Index of All Textual Comments

Jennifer Rogers

From:	dennis.katte@frontier.com
Sent:	Wednesday, February 23, 2022 7:05 PM
To:	PDS comments
Cc:	Peter Browning; Lisa Janicki; Ron Wesen; PlanningCommissioners
Subject:	Skagit County's Shoreline Master Program Update

LAKE CAVANAUGH NEEDS SPECIAL CONSIDERATION FOR EXTREME LAKE LEVEL FLUCTUATIONS

Extreme Water level fluctuations are a perpetual occurrence and a constant concern of its residents. The Army Corps of Engineers did a Flood Reduction Report in 1974 as did the State of Washington DOE. The Army Engineers performed a special study on Flood Plain Determination in 1996. In between, there have been several other studies including one by VTN Engineers and Skagit County. In addition, we have been taking level readings since 2013.

The important data to consider is this (per ACOE study and our records):

1. Recorded lake levels range from 1008' 10" to 1014'. High level of 1014' is usually from November-February, Summer level is usually about 1009' 6"' from March to mid-August, and low water from about mid-August to mid-October when the rains start. Just what is OHWM at Lake Cavanaugh with its three distinctive levels?

2. The surface area of the lake is 804 acres.

3. Drainage area is 8.2 square miles—we are at the bottom of the funnel. Adjacent 2000' high Frailey Mountain runs the length of the lake and is less than a quarter mile away.

4. There are 3 small inlets and one outlet.

HOW THIS AFFECTS STANDARDS FOR DOCKS AT LAKE CAVANAUGH

On page 99 (B) Minimum height (I) states that "The bottom of any piers or the landward edge of any ramp must be the maximum practical height from the ground, but not less than 1.5'above the OHWM".

On page 100 Table 14.26.420.1 , "MAX HEIGHT FROM SURFACE OF WATER" lists the measurement to be 3'. Presumably this is from the pier's walking surface. Yet it does not reference OHWM. We suggest OHWM be added in the title of the table as an easy fix. The verbiage should be modified to add clarification and avoid confusion.

Assuming this is now the case, a typical pier made from 2 x 6" walking surface and with 4 x 12" joists (actual wood size totals to 12.75" but is rounded up to 13" in the sketch). With the OHWM at the minimum 1.5' clearance to the pier bottom, the pier top distance of 31" meets requirements of 36" or less.

At low water of 1008' 10" if constructed (as above) to meet requirements at OHWM the pier top would be about 39" and higher than the water requirement of 36" or less.

At high water of 1014', if the pier is built conforming with the 1.5' pier bottom minimum to water, the pier top to water would be about 5' 6" above summer level greatly exceeding the 36" maximum to the water as well as creating a dangerously high pier.

It becomes obvious that even if the definitions are changed as suggested to reference the OHWM, just what is Lake Cavanaugh's ordinary high water? How can the suggested standards be met? The lake has both seasonal and full-time resident property owners who use piers year-round, thus some intermediate height standards must be made to accommodate stationery piers as well as floating pier ramps.

It might be justifiable to use the OHWM for lakes with little height variation, but that is simply not the case with Lake Cavanaugh as this data and photographs point out. We must conform to natures' "standard" as it exists here.

We would suggest a simple footnote to the Dock Standards Table to the effect that "*lakes with extreme water level fluctuations thereby making specified water and pier heights unachievable shall comply as best as is possible to meeting the intent of maximum pier height above OHWM and minimum pier height from OHWM.*

We think these comments will allow a reasonable solution to the challenge presented by Lake Cavanaugh, and to a somewhat lesser extent, to Big Lake.

Thank you for your consideration of our request.

Encl.

Respectfully submitted,

Dennis Katte, LCIA SMP Chairman

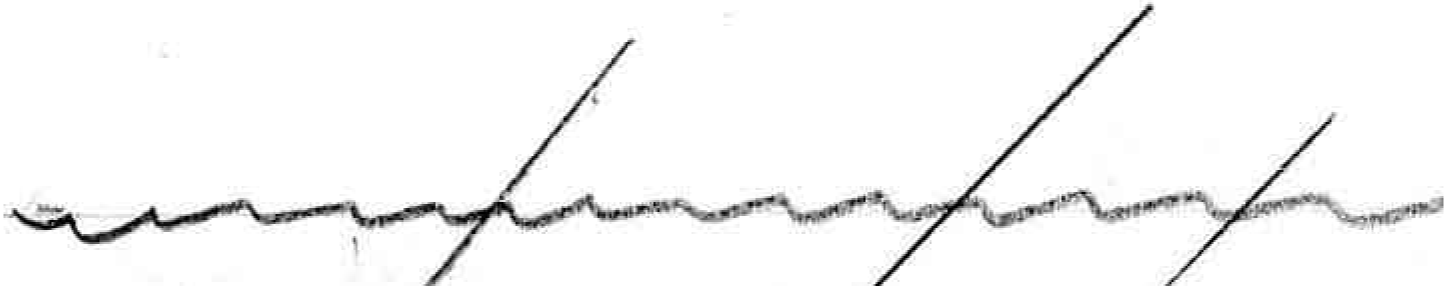
33164 West Shore Drive

Mount Vernon, WA 98274

206-734-1288

SUBMITTAL FOR S

LAKE CAVANAUGH SEASONAL PIER CLEARANCES



Jennifer Rogers

From: Anne Winkes <annewinkes@gmail.com>
Sent: Sunday, February 27, 2022 11:16 AM
To: PDS comments
Subject: Skagit County's Shoreline Master Program Update

Dear Commissioners Browning, Janicki and Wesen,

Climate change impacts were dramatically evident in Skagit County last Fall and this Winter as heavy rainfall caused the Skagit and Samish Rivers to overflow their banks, with the Skagit reaching near-record flood levels. Roadways and fields were flooded, businesses were damaged and thigh-high water forced some people from their homes, while stranding others. In January, the combination of King tides, powerful coastal winds, rain and rapid snowmelt flooded Edison. Scientists predict such events will be seen with increasing frequency as climate change brings wetter winters, stronger winds and rising sea level with associated storm surge to Skagit County.

The impacts of climate change on Skagit County's 228 miles of marine and estuarine shorelines will only worsen. The draft Shoreline Master Program (SMP) Comprehensive and Periodic update currently before you for consideration does not specifically address the impact of climate change on our county's shorelines. It must do so.

