Appendix A:
Hazards and planning context

1. Sea level rise and associated hazards along the lower Columbia River

Sea level rise, and other anticipated impacts of climate change, exacerbate multiple natural hazards that threaten communities and ecosystems in the project area. Most of these hazards, like flooding and erosion, have long been at work in the Lower Columbia River Estuary, but are made more impactful by development and other human activities occurring throughout the last century within and outside of the immediate project area. Climate-induced changes will, in most cases, increase the risk associated with these hazards. Primary natural hazards impacting the project area, and associated changes that can be expected from climate change, are summarized in this section.

I. Flooding

Flooding is a major concern in both the Baker and Grays Bay focus areas presently and is expected to worsen as a result of climate change. Both regions currently experience damage from flooding events in most years. Flooding is driven by a combination of fluvial influence from local watersheds that can interact with tides in the Columbia River, and is also influenced by several interrelated anthropogenic factors. Columbia River fluvial effects are not a significant factor at these locations in the lower estuary, where ocean tides are the dominant forcing factor and most flood energy has been dissipated further upstream. Flow regulation in the Columbia River, through a series of dams constructed from the 1930’s to 1970’s, has significantly altered the hydrologic regime relative to historical times. Peak flood magnitudes (typically seen in the spring and early summer due to snowmelt) which may have influenced flooding further downstream in the past have been significantly reduced as a result of hydropower and flood management.

a. Baker Bay flooding

The Baker Bay focus area (Figure A.1) includes two primary waterways that drain the watershed - the Wallacut River and the Chinook River. Basin statistics for these two sub watersheds are included in Table A.1. A smaller subwatershed drained by a minor unnamed tributary is also shown.

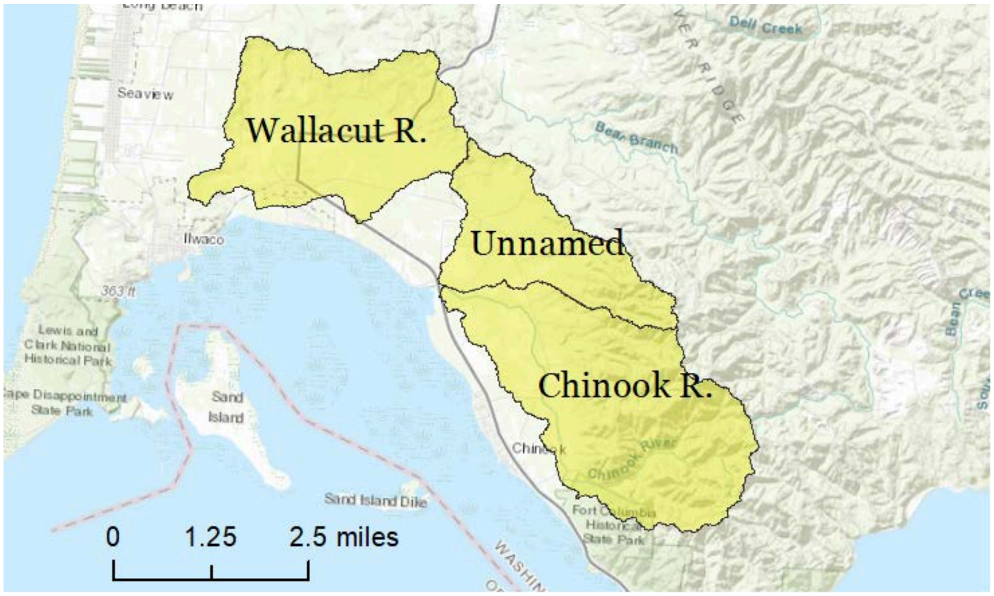


Figure A.1. The two primary sub watersheds that drain the Baker Bay focus area (Wallacut River, Chinook River), along with an unnamed sub-watershed which drains into the Chinook River.

Table A.1. Basin statistics for the Baker Bay focus area sub watersheds. Source: USGS Stream Stats.

Parameter	Wallacut River	Chinook River	Unnamed tributary
Drainage Area (sq. mi.)	5.3	7.1	3
Mean Slope (%)	6.6	31	15
% Canopy Cover*	60%	72%	73%
Max. elevation (ft.)	390	1380	1030
Min. elevation (ft.)	0	0	0
Mean elevation (ft.)	68	355	154
Mean annual precip. (in.)	79	91	83
% of area with >30% slope	0.3%	57%	17

**Values may be outdated due to ongoing timber practices in the upper portions of some watersheds.*

The subwatersheds within the Baker Bay focus area differ in ways that impact flooding here compared to the Grays Bay focus area. Baker Bay subwatersheds are considerably smaller than the Grays River, and somewhat smaller than the Deep River subwatersheds, resulting in less overall runoff from precipitation events. Another major difference is that both primary waterways in Baker Bay have tidegates installed at or near their confluences with the Columbia River (Figure A.8), whereas the Grays River tributaries do not. As a result, tidegate management in Baker Bay is a critical factor that determines flooding. For example, flooding can be a problem when high tides coincide with significant rain events. During these times, tidegates which are kept closed to prevent flooding from tides prevent runoff due to rainfall from draining out, leading to flooding. In Baker Bay, the primary tributaries are passed through culverts (and tidegates) at multiple locations upstream of the confluences, which can also back up flow behind them at these locations (Figure A.2). This differs from Grays Bay, where tributaries are spanned by bridge crossings at all locations in the floodplain. In general, whereas bank overtopping due to excess precipitation from a large drainage contributes to major flooding events in Grays Bay, flood issues along Baker Bay tributaries can largely be attributed to blockage of mainstem tributaries by flow control structures. These locations were identified and discussed at the project workshops. Many are located at major road crossings, which presents an additional safety concern when flooding prevents access along these emergency evacuation routes.

In addition to tributary flooding, localized flooding in the city of Ilwaco due to rainfall runoff is presently a concern. Stormwater projects at the Port of Ilwaco that are currently underway will alleviate some of these problems. Solutions for other locations were discussed with stakeholders during the project workshops.

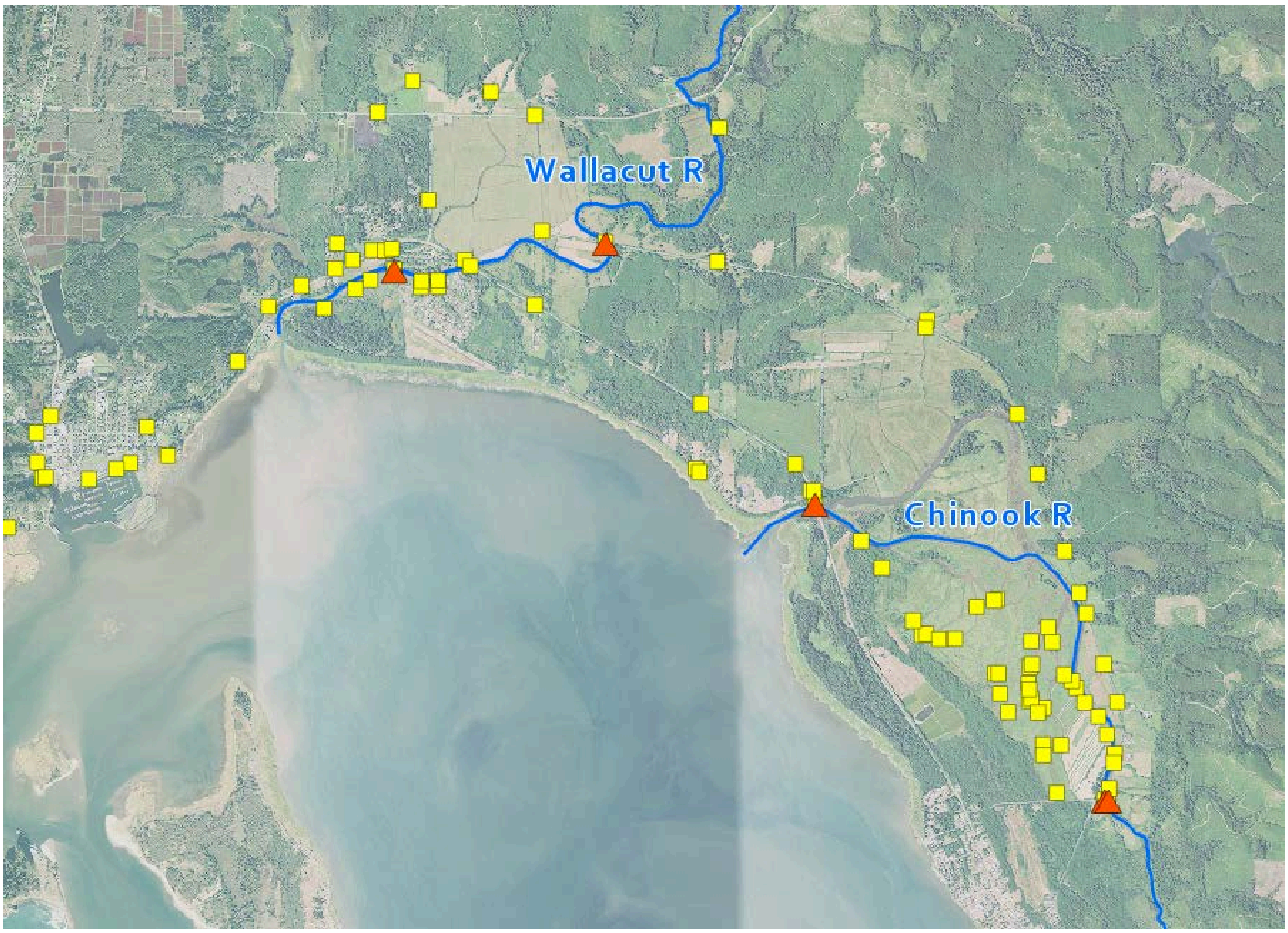


Figure A.2. Flow control structures in the Baker Bay focus area floodplain. Tidegates and culverts blocking the major tributaries (Wallacut and Chinook rivers) are shown as red triangular features.

