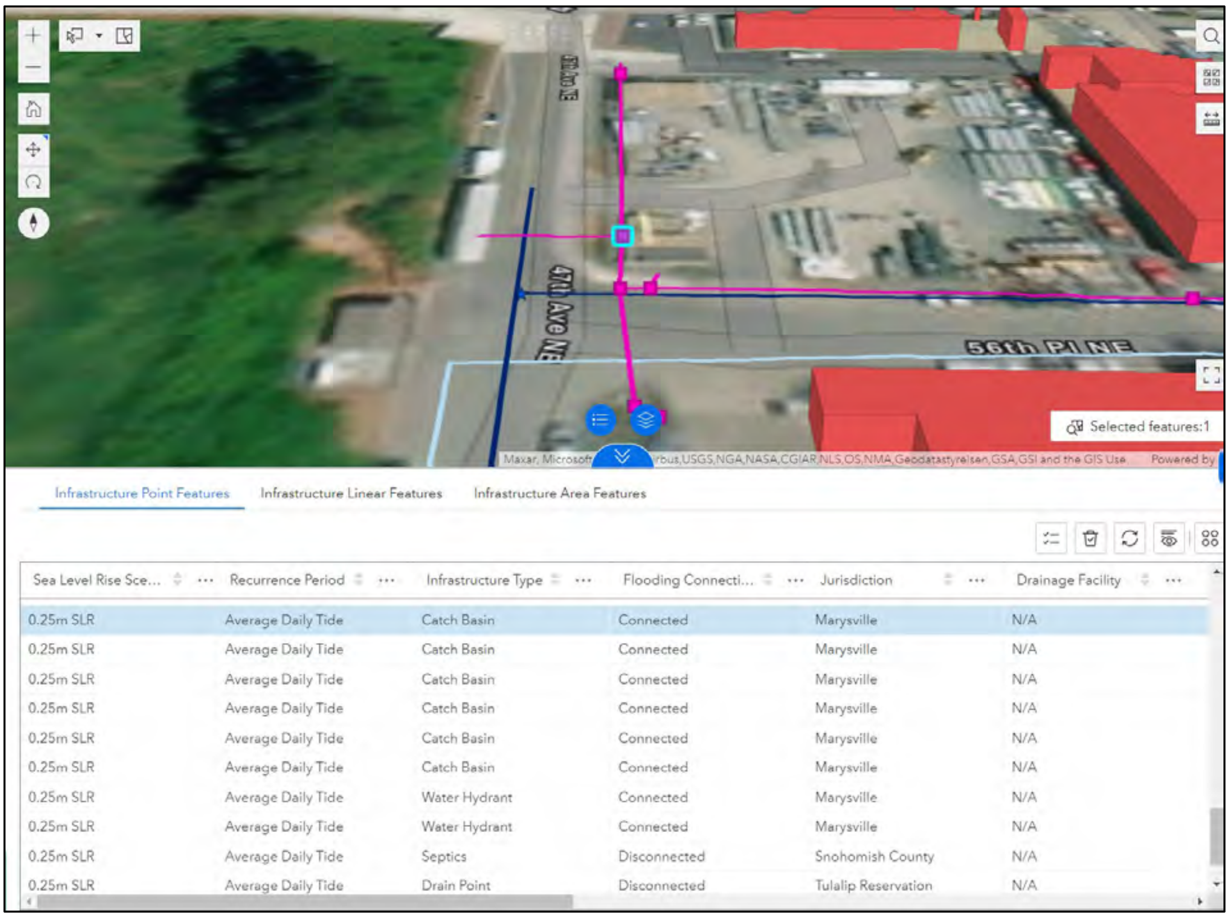
On the left side of the screen there is a list of bookmarked regions within and around the Tulalip Reservation. Clicking on each bookmark will move the map to a predetermined extent showing the named area in both the 3D and 2D views. Changing the map extent of one view will also change the map extent of the other to match. If users desire additional areas or map extents to view frequently, additional user defined bookmarks may be added using the + button located at the bottom of the list of bookmarks. User added bookmarks can be given unique names and deleted when no longer needed.



Attribute Table Panel

Below the Legend and Layer List button on the bottom-center of the screen is a tab that can be clicked to open the attribute table panel. 

Opening the attribute table panel will allow the user to view the data in the Data Viewer in table format. The table will respect the filters applied and clicking a feature will select and zoom to it on the map.