Baseline data can be gathered that will help guide you as you plan how best to protect our county from the impacts of climate change on our shorelines. Please include in the SMP update the need for a comprehensive assessment of sea level rise vulnerability.

Traditionally barriers have been our county's answer to shoreline damage. Dikes have been built and then reinforced and raised higher and higher. Shorelines have been armored. But barriers won't hold forever. Even Mount Vernon's new seawall was nearly topped by November's flood waters, and shoreline armoring while saving real estate values can cause loss of beaches and intertidal habitats.

Begin to consider non-structural approaches to address the problems climate change will bring to our shorelines. Please include a study of how managed retreat, "the purposeful, coordinated movement of people and assets out of harm's way" (https://www.pnas.org/content/117/24/13182),
might look in Skagit County as part of the updated SMP. Only by looking at all possibilities will you be able to best protect our lives and livelihoods.

Thank you for considering my comment.

Anne Winkes
annewinkes@gmail.com
18562 Main St.
PO Box 586
Conway, WA 98238
360-445-6914

Jennifer Rogers

From: Lorrie Webb <jannewebb@icloud.com>
Sent: Monday, February 28, 2022 7:38 AM
To: PDS comments
Subject: New Shoreline Zoning

##
CAUTION: This email originated from an external email address. Do not click links or open attachments unless you recognize the sender, you are expecting this email and attachments, and you know the content is safe.
##

I would like to understand more about the proposed change for our zoning.
What constitutes shoreline?
It seems the slough is different than an actual shoreline.
What are the advantages of this Re categorization. Is it for more allotment of funding?
How will it impact me as a homeowner?
How will it impact me as a taxpayer?
Will this have an impact on better conservation efforts for salmon etc. ?
How will this impact future permitting efforts for this lot/parcel?

Thank you very much for answering these questions and providing more general information prior to making this change.

Lorrie Webb
3685 Legg Road
Bow, WA
619 929-5077

Sent from my iPhone
LORRIE
😎😎😎

Jennifer Rogers

From: Michael <pinotmaster@msn.com>
Sent: Monday, February 28, 2022 10:32 AM
To: PDS comments
Subject: Skagit County's Shoreline Master Program update

Dear Board of County Commissioners,

I am writing to you concerning the Shoreline Master Program Update currently undergoing review. As a member of GIPAC, the Guemes Island Planning Advisory Committee, duly elected by the island to represent the island's interest's vis a vis the county, I am critically aware of the development pressures our shorelines face. I would like to address two issues I feel should be considered.

Hard Armoring:

When shoreline property owners use hard armoring, specifically large boulders and cable tied logs, to try and protect their property from erosion and flooding, they are in fact accelerating riparian destruction. Wave action hitting hard armoring undercuts beaches and causes a loss of spawning are for feeder fish critical to salmon. Here on Guemes Island we have seen property owners who have brought in large boulders to armor their shoreline, in spite of codes requiring soft armoring only. We have seen firsthand the degradation such armoring causes t the surrounding property owners, and support stricter rules requiring soft armoring only along shorelines.

Tree Cutting Along Shorelines:

Here on Guemes Island we have seen property owners who have cut trees, sone 150+ years old, on steep and unstable slopes. Guemes is home to sme of the best feeder bluffs in the Puget Sound, which help to provide nutrients for feeder fish the salmon rely upon. Such cutting promotes slope instablity and degrades shoreline ecological functions. The draft must delete the authorization for timber cutting along shorelines.

Thank you for your consideration,

Michael Brown
4366 Clark Point Rd
Anacortes, WA 98221

Jennifer Rogers

From: Debbie Clough <debbiecl@fidalgo.net>
Sent: Monday, February 28, 2022 10:32 AM
To: PDS comments
Cc: Debbie Clough
Subject: Shoreline map?

##
CAUTION: This email originated from an external email address. Do not click links or open attachments unless you recognize the sender, you are expecting this email and attachments, and you know the content is safe.
##
To whom it may concern,

It has come to my attention that Colony Creek is being changed to a shoreline designation. Why is that? What criteria has been used to arrive at this designation? Is this a mapping mistake? It doesn't appear to apply to Edison. Why is that?

Looking forward to answers to these questions.

Best,
Debbie Clough
15559 Flinn Rd
Bow, WA 98232

Sent from my iPhone

Jennifer Rogers

From:	Mary Ruth Holder <mruthholder@gmail.com>
Sent:	Monday, February 28, 2022 10:46 AM
To:	PDS comments
Subject:	Skagit County's Shoreline Master Program Update

CAUTION: This email originated from an external email address. Do not click links or open attachments unless you recognize the sender, you are expecting this email and attachments, and you know the content is safe.

February 28, 2022
Skagit County Planning and Development Services (PDS)
1800 Continental Place
Mount Vernon, WA 98273
Submitted electronically via pdscomments@co.skagit.wa.us
Re: Skagit County's Shoreline Master Program Update

Dear Skagit County PDS:
Please accept our public comment on the Skagit County Shoreline Master Program Update (hereinafter "SMP"). Our comments below are in response to the staff recommendations on the draft SMP update following its meeting with the Planning Commission and staff responses to the comments staff received April through June, 2021.

The SMP update presents an opportunity for the County to ensure the long-term resilience of Skagit's fragile shorelines, tidelands, unique estuarine habitats, communities and farmlands, even in the face of expected sea level rise. The PDS staff's recommendations in response to public comments on the draft SMP, however, would have the Board of Commissioners avoid that opportunity and responsibility.
Other counties and cities around us are striving to meet these challenges in their SMP updates. See, for just one example, ongoing updates to Island County's SMP, https://www.islandcountywa.gov/PlanningOld/Pages/D20_SMP.aspx. Why is Skagit behind the curve in developing SMP goals, policies, and regulations related to sea level rise?

Skagit County contains hundreds of miles of shorelines. We have not only marine shorelines but also rivers, sloughs, and inlets that affect the marine waters. The iconic Orcas and salmon, as well as forage fish and the eelgrass and kelp beds, all depend upon well-functioning shorelines. The Legislative finding in the Shoreline Management Act, RCW 90.050, (the Act) specifically recognizes that …" the shorelines of the state are among the most valuable and fragile of its natural resources… ." The finding's list of uses preferences are particularly important in Skagit, because under the Act, both Padilla Bay and Skagit Bay have been designated "shorelines of statewide significance." Based on this designation and the importance of Skagit's shorelines to fish and wildlife as well as to an economy based on a healthy and productive marine environment, the SMP update must contain provisions that actually, and adequately, protect Skagit's unique environment. In some important respects, the SMP update fails to move the County forward in meeting foreseeable future challenges.