At present, Pacific County does not have a comprehensive flood management plan. Flooding problems and mitigation measures are addressed at a coarse scale in the County's Comprehensive Plan and Emergency Management Plan. The Federal Emergency Management Agency (FEMA) completed a Flood Insurance Study for Pacific County in 2015 as part of the National Flood Insurance Program (NFIP). This study produced preliminary Flood Insurance Rate Maps (FIRM) and flood risk information, including modeled estimates of 100-year flood magnitudes. The FEMA 100-year flood extent for the Baker Bay focus area is shown in Figure A.3.

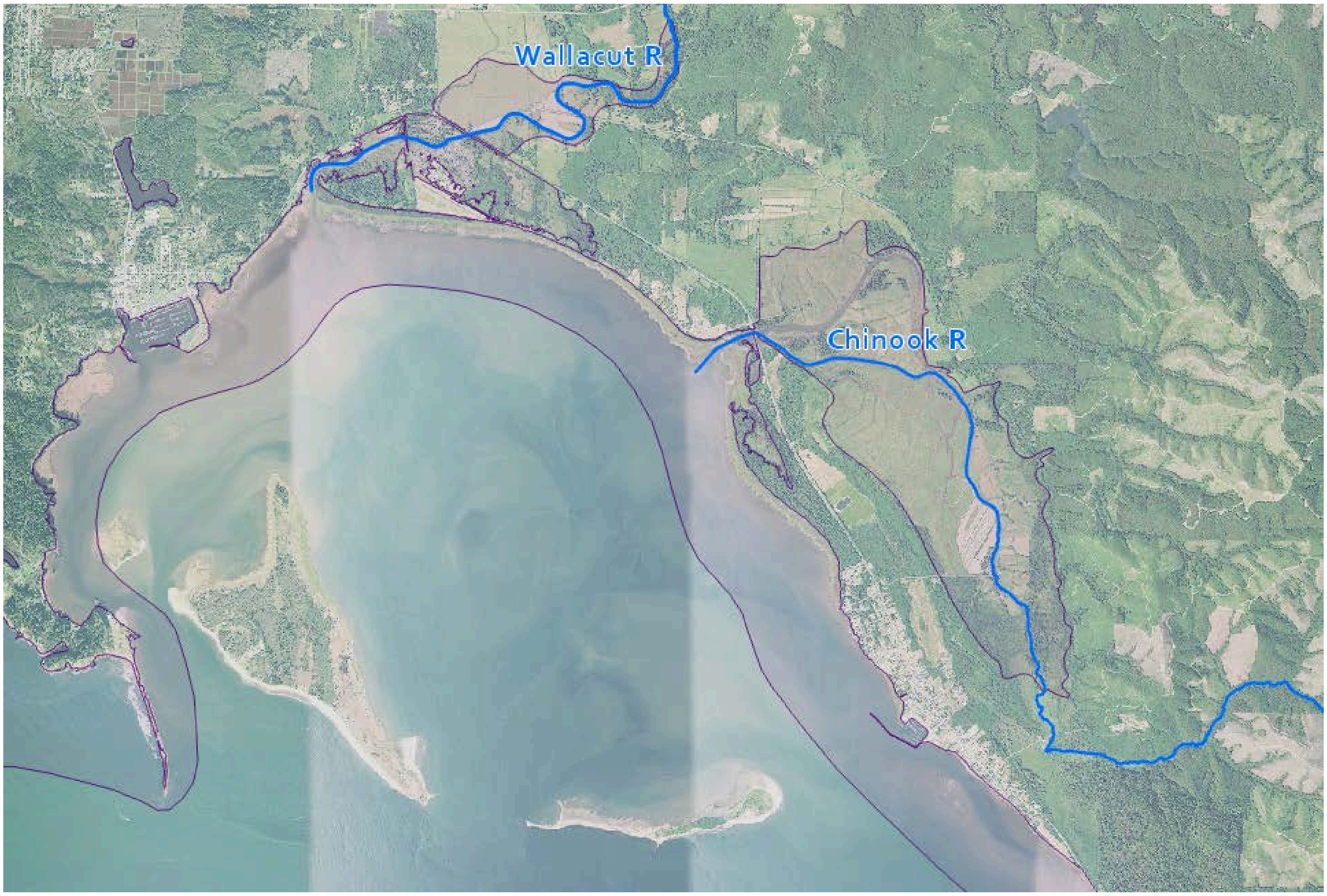


Figure A.3. Shaded extent of FEMA 100-year flood zone overlaid on aerial image of the Baker Bay focus area (FEMA, 2015).

Similar to Grays Bay, flood control measures in Baker Bay began shortly after European settlement in the late 19th century. The Wallacut Diking District was established in 1910. The area around Chinook was included in Flood Control District No. 1 when it was formed in 1960. Since then flood control authorities for areas in Baker Bay have largely been dissolved. Pacific County's current flood control authority is the Flood Control Zone District, established in 1985, but the active sub-zones it encompasses include drainage areas within Long Beach Peninsula only.

We are not aware of any long-term stream gauging efforts, current or historical, for streams in the Baker Bay focus area. Presence of tidegates along both the Wallacut River and Chinook River could complicate statistical hydrologic analyses derived from these data.

b. Grays Bay flooding

The Grays Bay focus area (Figure A.3) includes two primary waterways that drain the watershed - the Grays River and the Deep River. Basin statistics for these two sub-watersheds are included in Table A.1.

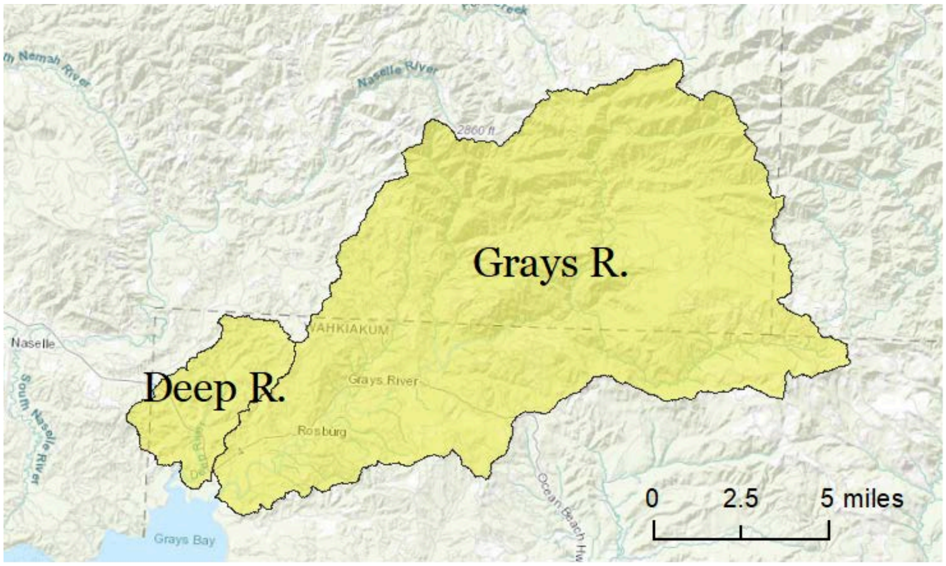


Figure A.4. The two primary watersheds that drain the Grays Bay focus area (Deep River, Grays River).

Table A.1. Basin statistics for the Grays Bay focus area sub-watersheds. Source: USGS Stream Stats.