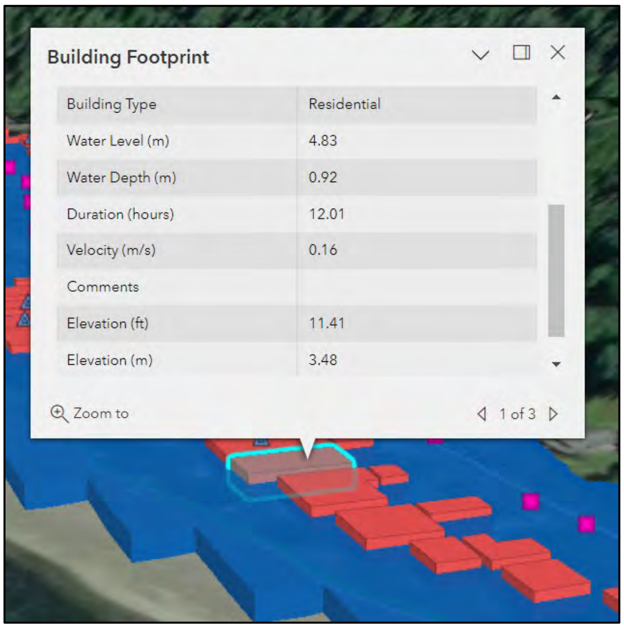


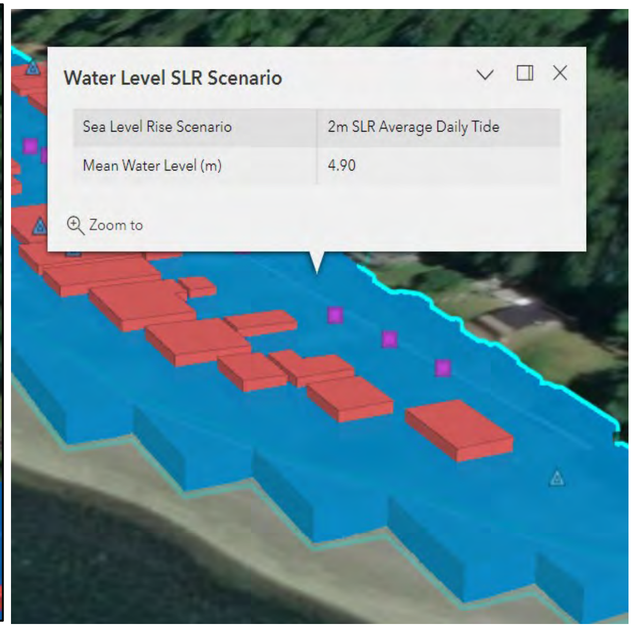
Multiple features can be selected. Using the Show Selection button will filter the table so only selected features are shown. The Clear Selection button will remove the selection and reset the table. The Actions button can be used to export the whole table or selected features in JSON or CSV formats.

There are three tables available after clicking the attribute table tab. Users can select the Infrastructure Point Features, Infrastructure Linear Features, or the Infrastructure Area Features tables by clicking the name of the table at the top of the attribute table panel. Clicking the tab again will close the attribute table panel. There is a similar tab to the left of the filters panel. The filters panel is open by default but can be closed for a larger view of the map or attribute table by clicking its associated tab.

Pop-Ups

The application includes pop-ups for users to retrieve detailed information on individual features within the Data Viewer maps. Clicking on a feature will select the feature and activate the pop-up. The pop-up is scrolling window that displays information such as the water level, depth, duration, and velocity of flooding events associated with specific CoSMoS SLR scenarios. Pop-ups for the visualization layers will display the mean water level, depth, velocity, or duration in the highlighted area for the selected SLR scenario.





Map Controls and Tools

Within the map(s) are controls and tools that can be used to navigate and manipulate the map and the features within. The navigation controls within the map(s) include the + and – buttons used to zoom the extent in and out, the home button for returning the maps to their original extent, the pan/rotate toggle buttons for 3D navigation (3D map only), and the reset orientation button for returning to map to a northern orientation. Navigation can also be accomplished using mouse/keyboard controls. For more information on navigating the map with mouse/keyboard controls, please see https://doc.arcgis.com/en/arcgis-online/get-started/navigate-scene.htm.

The tools available in the Data Viewer are the Select Tool for selecting multiple features directly from the map, the clear selection tool, the search bar, the measure tool, and the basemap gallery tool for changing the basemap from its default aerial imagery to a selection of other map types. The select tool and clear selection tool can be used in conjunction with the attribute tables to select certain features and export them to a JSON or CSV file if needed.