This comment addresses items of particular concern to us. Please ensure that the changes that follow are made to the final SMP update before its adoption.

Address sea level rise. Stunningly (and despite a significant number of comments calling for sea level rise to be included in the SMP update), the staff recommends no changes to the SMP to make Skagit, its citizens and resources resilient in the face of foreseeable climate change-caused sea level rise. Thus our county SMP *still* has no
policies, goals or regulations (all three elements are essential) to help us prepare and adapt to the fact of sea level rise. This critically important issue *must not* continue to be largely ignored in the County's SMP. The next SMP update may not occur until 8 years (or more?) from now. By that time, sea level rise could very well be a crisis
exacerbated by the County's failure to act now.

The facts and data concerning sea level rise are widely known, understood, and accepted. The impacts are already being experienced during storm tides and surges, for example the recent king tide that inundated Edison. Nevertheless, the staff recommended no change to the current out-of-date SMP that would address the
reality of the situation. With increasing sea level rise, Skagit's shorelines will move upward and inland; wetlands and aquatic vegetation will likely migrate. Skagit County has been projected to experience sea level rise between 1½ and 2.1 feet by 2100. See, for example, Cauvel, Kimberly (July31, 2018). Study shows 2 feet of sea
level rise likely for Skagit by 2100. Skagit Valley Herald.
https://www.goskagit.com/news/study-shows-2-feet-of-sea-level-rise-likely-for-skag
it-by-2100/article_b5f0e8b4-593f-5384-9c05-6f628a438fc5.html (accessed 6/18/2021.) A 2022 NOAA sea level technical report makes the need for Skagit to react by amending its SMP even more urgent. National Oceanic and Atmospheric Administration, 2022 Sea Level Rise Technical Report: Updated projections available through 2150 for all U.S. coastal waters.
https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-section
s.html, (accessed February 27, 2022).

The SMP must equip our County with a clear-eyed, candid plan for future impacts of sea level rise. The staff's response to comments on this issue amount to a shrug and a shirk. They use the dubious excuse that Act does not expressly require the SMP to address sea level rise. If that is the case then there must be many worthwhile provisions in Skagit's existing SMP that would fall by that logic. As the WA Department of Ecology has recognized, other local governments "have already incorporated sea level rise considerations into their Comprehensive SMP updates" and "SMPs are among many planning measures that local governments may need to deploy to assure the wise development of coastal areas and the protection of public resources as sea level increases." Addressing Sea Level Rise in Shoreline Master Programs, SMP Handbook, Appendix A, Publication Number 11-06-010 1 7/10; rev.
12/17, https://apps.ecology.wa.gov/publications/parts/1106010part19.pdf (accessed February 27, 2022).

The 2019 climate action plan referenced in staff's response to public comments contains recommendations rather than county policies, goals and regulations. This document, along with vague future plans to pursue grants relied on by staff, are ineffective stand-ins for SMP goals, policies, and regulations. There is no other existing alternative planning tool cited by staff to address sea level rise.

The failure to adequately address sea level rise in the SMP would subject result in allowing new residential building structures to be subject to the unacknowleged risk of inundation. This would harm property owners and residents, public health, and infrastructure and require future expenditures of perhaps even billions of dollars to
relocate people and structures. Additionally, it would damage forage fish and juvenile salmon habitat.

Instead, language must be included in the SMP applying the 2100 sea level rise predictions. New lots must be required to contain buildable areas outside the 2021 inundation zone and outside areas in which wetlands and aquatic vegetation will likely migrate during that time. For new lots that are sufficiently large enough to contain areas outside predicted 2100 inundation zones, there must be building setback requirements so that new buildings cannot be constructed on those lots within inundation areas or areas in which wetlands and aquatic vegetation will likely migrate. Provisions must require new and substantially improved structures to be elevated above the 2100 predicted sea level rise elevation over the useful life of these buildings. The setback requirement must last over the duration of the buildings' useful lives. (We note that this additional language as well as the language in all of in SMP 6C-15 relating to protection of shorelines, would better serve the urgency of the situation if stated in terms of requirements using "musts" rather than"shoulds.")

Without any reference in 6C-15.3(c) to sea level rise prediction and a requirement for residential buildings to be sustainable against sea level rise over their useful lifetimes, the current draft's admonition to avoid "future shoreline stabilization" methods could be rendered toothless. For example, if residential homes are planned for construction in an area subject to future sea level rise (as predicted), a permit might be issued now and then post construction a claim could made pursuant to SMP 14.26.480(2)(a) (based on current studies and data) raising a significant
possibility that sea level rise might cause damage "within three years" or more immediately. The county would then allow the addition of shoreline stabilization structures. This loophole must be closed in the final SMP to protect shoreline ecological functions, beaches, tidelands, marine species and estuarine wetlands.

The county's failure to plan sensibly now with an SMP that adequately addresses the ongoing, predicted sea level rise with effective policies, goal and regulations would will only create larger problems later and needlessly put communities and Skagit's shorelines of statewide significance in peril, undermining the intent of the Act.

Factor in sea level rise to strengthen agricultural land provisions. Sea level rise along with changes in precipitation and temperature are predicted to impact a significant area of low elevation agricultural lands. These lands will be
subject to inundation and river flooding. For example, Rising Sea Levels. Skagit Climate Science Consortium (2015).
http://www.skagitclimatescience.org/skagit-impacts/sea-level-rise/ (accessed June 21, 2021). Adding new dikes and filling to create new farmlands will only subject such newly created lands to the adverse impacts of sea level rise while destroying critically important tidelands, tidal marshes and associated wetlands. Defending new low lying farmlands will be costly and ultimately futile. Yet section 6C- 1.1 (d) of the draft only notes that "creation of new agricultural lands by diking or filling of tidelands, tidal marshes and associated wetlands …*should be discouraged*." (Emphasis added.) The best way to discourage them is by express prohibition. Diking and filling to create new farmlands in low lying areas must be prohibited.