Parameter	Grays River	Deep River
Drainage Area (sq. mi.)	123	11.7
Mean Slope (%)	29.4	25.7
% Canopy Cover*	75%	61%
Max. elevation (ft.)	3030	1060
Min. elevation (ft.)	0	0
Mean elevation (ft.)	1070	201
Mean annual precip. (in.)	113	102
% of area with >30% slope	41	39

**Values may be outdated due to ongoing timber practices in the upper portions of some watersheds.*

Flooding along the Grays and Deep rivers has been a regular occurrence throughout history (Figure A.5). Europeans settled the region in the mid to late-1800's and began installing localized diking structures to provide flood protection for farms and homesteads. Building and maintenance of these structures, as well as tide gates and streambank protection features, continued through the establishment of the Grays River Diking District (superseded by the Grays River Habitat Enhancement District) in the 1940's, in partnership with the U.S. Army Corps of Engineers. Formal flood investigation and planning began in 1974 with the Wahkiakum County Flood Damage Prevention Plan. The Federal Emergency Management Agency (FEMA) completed a Flood Insurance Study for all of Wahkiakum County in 1990 as part of the National Flood Insurance Program (NFIP). This study produced preliminary Flood Insurance Rate Maps (FIRM) and flood risk information, including modeled estimates of 100-year flood magnitudes. To date, this information has not been made available in digital, GIS formats or online map applications. The most recent flood zone map based on FEMA flood zone information was created by Wahkiakum County in 2012 (Figure A.6). In June 2023 the Columbia River Estuary Study Task Force (CREST) completed the Comprehensive Flood Hazard Management Plan (CFHMP) for Wahkiakum County (Wahkiakum County, 2023). This document is an update to the 1974 plan and provides a detailed examination of flood history, causes and effects, past and present management practices, and mitigation guidance for the Grays River watershed and other flood-prone areas of Wahkiakum County.

Figure A.5. Grays River floods. Left: historical (1910). Right: recent (Rosburg Community Hall, Dec 5 2023).

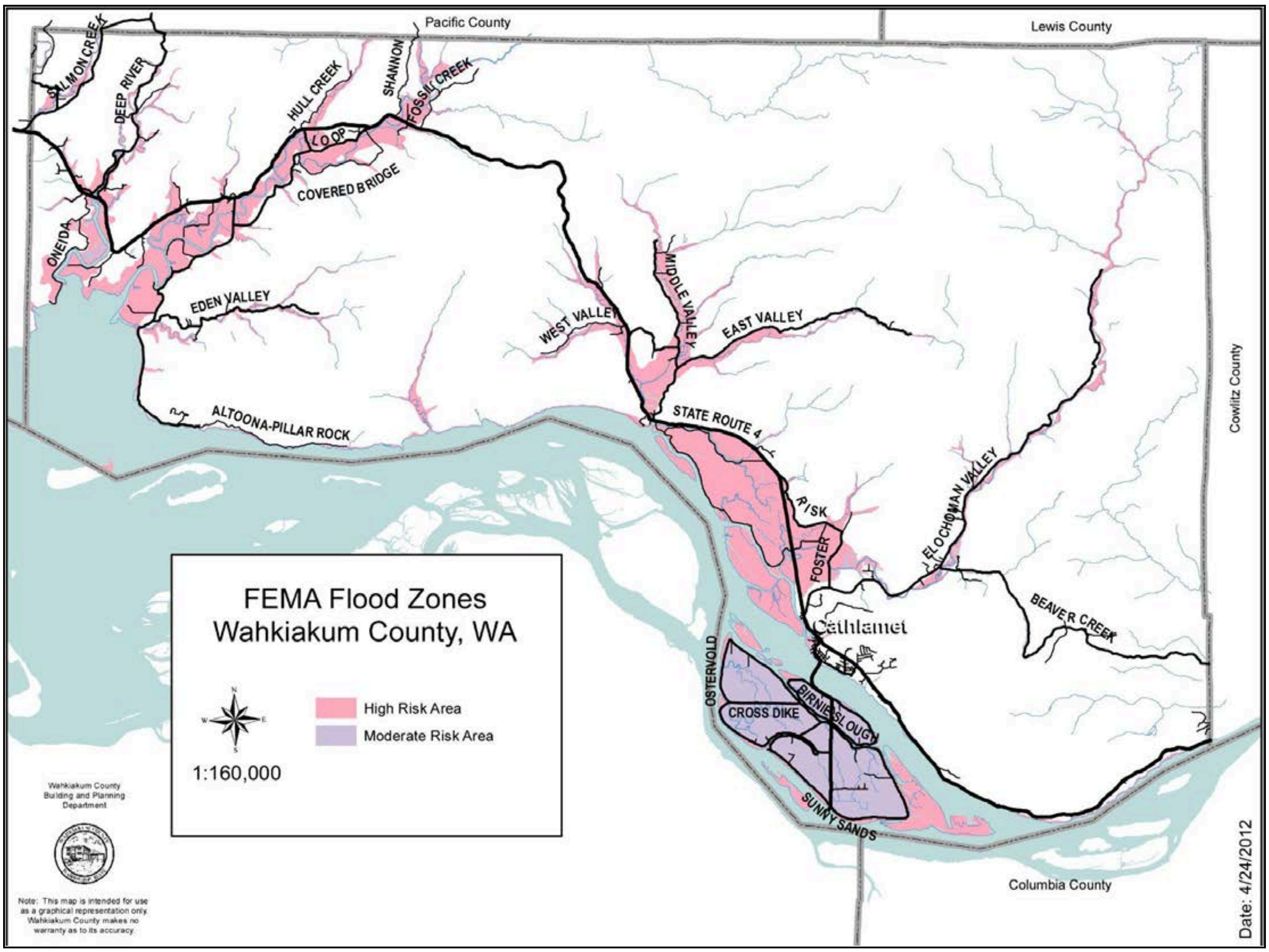


Figure A.6. Wahkiakum County Flood Zone Map from 2012.

Several interrelated factors contribute to causes and effects of flooding in the Grays and Deep rivers. These are detailed in the CFHMP, and can be summarized as follows:

- Maritime climate with heavy fall/winter precipitation, particularly during extreme precipitation events (atmospheric rivers).
- Columbia River tidal influence, which can amplify flooding effects when high tides coincide with heavy precipitation.
- Steep topography in the upper Grays River watershed increases flow (and sediment) delivery to the lower watershed.
- Low soil infiltration rates in the floodplains have reduced capacity to absorb runoff.
- Timber harvest practices in the upper watershed, contributing to increased runoff.
- Accelerated deposits of sediment in Grays Bay, due to anthropogenic activities in the Columbia River, reduce capacity of the bay to absorb flood flows.
- Flow control structures including tidegates and culverts that are improperly sized and/or poorly maintained.
- Flood control measures in the watersheds, while providing localized protection, have impacted drainage patterns and reduced capacity to absorb flood flows.
- Increased sediment supply as a result of upstream anthropogenic activity has altered drainage patterns and resulting flood capacity.

Stream gauge information, essential for flood hazard planning and emergency preparedness, is limited in the Grays Bay focus area. Currently, a single water level gauge operated by Washington Department of Ecology (DOE) provides the only continuous long-term hydrologic monitoring in the basin. The gauge has been operating since 2005 and is installed at the Covered Bridge over the middle reach of the Grays River, near the upstream extent of the floodplain (Figure A.7). Wahkiakum County funds the operation of this gauge, and the National Weather Service's Grays River flood forecast is based on its stage record. There are a number of issues with the gauge, including the fact that it has not recorded flow since 2015. Upgrading the gauge location with more modern technology, including improved flow measurements, has been identified as a potential outcome of this project (see Appendix H). Prior to installation of the DOE gauge, USGS monitored Grays River flow in the 1950's – 1970's at a few locations. Table A.2 summarizes long term stream gauging operations in the basin.

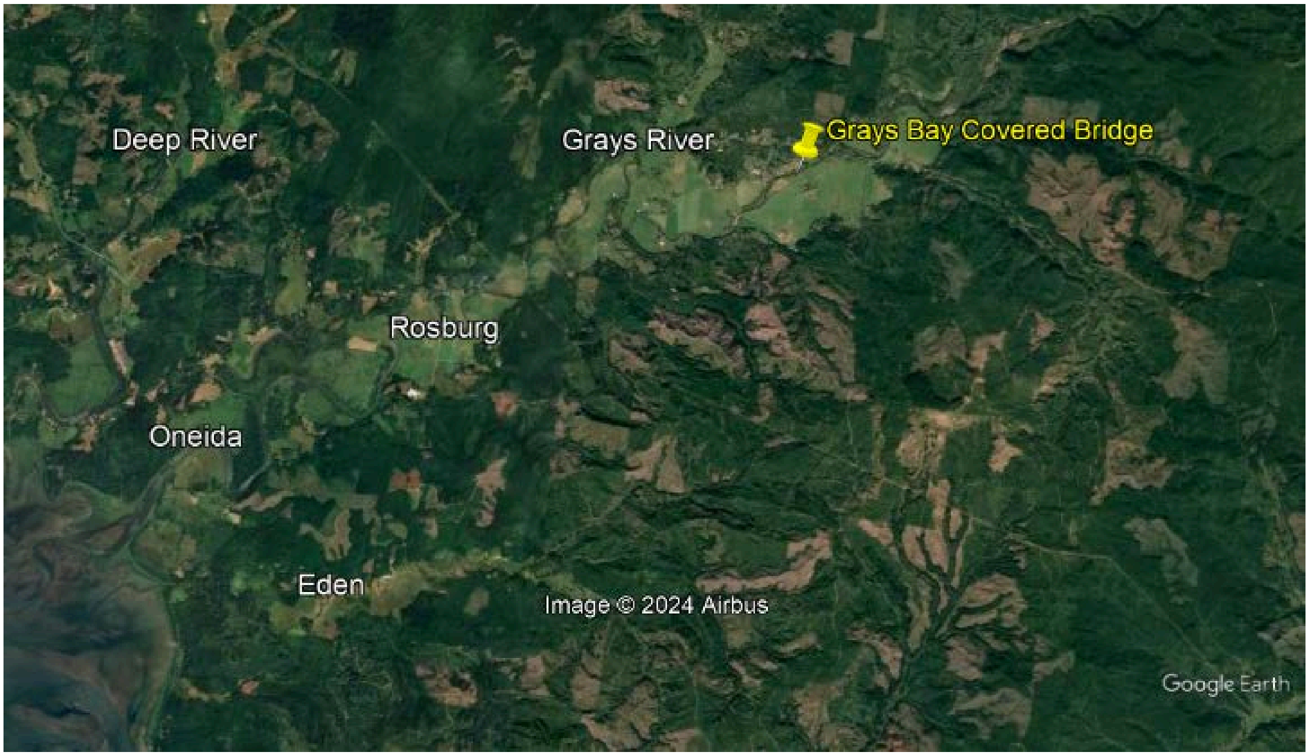


Figure A.7. Location of the WA Dept. of Ecology stage-only stream gauge at Grays River Covered Bridge.

Table A.2. Current and historical stream gauging operations in the Grays Bay focus area.

Gauge location	Owner	ID	Period of Record	Type of Record
Grays River Covered Bridge	Washington Dept. of Ecology	25B060	2005–Present	Stage & flow before 2015. Stage only since 2015.
Grays River near Grays River	USGS	14250000	1949–1951	Stage & flow
West Fork Grays River	USGS	14250500	1949–1969	Stage & flow
Grays River below South Fork	USGS	14249500	1955–1960	Stage & flow
Grays River above South Fork	USGS	14249000	1955–1975	Stage & flow

The National Weather Service (NWS) provides flood estimates, forecasts, and history for the Grays River through its Advanced Hydrologic Prediction Service. Information is based on the currently operating DOE stage-only stream gage. Table A.3a provides stage and estimated flow values for flood conditions on the Grays River. Table A.3b provides estimated flood flows at selected recurrence intervals calculated by the USGS Stream Stats software, for comparison.

With a much smaller drainage area (approximately 1/10 the size), the Deep River does not experience as severe flooding as the Grays River. However, flooding does occur and is of particular concern in locations where road access to homes and other infrastructure is impacted. Published information about flooding along the Deep River is sparse. Conversations with stakeholders during this project seem to indicate that flooding concerns along the Deep River are primarily related to localized flooding of roads and properties due to extreme high tides and/or flow control structures such as culverts and tide gates that are undersized or have been improperly maintained.Bank and levee overtopping during extreme precipitation events occurs less frequently along the Deep River compared to the Grays River.

Table A.3a. NWS flood estimates for the Grays River

Flood category	River level (ft)	Estimated Flow (cfs)
Action stage	11	6,394
Flood stage	12	8,200
Major Flood	16	18,548

Table A.3b. USGS Stream Stats flood statistics for the Grays River

Flood Recurrence Interval (Years)	Flood Flow (cfs)
2	8,270
5	11,600
10	14,100
100	19,400

Table A.4 lists peak river levels and respective dates for major flood events (16' or higher river stage, as defined by NWS) that have occurred since the DOE gauge went into operation in 2005. There is not a clear pattern over the last two decades of peak floods on the Grays River increasing in magnitude or frequency, although the last three years have had more high-water days than the prior several years did (Wahkiakum County, 2023)

Table A.4. Historic major flood events on the Grays River since 2005.*

Date	Peak Stage (ft.)
12/03/2007	16.50
01/07/2022	16.16
01/07/2009	16.15
11/07/2015	16.10
11/19/2012	16.03
11/07/2006	16.00

**Data for the major flood event that occurred on 12/5/2023 was not yet available at the time of this report. The event is not included here for that reason.*

c. Climate change effects on flooding

Flooding is expected to increase as a result of climate change due to two factors - changes in precipitation and sea level rise.

Precipitation

Climate in the two focus areas is characterized as 'mid latitude West Coast' with most precipitation received from October and April and the highest rates (daily and monthly) typically occurring from November through January. Extreme precipitation events known as 'atmospheric rivers' occur during this period which can produce several inches of precipitation in a 24-hour period. These storms are often accompanied by warmer temperatures, with precipitation falling as rain over higher elevations. This can result in melting of existing snowpack, producing additional runoff that exacerbates flooding. Atmospheric river events during late-fall and winter account for much of the flooding in the study area. Climate projections from the University of Washington Climate Impacts Group (Miller et al., 2018) suggest that these extreme precipitation events will become more common, and produce even higher precipitation totals. Averages of available projections, which vary widely, suggest that rain events with return intervals ranging from 2 to 100 years will produce 6–9 % more precipitation by the 2040's (Wahkiakum County, 2023) and as a result lead to increased flooding and flood damage.

Sea level rise

Sea level rise projections for the Columbia River in the vicinity of the project area are provided by the University of Washington Climate Impacts Group (Miller et al., 2018) The projections take into account regional estimates for vertical land movement. In general, the projections suggest that sea level will continue to rise by some amount due to warming climate, even under conservative greenhouse gas emissions scenarios. Most likely estimates of sea level rise above current sea level range from 0.4'/0.5' of rise by 2050 under low/high respective emissions scenarios, and 0.7'/1.6' of rise by 2100 under low/high respective emissions scenarios. Because the floodplains within both focus areas are influenced by Columbia River tides, sea level rise will contribute to additional flood risk.

II. Erosion

Erosion occurs when sediments that comprise a land feature are worn away by interactions with water. These may be physical forces such as currents, tides, wind and wave action from a surrounding body of water; or impact from heavy precipitation falling on a steep, exposed slope with unconsolidated sediment. They may also be chemically reactive forces depending on the composition of water and sediment. Both coastal shoreline erosion and streambank erosion present hazards at various locations in the project area.

a. Baker Bay erosion

In the Baker Bay focus area, the concern related to erosion is localized shoreline erosion along the Baker Bay coastline, primarily in the vicinity of the Port of Chinook and Chinook County Park (Figure A.8). While not specifically called out in Pacific County's Comprehensive Plan or Hazard Mitigation Plan ("*The ports of Chinook, Ilwaco, Peninsula, and Willapa Harbor are not currently at risk to coastal erosion"*: *pg. 85, Pacific County Hazard Mitigation Plan*), these areas were identified as concerns by multiple stakeholders during project workshops. The Port of Chinook erosion is also included in 'Projects and Solutions to Water Resource Problems on Lower Columbia River' (Pacific International Engineering, 2002) (Figure A.9), a planning document prepared for the Lower Columbia River Port Communities, however it is unclear if any remediation actions have occurred after that document was published. At the time of publication, shoreline erosion immediately to the east of the Chinook Marina was threatening the rubble revetment that protects the marina parking lot, which serves doubly as a disposal area for maintenance dredging of the marina basin. Over the years the revetment has sustained damage from wave action. The coastline in this area is subject to considerable wave action during winter storms, when prevailing southwest winds, combined with limited ocean influence, can generate damaging wave heights over the relatively long fetch across the mouth of the estuary.

Figure A.8. Areas of erosion east of Chinook Marina (top), and at Chinook County Park one mile southeast of Chinook Marina (bottom), due to bank revetment damage from ongoing wave action. At Chinook Marina, dredge disposal activity is evident in the adjacent parking lot. Source: Google Earth 2018 image.

Resulting failure of the revetment has led to erosion of the parking lot and resuspension of dredged materials into the Bay. Similar bank protection failures along the shoreline at Chinook County Park, approximately 1 mile to the southeast of Chinook Marina, were noted at the project workshops.

Combined effects of rising sea levels and possible increased wave action due to more intense and frequent winter storms, are almost certain to increase erosional impacts along the Baker Bay shoreline.