Shoreline buffers must be limited to no more than 25%. The Planning Commission's recommendation to allow shoreline buffers to be reduced from between 25% to 50% with only an administrative variance must be rejected. Such reductions should be limited to no more than 25% as recommended by the WA Department of Ecology.
The SMP update should adopt State of Washington Department of Fish and Wildlife's up-to-date buffers that are based on science, to protect Chinook and other salmon and the prey on which they rely. Reductions should not be a matter of administrative variance. The impacts of these reductions are too significant for shoreline values and

functions to cut public review and comment out of the process. Shoreline reductions should require review by Department of Ecology and should be determined by the Hearing Examiner.

Establish and defend adequate riparian buffers. The sections concerning riparian buffers need to be strengthened. Particularly in a warming climate and hotter years, it is essential to preserve riparian buffers to provide shade and cooler water temperatures for vulnerable salmonids. These buffers also work to stabilize banks, retain runoff during peak flows, provide detritus for aquatic insects, and filter toxins before they reach streams. They provide valuable habitat for birds and amphibians, and resting and rearing places for mammals like river otter and beaver. To protect ecological functions, buffers must be as as wide as a mature tree. In light of the critical need to meet the challenges of a warming climate and what is known about the importance of buffers to salmon, drafters should carefully consider whether continuing to allow timber harvest in riparian buffers is still appropriate or whether section 14.26.574 needs to be more restrictive. Based on the urgent need to protect riparian buffers going forward, the Shoreline Variance provision, 14.26.735(a), should not allow administrative variances to reduce riparian buffers by 50%. Buffer widths should not be allowed to be decreased, 14.26.534, under any circumstances.

Prohibit new commercial net pens. The SMP must prohibit these net pens, especially in light of the failure of net pens off Cypress Island in 2017 that released thousands of Atlantic Salmon. These released salmon were found swimming up the Skagit River as far east as Concrete even months after the net pen collapse. Mapes, Linda V. (December 12, 2018). Escaped Atlantic salmon found 42miles up Skagit River. The SeattleTimes. https://www.seattletimes.com/seattle-news/environment/escaped-atlantic-salmon-found-42-miles-up-skagit-river/.(Accessed June 21, 2021). Finfish net pens introduce chemical and drug contaminants, concentrate contaminants, increase growth of algae, disrupt marine food webs and can pass along disease to wild native salmon. Fish from accidental releases can prey on forage fish and juvenile salmon and compete for food with wild salmon. The SMP must be revised to: 1.) amend Table 14.26.405-1, Shoreline Use and Modifications Matrix for Aquaculture Net Pens from a Conditional Use (CU) to a prohibited (X) and 2.) amend 14.26.415(7), Net Pens, by striking the current language and replacing with: (a) New commercial net pen aquaculture operations to propagate non-native finfish or native finfish species in marine waters is prohibited.

Revise residential hard armoring sections and reclassify boulders. The SMP draft's stabilization structures sections need revision to avoid exacerbating the problems arising from the draft's failure to address sea level rise. It is well known that shoreline armoring harms nearshore habitat and destroys prey food of juvenile salmon and marine birds.

Staff is recommending no change to the present provision. This is a unacceptable. As discussed in the example given above, as currently written, SMP draft 14.26.480(2)(a) creates a loophole for construction in areas currently within the sea level rise predictions to allow shoreline stabilization structures post permitting and construction. To close this loophole, the draft should be worded to make it applicable only to residences that exist as of the date the SMP is adopted. 14.26.480 (1)(a)(ii) includes boulders within the definition of "soft armoring." We have seen few "soft boulders." Instead, they should be included as hard armoring because they have hard solid surfaces and their use can have the same harmful effects as bulkheads. Additionally their use fits within the provisions for "hard structural stabilizing measures" in 14.26.480 (4)(b)(i) and (ii)(B).

Protect eel grass and kelp beds from new dock construction and boat canopies. The draft SMP would allow the construction of new docks, boat canopies and other overwater structures to extend over protected kelp and eel grass beds. Particularly in light of the importance of productive and healthy eel grass and kelp beds to Skagit County's natural environment and our economy, it is imperative that new construction of these structures not be allowed to harm them. These structures prevent light from reaching eel grass and kelp beds that is necessary for their health and productivity. The structures can also hide salmon predators in their shadows. Boat storage canopies must be required to be transparent to allow light through them. Additionally, the SMP should incorporate language consistent with the WA Department of Fish and Wildlife standards concerning such overwater structures.

In addition to these comments, we also adopt by reference hereto and incorporate herein for all purposes the comments on the draft SMP made by Washington Environmental Council, Evergreen Islands, RE Sources, Skagit Audubon and the Skagit Land Trust. The comments submitted by these organizations are based on science and correct legal interpretations of the Act.

We request that the Commissioners direct staff to make additional changes to the SMP update that we and others have requested to protect our county, its citizens and unique fragile environment. Thank you for your careful consideration of our comments on the draft SMP.

Sincerely,

Mary Ruth and Phillip Holder
201 S. 7th St.
Mount Vernon, WA 98274
Ph: (360) 336-1908
Email: mruthholder@gmail.com
c. Skagit County Board of Commissioners

Jennifer Rogers

From:	Randy Good <rlgood30@frontier.com>
Sent:	Monday, February 28, 2022 10:52 AM
To:	PDS comments
Cc:	Ellen Bynum; Lori Scott; Andrea Xaver; Gene Derig
Subject:	Skagit County's Shoreline Master Program Update

Skagit County Commissioners, Feb. 28, 2022

Public comments on Skagit County Shoreline Master Program - 2022 BOCC Review Draft;

Page 75-76 (4) Shoreline Public Access Plan
(a) The Skagit Countywide UGA Open Space Concept Plan ....for public access.

The Skagit County Planning Commissions recorded recommendation - Amend SMP Section 14.26.370(4) to remove the Countywide UGA Open Space Concept Plan.

The Skagit Countywide UGA Open Space Concept Plan's website states "The plan does not mandate that identified areas be regulated or protected, and does not create a regulatory land use designation nor allow public access by default. Instead, the plan identifies priority areas within the county to be considered for a strictly voluntary open space preservation program."

The ordinance adopting the Concept Plan shows this as another concept advisory resource for the BOCC, the Planning Commission and the public to consider during annual and 8 year Comp Plan Updates. The definition of concept- an idea, a thought.

The Skagit Countywide Open Space Concept Plan does not qualify and cannot be used to satisfy the SMP public access plan. It was not intended or created to do so.

We encourage the BOCC to support the Skagit County Planning Commission's recommendation to remove the Skagit Countywide Open Space Concept Plan from this SMP Update.