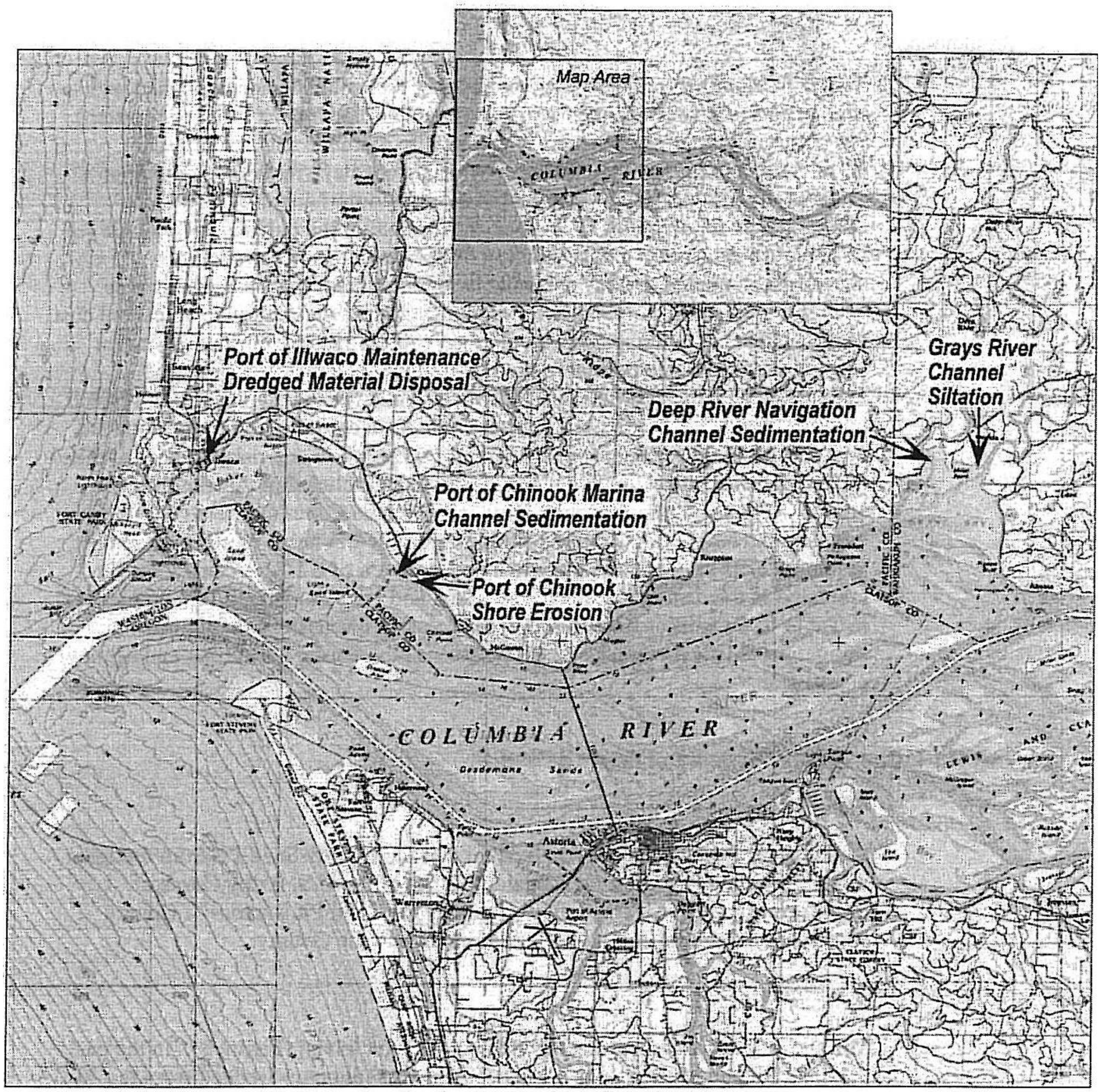


Figure A.9. Projects identified in Projects and Solutions to Water Resource Problems on Lower Columbia River (Pacific International Engineering, 2002), including Port of Chinook Shore Erosion.

b. Grays Bay erosion

The primary erosion concern in the Grays Bay focus area is streambank erosion along the Grays River and the resulting lateral channel migration and/or risk to adjacent infrastructure. Streambank erosion in the Grays River is described in the Wahkiakum County CFHMP (Wahkiakum County, 2023), and several interrelated causes are identified. Streambank erosion in the Grays River is closely tied to other problems including flooding and sediment accretion, all of which have worsened with increasing human activity.

Timber harvesting in the upper Grays River watershed peaked in the 1970s – 1980’s, and along with associated road building has likely resulted in increased sediment loads being delivered to the Grays River valley. The upper watershed has erosive soils and steep slopes, and is therefore susceptible to mass wasting after vegetation is disturbed (Wahkiakum County, 2023). Resulting transport of these sediments downstream, combined with increased streamflow during extreme precipitation events has led to changes in erosional and depositional patterns in the lower gradient floodplain, resulting in changes in the shape and direction of the river channel which can then lead to further bank erosion and channel migration (Wahkiakum County, 2023). This problem is exacerbated by the extensive conversion of riparian areas to pasture lands that occurred in the late 19th and early 20th centuries.Trees and shrubs that would normally provide bank protection from erosional stream forces have been removed from the Grays River’s banks throughout much of the valley floodplain, greatly increasing their susceptibility to erosion. Examples of Grays River streambank erosion, provided by local landowners, are shown in Figure A.10. A map from the CFHMP of identified streambank erosion areas as shown in Figure A.11. Table A.5, also from the CFHMP, provides estimated erosion and lateral channel migration rates for the Grays River from a prior study. These estimates show sharp increases in the years following peak timber harvests in the late 1970’s and early 1980’s.

Figure A.10. Streambank erosion along the lower Grays River. Sources - upper: Jackson Blalock; lower: Austin Burkhalter.

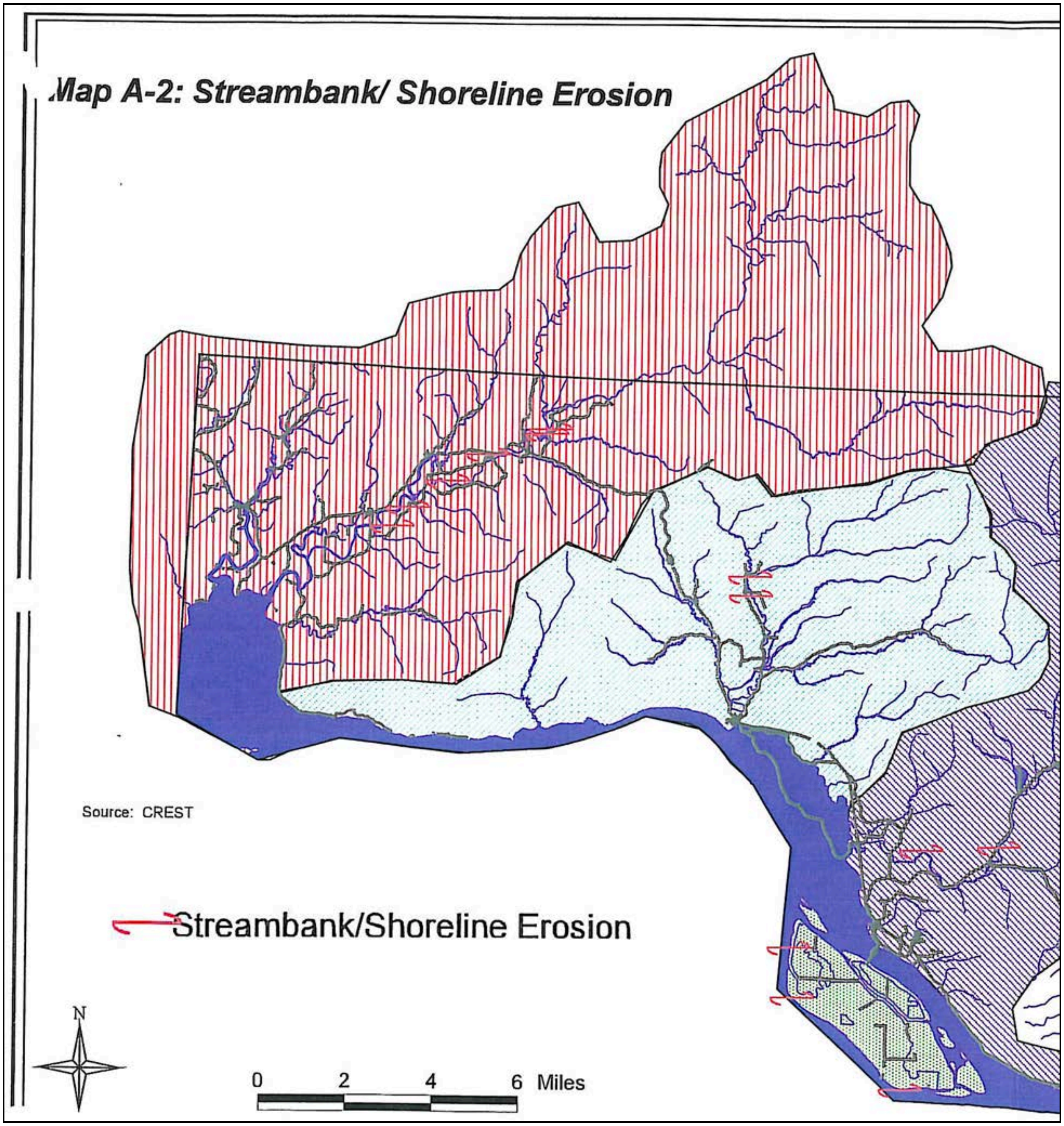


Figure A.11. Zoomed in section of CFHMP map of identified areas of streambank erosion in the Grays Bay focus area. Source: Wahkiakum County, 2023.