Thank you

Randy Good President Friends of Skagit County
35482 State Route 20
Sedro Woolley Wa. 98284
360-856-1199

Jennifer Rogers

From: Patty Rose <pattyrose.pr@gmail.com>
Sent: Monday, February 28, 2022 11:09 AM
To: PDS comments
Cc: John Rose
Subject: Skagit County's Shoreline Master Program Update

To the Skagit County Board of Commissioners:

I appreciate the opportunity to comment on the proposed revisions to the Shoreline Master Program (SMP). I am speaking as a Guemes Island citizen and shoreline property owner. Our well on North Beach has been compromised by seawater intrusion.

I agree with the Aquifer recharge areas intent (14.26.540) as stated in the BOCC Review Draft which I quote:

> *(a) Define minimum regulatory requirements to protect groundwater quality and quantity for existing and future use;*
>
> *(b) Identify practices, alternatives, and mitigation measures that can minimize the adverse impacts of proposed projects;*
>
> *(c) Ensure adequate design, construction, management, and operations to protect groundwater quality and quantity.*

I am pleased to read in the draft that Guemes Island, as a sole source aquifer and an area of known seawater intrusion, is an area "*in need of aquifer protection where a proposed land use may pose a potential risk which increases aquifer vulnerability" (14.26.541)* And I appreciate these statements under Aquifer recharge areas site assessment requirements: (14.26.543)

> *A description of the site-specific hydrogeological characteristics regarding potential impact(s) to the quantity or quality of underlying aquifer(s). At a minimum this will include a description of the lithology, depth and static water level of known underlying aquifer(s), and depiction of groundwater flow direction and patterns on the appropriate map*
>
> *Assessment of the potential for pumping-induced seawater intrusion.*

The problem as I see it is that the above provisions are not being applied or enforced on Guemes Island when landowners decide to drill a well without applying for a building permit. Language needs to be added that no wells be drilled within 200 ft of the ordinary high water mark in areas of saltwater intrusion and wells to be drilled within 1000 feet of marine shorelines should have a hydrogeological study prior to drilling to avoid further seawater intrusion and damage to existing wells. This does not need to present a financial burden to Skagit County, but hydrogeological study should be paid for by the landowner who wishes to drill a well.

As a shoreline resident I also read the Management policies for shoreline residential (6 B-6.2) with interest. I quote the SMP below: (emphasis mine)

> *Standards for density or minimum frontage width, setbacks, lot coverage limitations, buffers, shoreline stabilization, vegetation conservation, critical area protection, and water quality **should ensure no net loss of shoreline ecological functions**. Such standards should take into account the environmental limitations and sensitivity of the shoreline area, the level of infrastructure and services available, and other comprehensive planning considerations*.

In this case, I believe it is very important to prohibit administrative variance reductions without citizen input. Our island population is growing and we must not degrade the island environment by continually reducing wetland and shoreline buffers, which will certainly over time cause a net loss of shoreline ecological function.

Thank you for your time, hard work and attention.

Sincerely,

Patty Rose

4829 Guemes Island Road

Jennifer Rogers

From:	Kevin Morse <kevinm@cairnspring.com>
Sent:	Monday, February 28, 2022 11:41 AM
To:	PDS comments
Cc:	kirtymorse@gmail.com
Subject:	"Skagit County's Shoreline Master Program Update

Dear Commissioners,

I live at 15255 South Blanchard Road in Bow, Washington and am writing in response to the proposed updates to Skagit County Shoreline Management Plan.

My wife and I are particularly concerned about the extension of the SMP upstream of the tide gates on McElroy Slough and the designation of the area as Rural Conservancy for several reasons:

- The new designation will require landowners in our community to comply with new and substantial permitting requirements and result in expensive fees required with new permit submittals.
- There seems to be a discrepancy on how the county is applying the jurisdictional shoreline areas. When reviewing the maps, it appears that there is NOT an extension of the SMP upstream of the Edison Slough tide gates just north of us. Why is this? What is the rationale and why has the county proposed to extend the SMP past the tide gates on McElroy Slough?
- Increased runoff from development on this hills to the west of Blanchard and our property are causing an increase in damaging flood events at our home and the surrounding community and we are concerned the increase in regulations that accompany the SMP designation may make it more difficult to address our long term flood protection needs.

In conclusion, we are opposed to the proposal to include McElroy Slough upstream of the tide gates in the SMP.

Thank you in advance for considering our comments and for addressing our concerns.

Kevin and Kirsten Morse
15255 South Blanchard Road
Bow, WA 98232

Jennifer Rogers

From: Timothy Manns <bctm@fidalgo.net>
Sent: Monday, February 28, 2022 11:52 AM
To: PDS comments
Subject: Skagit County's Shoreline Master Program Update

Dear County Commissioners Janicki, Wesen and Browning and Planning Director Hart,

We are writing on behalf of Skagit Audubon Society to comment on Skagit County's draft *Shoreline Master Program Comprehensive Update and Periodic Review* (SMP). Please accept these comments as part of the official record on this matter.

Skagit Audubon's 413 members share an interest in the protection and restoration of birds, other wildlife, and the habitat they require. The provisions of the Shoreline Management Act support our interests, and we favor a Shoreline Master Program rigorously complying with both the letter and the intent of the act.

We appreciate your attention to the following comments.

The proposed SMP draft update is an improvement over the existing Shoreline Master Program; however, we are concerned that the revised plan provides insufficient protection for the environment and shoreline habitats. The draft SMP with the recommendations from the Planning Commission does not provide adequate protection for shoreline resources from the impacts of armoring, it allows reductions in shoreline buffers with less review, and the draft plan completely fails to address the critical issue of sea level rise.

<u>Sea Level Rise and the Shoreline Master Program</u>
The science and data for sea level rise (SLR) are overwhelming. While predictions vary on the elevation of the rise, in part dependent upon actions throughout the world in the next decade or two, the fact of sea level rise is beyond dispute and must be addressed. Actual measured SLR to date is on the upper end of predictions from a decade ago, supporting forecasts of a more rapid rise than earlier estimates.

The recent flooding of Edison's streets during a king tide provides a vivid picture of what sea level rise will mean for Skagit County's low lying farmlands and communities. There is no time to lose in planning how to adapt to this inevitability.

The issue of SLR and the need for its inclusion in the Skagit SMP is not new. Sea level rise was clearly included in the report from the Technical Advisory Group on the first round of the Shoreline Master Program update, which paused in 2016. It was included in county staff reports to the Planning Commission at that time, and the Washington Department of Ecology guidelines on SMPs strongly encourage addressing SLR. Yet sea level rise was not included in the draft plan five years ago, upon which this update is based, and is not addressed in this draft update, which is ironically termed comprehensive.

Failure to plan for SLR now will only make it more difficult, more expensive, and more dangerous to address in the future. This failure to plan and to act will magnify future impacts to infrastructure, homes, and lives, as well as to shoreline ecological resources. Ignoring SLR nowwill lead to more homes being built in harm's way. It will leave fewer options to avoid impacts and manage strategic retreat from the rising sea. That will in turn lead to more pressure to allow impacts to shoreline ecological resources through measures such as hard armoring with their well-known detrimental ecological effects.

Many public comments submitted to the Planning Commission on the draft SMP pointed out the importance of addressing sea level rise in the county's plan for shoreline management. Without that, the plan can hardly be accurately called a "comprehensive update." The response of the county to the SLR issue being raised by multiple commenters was that the Department of Ecology and state law do not require addressing this very real and relevant issue in the SMP. Meeting the minimum legal requirement does not stop or slow the rising of the sea.

Those responding to public comments also cited the county's Climate Action Plan (2010). In its list of implementation measures that plan includes, "Skagit County shall develop and implement goals that involve … the Shoreline Management Plan." Yet this SMP update, eleven years later, fails to include this aspect of climate change which certainly affects Skagit County.

This is poor planning. The next required update to the SMP will be in eight years. We know sea level rise has already started and will continue with growing impacts and increasing risks. Yet the plan fails to even acknowledge this critical problem, much less address it. Skagit Audubon urges the Board of County Commissioners to include response to sea level rise in this SMP update or to at least prioritize an update to the SMP to address SLR as soon as feasible and not wait eight more years to begin to plan for this critical factor in shoreline management.

<u>Residential Development</u>

Residential Development, as stated in the current SMP draft (6C-15.2), "should be located …to avoid [frequently flooded areas] and storm tides or surges … without placement of extensive flood hazard management facilities or hard shoreline stabilization." Language should be added regarding avoiding such tidal and storm surge areas at elevations predicted to be impacted for the lifetime of the proposed structure. The following language should be added.

14.26.320 (1)(a) – New Development must be located / designed to avoid the need for future shoreline stabilization during the lifetime of the structure including consideration of projections of sea level rise.

<u>Shoreline Stabilization Structures</u>

Shoreline stabilization structures, in particular hard armoring, have major impacts on shoreline values and functions. Recent studies have especially singled out this use as a major driver of habitat loss for forage fish species, such as sand lance and surf smelt. These losses in turn impact species up the food chain including salmon, orca, and marine birds. Regulations in the proposed plan are not sufficiently protective of shoreline resources from the impacts of hard armoring. Suggested changes are noted below.

Current wording:

14.26.480 (2)(a)(i) New hard shoreline stabilization structures are prohibited except…to protect an existing primary structure likely to be damaged within 3 years.

Should be changed to:

14.26.480(2)(a) i. New hard shoreline stabilization structures are prohibited except…to protect a primary structure existing at the date of adoption of this Shoreline Management Plan.

Current language

14.26.480 (1)(a)(ii) "soft shoreline stabilization" may include use of ... boulders ...

This language opens the door far too wide to a greater use of boulders, which are a form of hard armoring. The language should clarify that boulders may be used as a minor component of a soft armoring project, primarily to tie-in the soft components with existing hard armoring of adjacent properties consistent with Department of Ecology guidelines and accepted practice in Puget Sound.

The criteria for allowing new, expanded, or replacement hard armoring are not sufficiently protective of key shoreline ecological resources often adversely impacted by such structures. We suggest adding additional criteria at:

> *14.26.480(4)(b)(v)(D) – Minimize impacts to shoreline ecological resources from impacts of hard shoreline stabilization structures, including to sand lance and surf smelt spawning beaches, eel grass beds and critical habitat for Threatened and Endangered species.*

Shoreline Buffers

The Planning Commission recommendations include allowing shoreline buffers to be reduced from between 25% to 50% with only an administrative variance. This would allow potentially very significant reductions in shoreline buffers and associated increases in impacts to shoreline values and functions without a hearing to prove that the standard buffers are in fact a significant hardship. This reduction in buffer protection should not be allowed, and we urge you to reject this Planning Commission recommendation.

Thank you for your attention to our concerns. Well managed, protected, and accessible shorelines are essential to maintaining and improving an aspect of Skagit County that Skagit Audubon members value especially highly.

Sincerely,

Jeff Osmundson
President
Skagit Audubon Society
P.O. Box 1101
Mt. Vernon, WA 98273

Timothy Manns
Conservation Chair
Skagit Audubon Society

Jennifer Rogers

From:	Commissioners
Sent:	Monday, February 28, 2022 12:01 PM
To:	PDS comments
Subject:	FW: Shoreline Master Program

Public comment from Oscar Graham below.

Sincerely,

Amber Erps, CMC
Skagit County Commissioners Office | Clerk of the Board
1800 Continental Place, Suite 100, Mount Vernon, WA 98273
360..416..1300 ambere@co.skagit.wa.us | find us online

From: Oscar Graham <gba@wavecable.com>
Sent: Monday, February 28, 2022 11:41 AM
To: Commissioners <commissioners@co.skagit.wa.us>
Subject: Shoreline Master Program

Dear Commissioners ~ I know that all of you have personal experience with shoreline regulations. After some 40 years working with these regulations, from both public and private perspectives, I have to ask myself; what benefit is derived from them and are the costs commensurate with benefits? After investing more than a decade on this update, who will bear the burden of implementation of these regulations? I hope you will ask yourselves these questions before signing the adopting ordinance. Your signatures, as our elected officials, carry more weight than those of the planning staff and consultants who crafted the document. Sincerely, Oscar Graham