Table A.5. Grays River erosion rates reported in 2005. Source: Wahkiakum County, 2023 (Figure 6).

Reach/Sub-Reach	Photo Period	Erosion Rate (m^2/year)	Lateral Migration Rate (m/year)
State Route 4	1939-1966	3.94	0.17
Gorley	1966-1960	3.858	1.71

West Fork response reach	1970-1982	3.488	1.46
South Fork response reach	1982-1996	3.978	1.57
	1996-2003	8.684	3.43
Gorley	1939-1966	1.709	0.72
	1966-1960	3.364	1.38
	1970-1982	3.291	1.29
	1982-1996	6.691	2.71
	1996-2003	11.292	5.13
West Fork response reach	1970-1966	1.595	1.06
	1996-2003	5.53	0.64
South Fork response reach	1970-1966	3.041	1.35
	1996-2003	1.253	1.01

According to the CFHMP, sediment loads to the Grays River could decrease as forests recover to some degree from timber harvests that peaked in the late 70's – 80's. These trends in timber activity are based on predictions from the Grays River Watershed & Biological Assessment (May et al., 2006), however more recent confirmation of this trend, and a more contemporary assessment of sediment production and distribution in the watershed has not been completed. Even if the watershed were to produce less sediment in the future due to a reduction of forest practices, the substantial amount of sediment currently working its way downstream as a result of prior practices will continue to impact the Grays River valley for some time to come. Furthermore, any reductions could be negatively offset to some degree by an increase in sediment load due to climate change, as more severe and more frequent extreme precipitation events erode and transport larger quantities of sediment from the steeper slopes of the upper watershed.

III. Sedimentation

Accretion of sediment is closely tied to erosion and flooding, and as with those two is a major concern in both of the project focus areas, particularly in the bays themselves. Sedimentation in both bays has occurred largely as a result of major modifications to the Columbia and Willamette river systems over the past century, although in the case of Grays Bay excess sediment being delivered from the watershed may also be a contributing factor. Columbia and Willamette river dam construction has altered the timing and magnitude of Columbia River discharge, reducing high flows that historically would have re-configured drainage patterns at tributary mouths in the estuary. Pile dikes, dredging, dredge material deposits, and other related Columbia River Federal Navigation Channel activities have further modified flow patterns in the estuary. Together these upstream and local actions have contributed to the accumulation of sediment in Grays and Baker bays (Wahkiakum County, 2023). Several sediment related projects are identified in 'Projects and Solutions to Water Resource Problems on Lower Columbia River' (Pacific International Engineering, 2002) (Figure A.13), a planning document prepared for the Lower Columbia River Port Communities.

Sedimentation in Grays Bay has filled the previously maintained navigation channel connecting the Deep River to the mainstem Columbia River. Deep River is a federally authorized navigation project (authorized in March 1925) which was maintained by the Corps of Engineers Portland District until approximately 1980 when it became inactive. Since then the channel has shoaled to the point that commercial vessels can no longer access commercial sites upstream (Pacific International Engineering, 2002). Wahkiakum County has recently applied for funding through a Corps of Engineers grant program to dredge the channel and restore commercial access.

Sedimentation in Grays Bay and the lower Grays River is also perceived to be limiting the discharge capacity of the Grays River, contributing to flood risks (Wahkiakum County, 2023). Of all issues raised at the series of project workshops, flood impacts from sediment in the Grays River was the one most commonly voiced by stakeholders. The Grays River is also a federal navigation project (authorized in May 1907). Like the Deep River it has been inactive for sometime. Unlike the Deep River, it does not have a commercial facility upstream, and thus sedimentation does not present a navigation concern.

Sedimentation in Baker Bay creates a navigation and safety hazard for vessels accessing the Port of Ilwaco and the Port of Chinook, which require ongoing maintenance dredging to keep both channels navigable. Both ports support sizable fleets of commercial fishing vessels, and both are federal navigation projects (Ilwaco authorized in 1933, Chinook authorized in 1938) maintained by the Corps of Engineers Portland District (Pacific International Engineering, 2002). Due to the required frequency of maintenance dredging both ports are faced with challenges related to dredge material disposal.

IV. Habitat Loss

Columbia River floodplain and low-lying tributary floodplain comprise a large percentage of both the Baker Bay and Grays Bay project areas.Thus, potential for the loss of intact floodplain habitat resulting from sea level rise is significant. Furthermore, most of these floodplain areas transition steeply to higher elevation uplands, limiting the potential for wetland habitats to migrate upslope as currently functioning wetlands become inundated. Overall then, a net loss of tidal wetland habitat is expected to occur in both project areas as a result of sea level rise.

Tidal wetlands loss due to sea level rise would come on top of extensive human-induced wetlands habitat losses that have occurred since anglo-european settlement of the region began in the 1800’s. Estimates for overall historical tidal wetland loss in the lower Columbia floodplain range from 68% to 75% depending on wetland type (Marcoe & Pilson, 2017). Tidal wetlands losses in the Baker Bay and Grays Bay areas are consistent with these estimates.

Actual quantities of wetlands that may be impacted due to sea level rise are difficult to estimate, due to the extensive network of dikes, levees, and tidegates in both areas, which complicate inundation patterns. Impacts to existing tidal wetlands are relatively straightforward, however the trajectory of former tidal wetlands that are now diked will largely depend on the response of the system of levees and tidegates that isolate these areas, and how much inundation occurs. The Estuary Partnership completed a study of predicted wetlands impacts due to sea level rise in 2018, for the entire lower Columbia River floodplain (Lower Columbia River Estuary Partnership, 2018).. A summary of that analysis as it relates to Baker Bay and Grays Bay is included below.

i) Sea level rise impacts on Baker Bay wetland habitats

A large percentage of historical tidal wetlands in Baker Bay have been converted to human use over the last several decades. These areas are protected by an extensive system of levees, dikes, and tidegates, These protective features vary in their vulnerability to sea level rise, depending on overall height, condition, and other factors. The Estuary Partnership study included a coarse assessment of frequency of inundation (i.e. levee overtopping) of these areas over a range of sea level rise magnitudes, based on modeled water surface elevations. From this assessment we categorized the likelihood of additional wetlands loss, or gain, using two categories: likely, and possible. Under the likely scenario, levee features inundate frequently under the future water level regime, and thus higher confidence is assumed. Under the 'possible' scenario, levee features inundate less frequently, and thus wetlands behind levees 'may' assume a trajectory towards a more natural state, but it is unclear.

Figure A.12 shows predicted wetlands impacts for a 0.5 meter sea level rise scenario. 0.5 meters of rise is the closest of the scenarios that were run to the 1' of sea level rise that has been assumed for this study as likely to occur by the year 2100. Figure A.13 summarizes results of this change graphically. The likely outcome is that Baker Bay would experience approximately 27% of net additional wetland loss under a 0.5 meter sea level rise scenario. However, if areas behind levees inundate frequently enough (the 'possible scenario'), a net wetlands gain, of ~135%, could occur. This range of 27% loss to 135% gain represents the range of expected impacts. We hope to refine this estimate in future studies if improved hydrodynamic simulation data can be obtained.

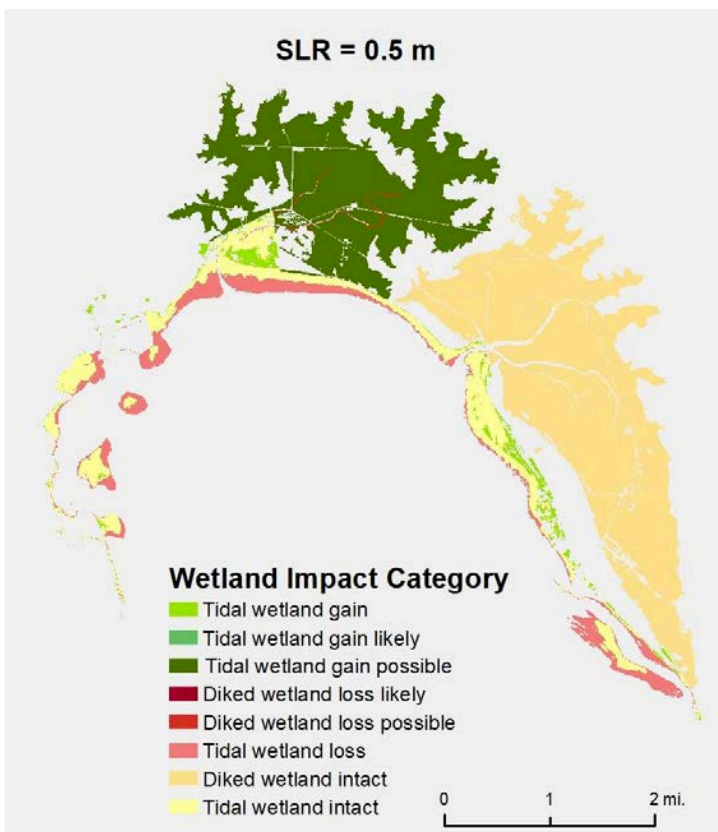


Figure A.12. Predicted impacts to Baker Bay wetlands due to 0.5 meters of sea level rise. Source: Estuary Partnership Sea Level Rise Analysis, 2018 (not published).