3643 Legg Road
Bow, WA 98232
(360) 766-4441
gba@wavecable.com

RECEIVED
FEB 2 8 2022
SKAGIT COUNTY
PDS

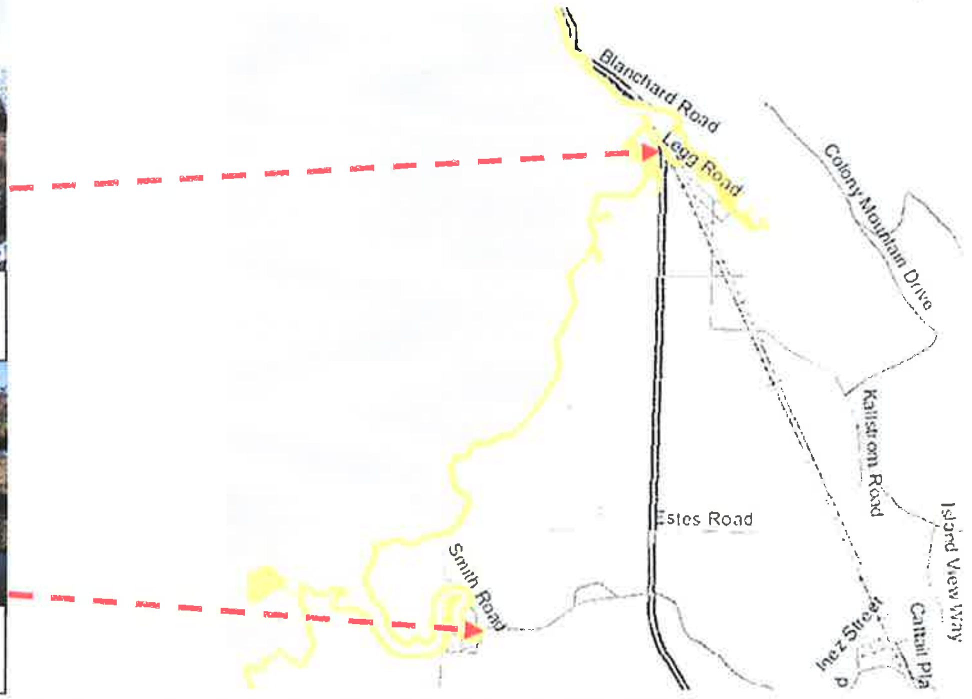
Comments on Proposed Skagit County's Shoreline
Master Program Update
Planning and Development Services
1800 Continental Place
Mount Vernon, WA 98273

Two similar sloughs in the Lower Samish Watershed have received differing treatment under the Draft Shoreline Master Program. The portions of McElroy Slough and Edison Slough above the self- regulating tide gates (SRTs) are not currently mapped as shoreline jurisdiction. Under the draft SMP shoreline jurisdiction at McElroy Slough in Blanchard is extended more than .5 miles upstream of the tide gates and designated Rural Conservancy on the draft Shoreline Area Designation Map.

McElroy Slough upstream from SRT at N. Blanchard Road.

Edison Slough upstream from SRT at McTaggart Street.

Photos 02.24.22



Draft Shoreline Designation Map (Skagit County Website)

Shoreline jurisdiction on Edison Slough is shown to end at the tide gates. This may seem like a trifling matter, but it is not. The extension of shoreline jurisdiction upstream of the tide gates at McElroy Slough will require property owners to comply with the substantive and procedural requirements of the SMP including permit procedures, accompanied by substantial submittal fees. Conversely, whatever benefits are derived from the SMP will not be provided for the area of Edison Slough above the tide gates.

As parties with an interest, and experience in shoreline management, we are also property owners on McElroy Slough who are directly affected. What to us, is an apparent discrepancy in identifying the shoreline jurisdictional area may be explained by providing the stream/tidal data upon which proposed jurisdiction is based or perhaps this can be explained as a simple mapping error. In any case we are requesting a response to clarify the matter. We made our initial inquiry in May of 2021 and have not received a response to date.

To be clear, we are not requesting that shoreline jurisdiction be extended above the tide gates on Edison Slough. Nor are we asserting that jurisdiction be removed on McElroy Slough. We are requesting that the basis for extending jurisdiction in Blanchard be provided to owners of property along the affected area of McElroy Slough. In addition the impact of shoreline regulatory authority should be made clear to those affected. Thank you for considering our comments.

Oscar Graham & Patricia Bunting – 3643 Legg Road – Bow WA 98232

Oscar Graham & Patricia Bunting

Jennifer Rogers

From:	Fernando Pratesi <fernandopratesi@yahoo.com>
Sent:	Monday, February 28, 2022 2:03 PM
To:	PDS comments
Subject:	Skagit County's Shoreline Master Program Update

Hello,

The proposed map has designated McElroy Slough as a Shoreline of the State.
I do not believe it meets the criteria for that designation. My property will be affected by that designation which will put additional restrictions and costs from what already exists.

Kindly,

Fernando Pratesi

Jennifer Rogers

From: Kirk Johnson <kirkjohn@comcast.net>
Sent: Monday, February 28, 2022 2:12 PM
To: PDS comments

Subject: Skagit County' s Shoreline Master Program Update

Commissioners,

Thank you for the opportunity to comment on the revision and update of Skagit County's Shoreline Master Program (SMP). I am pleased to see the overall progress and improvements in the County's Shoreline Management Program Draft.

Address Climate Change and Sea Level Rise

However, I urge you to begin addressing the effects of climate change on the development, protection, and restoration of shorelines through the current SMP Update. Further modifying the SMP now to begin to meet the reality of climate change will help avoid the need for emergency revision before the next required eight-year review and avoid costly mistakes.

Several counties and municipalities have incorporated sea level rise considerations in their SMPs, creating case studies and guidance on how this can be done. The Department of Ecology's publication, Lessons Learned from Local Governments Incorporating Sea Level Rise in Shoreline Master Programs (July 2021, Publication 21-06-014) is an excellent resource. WAC 173-26-090 encourages jurisdictions to consider new information and consult Ecology guidance on emerging topics such as sea level rise. I understand the Department of Ecology will be offering grants to counties to incorporate consideration of climate change in their SMPs.
Skagit County should take advantage of this opportunity as soon as possible.

Remove Logging Road Exemption

The Planning Commission recommendations include that logging roads within the shoreline zone be exempt from the requirement of submitting a substantial development permit. You should reject this Planning Commission recommendation, for the following reason: Forest practices under the Forest Practices Act are already exempt because they are adequately covered by that Act.

However associated logging roads are not exempt from this review.

Ecology's Shoreline Permitting Manual Guidance for local governments states "The development of roads, trails and bridges and placement of culverts associated with forest practices are typically considered to be substantial development and require substantial development permits."

Strengthen Shoreline Variance Requirement

The proposal also includes changing the shoreline variance requirement to allow buffer reductions of between 25% and 50% via administrative review rather than requiring a shoreline variance through a hearing examiner.