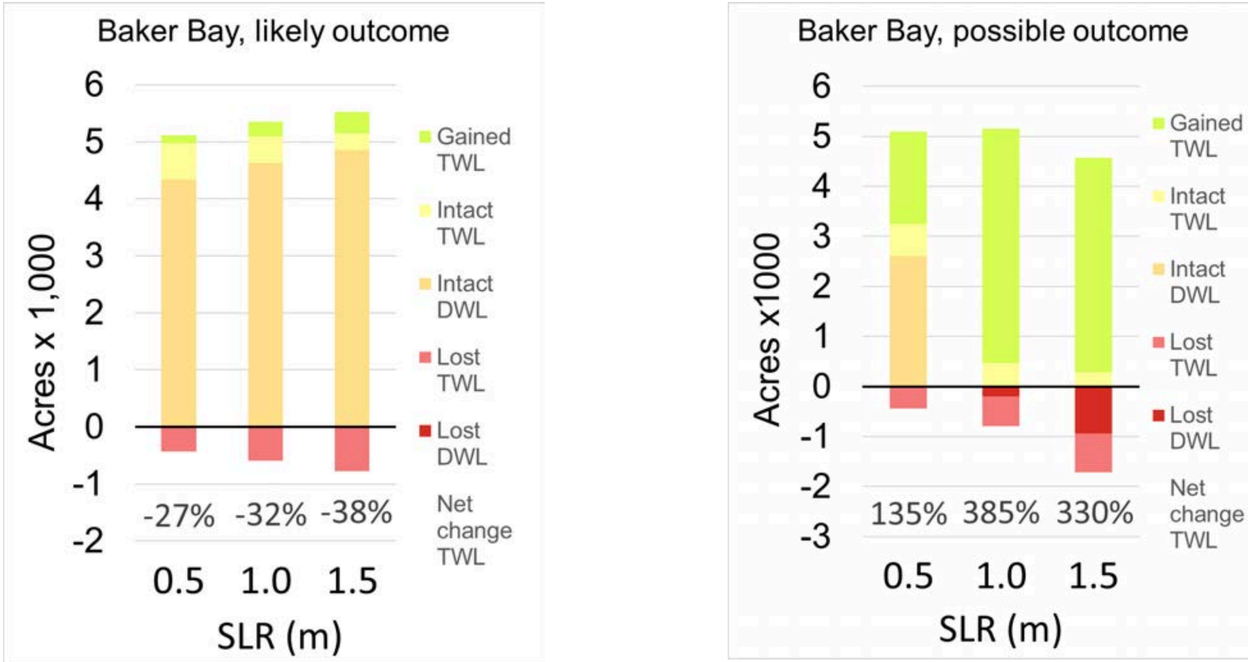


Figure A.13. Results of predicted impacts to Baker Bay wetlands due to sea level rise for three scenarios: 0.5, 1.0. and 1.5 m of sea level rise. Source: Estuary Partnership Sea Level Rise Analysis, 2018 (not published).

ii) Sea level rise impacts on Grays Bay wetland habitats

Similar to Baker Bay, Grays Bay has also seen a large percentage of its historical tidal wetlands converted to human use over the last several decades. These areas are protected by an extensive system of levees, dikes, and tidegates, These protective features vary in their vulnerability to sea level rise, depending on overall height, condition, and other factors. The Estuary Partnership study included a coarse assessment of frequency of inundation (i.e. levee overtopping) of these areas over a range of sea level rise magnitudes, based on modeled water surface elevations. From this assessment we categorized the likelihood of additional wetlands loss, or gain, using two categories: likely, and possible. Under the likely scenario, levee features inundate frequently under the future water level regime, and thus higher confidence is assumed. Under the 'possible' scenario, levee features inundate less frequently, and thus wetlands behind levees 'may' assume a trajectory towards a more natural state, but it is unclear.

Figure A.14 shows predicted wetlands impacts for a 0.5 meter sea level rise scenario. 0.5 meters of rise is the closest of the scenarios that were run to the 1' of sea level rise that has been assumed for this study as likely to occur by the year 2100. Figure A.14 summarizes results of this change graphically. The likely outcome is that Grays Bay would experience approximately 4% of net additional wetland loss under a 0.5 meter sea level rise scenario. However, if areas behind levees inundate frequently enough (the 'possible scenario'), a net wetlands gain, of ~33%, could occur. This range of 4% loss to 33% gain represents the range of expected impacts. We hope to refine this estimate in future studies if improved hydrodynamic simulation data can be obtained.

Overall percentage of predicted loss for Grays Bay is considerably lower relative to Baker Bay, and the overall range of uncertainty is smaller. This is likely a result of the fact that more restoration has occurred in Grays Bay, opening up more habitat to tidal inundation. These areas are easier to predict future impacts due to sea level rise, relative to intact diked area, which comprise a much larger proportion of the Baker Bay project area.

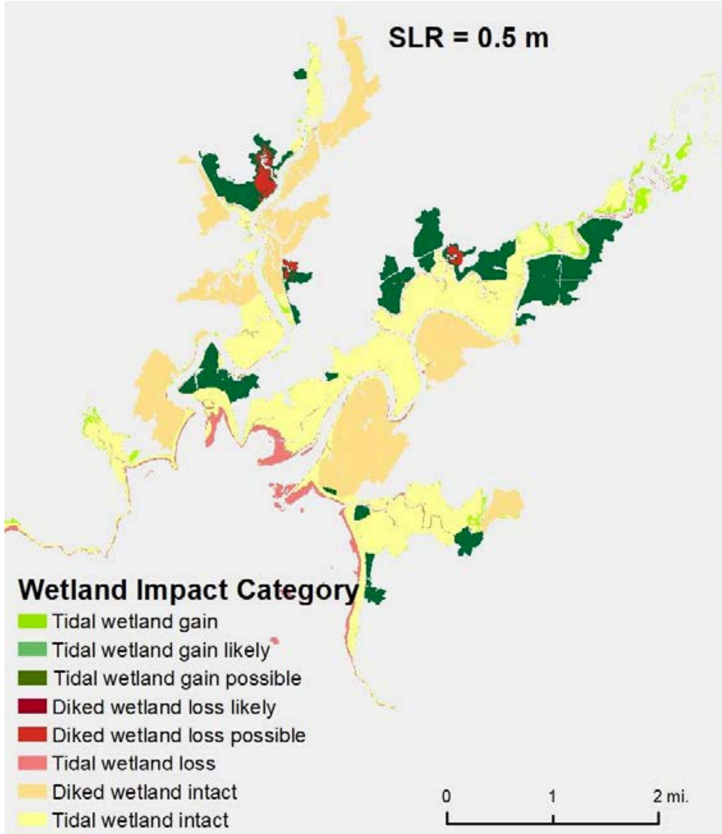
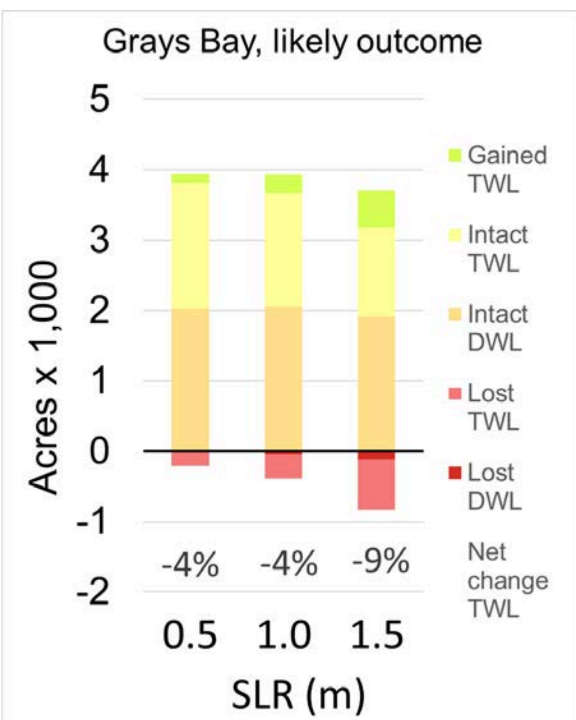


Figure A.12. Predicted impacts to Baker Bay wetlands due to 0.5 meters of sea level rise. Source: Estuary Partnership Sea Level Rise Analysis, 2018 (not published).



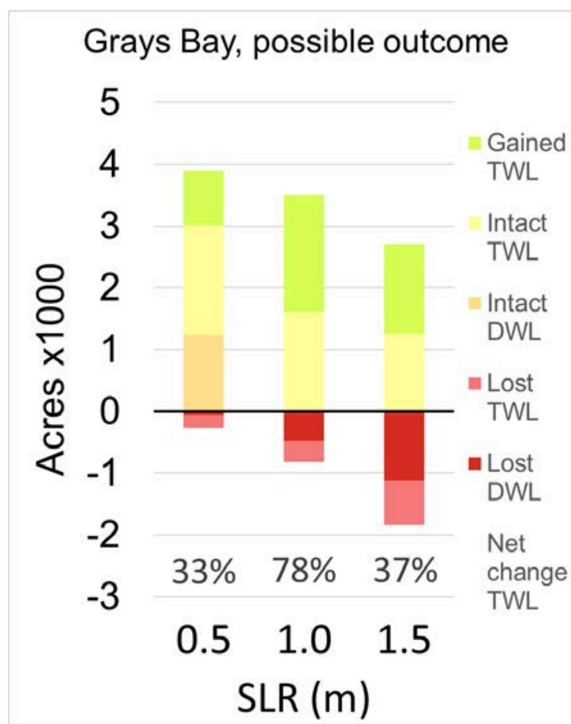


Figure A.13. Results of predicted impacts to Baker Bay wetlands due to sea level rise for three scenarios: 0.5, 1.0. and 1.5 m of sea level rise. Source: Estuary Partnership Sea Level Rise Analysis, 2018 (not published).

2. Existing studies, plans, and related work

This project builds from uncountable millennia of environmental changes, over a century of anthropogenic hydrological and landform alterations, and other activities across Baker Bay, Grays Bay, and their watersheds - many in service of reducing impacts of coastal hazards such as flooding. While some of these efforts have not been documented, a collection of available recent publications related to hazards reduction across both bays are listed below to assist future work and funding proposals. Documents are grouped by jurisdiction/region (color coded column) and are listed in reverse chronological order, with the most recent document for each jurisdiction/region at the top.

	Title[1]	Year	Jurisdiction/region[2]	Project holder[3]
1	Sea Level Rise Risk Assessment: Pacific County, Phases 1 and 2	2023 (Phase 1), ongoing (Phase 2)	Pacific County	Pacific County Department of Community Development
2	Pacific County Shoreline Master Program	2023	Pacific County	
3	2023 Parks Plan	2023	Pacific County	Pacific County Public Works
4	Pacific County Comprehensive Emergency Management Plan	2022	Pacific County	Pacific County Emergency Management Agency
5	2022 to 2027 Parks Capital Improvement Plan	2021	Pacific County	
6	Six Year Transportation Improvement Plan	2021	Pacific County	
7	Comprehensive Plan 2020 – 2040	2021	Pacific County	
8	Ordinance 180 Critical Areas and Resource Land	2016	Pacific County	
9	Chinook Park Improvement Plan	2003	Pacific County	Pacific County Public Works
10	Sea Level Risk Assessment	TBD (ongoing)	City of Ilwaco	
11	Shoreline Master Program (January 2017 with 2023 amendments)	2023	City of Ilwaco	

[1] This list attempts to be comprehensive but likely unintentionally omits some relevant information. Web links are included to assist accessibility of these documents, however the authors of this report do not maintain these links and cannot guarantee their continued functionality. If a document's title does not have a hyperlink, no public link was found.
[2] "Columbia River estuary" region includes documents covering the entire Columbia River as well, as this project's scope of work only covers the estuary. Other geographic mismatches are noted.
[3] If different than "Jurisdiction or region"

12	2020 Comprehensive Plan	2020	City of Ilwaco	
13	Ilwaco Traffic Analysis	2020	City of Ilwaco	
14	Ilwaco Comprehensive Plan	2020	City of Ilwaco	
15	Stormwater Drainage Handout	2019	City of Ilwaco	
16	Ilwaco Future Land Use Map	2019	City of Ilwaco	
17	City of Ilwaco Shoreline Analysis Report	2015	City of Ilwaco	
18	Port Of Ilwaco Marina Master Plan	2019	Port of Ilwaco	
19	Comprehensive Plan (scanned document)	no date	Wahkiakum County	
20	Comprehensive Flood Hazard Management Plan (Chapters 0-6, Appendices A-I, Combined Flood Plain Management Ordinances, and Flood Protection Information)	no date	Wahkiakum County	
21	Comprehensive Flood Hazard Management Plan (DRAFT)	2024	Wahkiakum County	
22	DRAFT Wahkiakum County CFHMP 2023	2023	Wahkiakum County	
23	Shoreline Master Program	2021	Wahkiakum County	
24	Wahkiakum County Hazard Mitigation Plan	2019	Wahkiakum County	
25	Appendix D: Minutes from the Wahkiakum County River Summit	2004	Wahkiakum County	
26	Critical Areas Ordinance No. 131-00	2000	Wahkiakum County	
27	Grays River Habitat Restoration Technical Report	2010	Grays River watershed	Lower Columbia Fish Recovery Board
28	Grays River Watershed and Biological Assessment	2007	Grays River watershed	Pacific Northwest National Lab (PNNL)
29	Grays River Assessment and Rehabilitation Plan	2004	Grays River watershed	
30	Volume II, Chapter 4 Grays River Subbasin	2004	Grays River watershed	Northwest Power and Conservation Council
31	WRIA 25/26 Grays-Elochoman and Cowlitz Watershed Management Plan (and associated documents)	2004	Grays River watershed (and Elochoman, Cowlitz Rivers)	Lower Columbia Fish Recovery Board

32	Sea Level Rise Impacts to the Lower Columbia River and Estuary	no date	Columbia River estuary	Lower Columbia Estuary Partnership
33	Lower Columbia River Channel Maintenance Plan (draft document pending)	2024	Columbia River estuary	US Army Corps of Engineers
34	Mouth of Columbia River Regional Sediment Management Plan - 2021 Update	2023	Columbia River estuary	Lower Columbia Solutions Group
35	Pacific Lamprey 2022 Regional Implementation Plan for the Lower Columbia/Willamette Regional Management Unit Lower Columbia Sub-Region	2022	Columbia River estuary	USFWS
36	Predicted Impacts to Lower Columbia River Wetlands Due to Sea Level Rise: Summary of Results	2018	Columbia River estuary	Lower Columbia Estuary Partnership
37	Habitat change in the Lower Columbia River and Estuary, 1870 - 2011	2017	Columbia River estuary	Lower Columbia Estuary Partnership
38	Investigating Freshwater and Ocean Effects on Pacific Lamprey and Pacific Eulachon of the Columbia River Basin: Projections within the Context of Climate Change	2017	Columbia River estuary	Columbia River Inter-Tribal Fish Commission (CRITFC)
39	Potential Impacts of Sea-Level Rise to Traditional Cultural Landscapes, Properties, and Resources	2016	Columbia River estuary (and Oregon coast)	Confederated Tribes of Grand Ronde
40	Juvenile Salmon Ecology in Tidal Freshwater Wetlands of the Lower Columbia River and Estuary: Synthesis of the Ecosystem Monitoring Program, 2005–2010	2013	Columbia River estuary (and Oregon coast)	Bonneville Power Administration
41	Mouth of the Columbia River Regional Sediment Management Plan	2011	Columbia River estuary	Lower Columbia Solutions Group
42	Lower Columbia Regional Culvert Inventory and Tidegate Assessment Final Report	2010	Columbia River estuary	Lower Columbia Fish Recovery Board
43	Washington Lower Columbia Salmon Recovery and Fish and Wildlife Subbasin Plan	2010	Columbia River estuary	Lower Columbia Fish Recovery Board
44	Final Revised Regional Culvert Inventory Report 12-2007	2007	Columbia River estuary	Lower Columbia Fish Recovery Board
45	Changes in Columbia River Estuary Habitat	1983	Columbia River estuary	Columbia River

	Types Over The Past Century			Estuary Data Development Program
46	WA State Enhanced Hazards Mitigation Plan	2023	Washington State	Washington State Emergency Management Division
47	Coastal Erosion Hazard Assessment	2021	Washington State	WA Department of Ecology Coastal Monitoring and Analysis Program
48	Heavy Precipitation Projections For Use In Stormwater Planning	2021	Washington State	University of Washington Climate Impacts Group
49	Sea Level Rise Research & Tools (2018 Washington State Sea Level Rise Projections)	2018	Washington State	Washington Coastal Hazards Resilience Network
50	Climate Impacts Vulnerability Assessment	2011	Washington State	Washington State Department of Transportation

Appendix A References

Lower Columbia Estuary Partnership, 2018. *Sea Level Rise Assessment - predicting the impact of sea level rise on lower Columbia River wetlands. Summary of results*.

Marcoe, K., Pilson, S., 2017. *Habitat change in the lower Columbia River estuary, 1870–2009.* J Coast Conserv 21, 505–525 (2017). https://doi.org/10.1007/s11852-017-0523-7

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Pacific International Engineering, 2002. *Projects and solutions to water resources problems on the lower Columbia River. Prepared for the lower Columbia River port communities.*

Wahkiakum County, 2023. *Draft Wahkiakum County Comprehensive Flood Hazard Mitigation Plan*.