I oppose this change in process, which could allow significant reduction in buffer protections without a hearing.

It is most cost effective to ensure development happens in the right places and in the right way, now, rather than to have to fix problems in the future. Risk management issues can also occur when buffers are reduced without adequate review.

The proposed Shoreline Master Program Update is a step in the right direction and is long overdue. Please further strengthen the plan by addressing the issues mentioned above, as further described in the Skagit Land Trust's comment letter.

Sincerely,
Kirk Johnson
Mount Vernon

Sent from Mail for Windows

Jennifer Rogers

From:	Stephen Orsini <sailingorsini@gmail.com>
Sent:	Monday, February 28, 2022 3:16 PM
To:	PDS comments
Subject:	Skagit County's Shoreline Master Program Update

In sections 14.26.540 – 544 of the February 15, 2022 Draft Skagit County Shorelines Master Plan there is a discussion of the Aquifer Recharge Areas and how activity in these areas should be managed to protect the aquifers and maintain their water quality. There is even reference to an aquifer recharge area map. The fact is we are not sure where the recharge areas are on Guemes Island.

The Guemes Island Planning Advisory Committee (GIPAC) approached Skagit County over four years ago to join it in sponsoring a US Geological Survey study to identify the aquifer recharge areas on Guemes Island. Although Skagit County Planning staff thought this a good idea, nothing further was done to help co-sponsor the study, leaving GIPAC to find the $80,000 matching funds on its own. After years of effort, GIPAC was able to secure money through the State Legislature to co-fund the study. In the process, San Juan County learned of the proposed study and requested that it be expanded to its islands. In San Juan County, their Department of Health led the effort to help secure the necessary co-funding. This study is just beginning on Guemes and will take another two years to complete. Then, and only then, will the verbiage in sections 14.26.540-544 take on any meaning. Unfortunately, although there will be best available science to back up the intent of protecting the sole source aquifers on Guemes, the management directives contained in 14.26.540-544 need not be implemented.

Skagit County issued a legal opinion in 2020, that due to an interpretation of responsibility between Skagit County and the Department of Ecology, Skagit County has no authority to regulate wells on Guemes Island. Actually, no member of the public is exactly sure what the legal opinion says. In its filing of a Freedom of Information Act to obtain a copy of the legal opinion, GIPAC received 4 completely black, redacted pages, with the explanation that the entire opinion was subject to attorney/client privilege- that is between the Skagit County Prosecuting Attorney's office and its client the Board of County Commissioners. Yet that opinion is being adhered to by the County and they are not regulating well drilling on Guemes. So all the words in this SMP in 14.26.540-544 as well as in 14.26.550, regarding Seawater Intrusion, are meaningless legally. Well drilling goes on at an increasing pace everywhere on Guemes Island and the number of households experiencing seawater intrusion in their wells is increasing.

Thank you,
Stephen (Steve) Orsini
4971 Guemes Island Rd
Anacortes, WA 98221

Jennifer Rogers

From: Paul Newman <ptnew8@gmail.com>
Sent: Monday, February 28, 2022 3:23 PM
To: PDS comments
Subject: Shoreline Master Program Update (SMP)

Attn: Betsy Stevenson,

I'm the owner of P48072 & P48073 (Site Addresses: 3726 & 3727 Washington St, Bow, WA, 98232).

My request is to remove the proposed extension of this jurisdiction past the tide gates or explain how it got there. The effect it will have on those of us in this new designation is: more permits will be required for any improvements made to our properties when a permit is required.

It could affect the cost of permitting by 2,000.00 to $10.000.00 more dollars and may require a hearing.

Also I believe it will affect our flood insurance. Some insurance companies don’t want to insure properties with a shoreline designation.

Thank you,

Paul Newman
604-908-3108

By Email

February 28, 2022

Skagit County Planning and Development Services
1800 Continental Place
Mount Vernon, WA 98273
Pdscomments@co.skagit.wa.us

Re: Skagit County Shoreline Master Program Comprehensive Update & Periodic Review-- ***Supplemental Comment Letter of Evergreen Islands and Washington Environmental Council***

Dear Board of County Commissioners,

Evergreen Islands, Washington Environmental Council, and Guemes Island Planning Advisory Committee respectfully submit these supplemental comments to assist Skagit County in adopting a Shoreline Master Program Update ("SMP Update") that achieves the ecological protection mandated by Washington's Shoreline Management Act ("SMA"). We appreciate proposed amendments to address a handful of our earlier comments, but want to highlight several provisions that must be revised for consistency with the SMA, Chapter 90.58 RCW, and its implementing Guidelines, Chapter 173-26 WAC. These comments are intended to supplement the comments and attachments that we submitted on June 16, 2021. Due to the voluminous size of those materials, we are not resubmitting them at this stage in the commenting, and incorporate them and their attachments herein by reference.

First, we appreciate this opportunity to comment on the revised SMP Update. However, we urge you to extend the comment period so that it reflects a realistic time frame for the public to review and comment on lengthy documents. Public comment affords the citizens who will benefit from the SMP an essential opportunity to express their vision for the future of our community's shorelines. It also provides the County an opportunity to review the evolving code language to confirm that it is consistent with the SMA or, if it is not, to revise it to meet the law's requirements. In this instance, the County's 14 days' notice for review and comment is inadequate, **and should be extended for a minimum of 14 days**.[1]

Second, we express our support for the detailed comments submitted by the Swinomish

[1] While the County notice for public comment stated that the County would accept comments from February 10 through March 1, that notice was not circulated until February 15.

Indian Tribal Community on June 22, 2021, and urge you to implement their recommendations. We believe those recommendations did not receive the attention they deserved during the Planning Commission phase of the SMP Update review, and rely on you to correct that oversight. As stakeholders with hard-fought Treaty rights for meaningful access to fish, their recommendations to preserve those fish and the habitat upon which they depend merit special attention.

Third, we appreciate that the County incorporated the following recommendations into the SMP Update:

- **Directing lighting away from critical areas, unless necessary for public health and safety. (14.26.320(8));**
- **Prohibiting new commercial non-native finfish net pens. (14.26.415(7)(e));**
- **Adjusting the review distance to 300 feet for ascertaining the existence of critical areas, consistent with the critical areas ordinance. (14.26.515(4));**
- **Referring to the use of Best Available Science and Best Management Practices for critical areas reviews. (14.26.515(4)(b);** and
- **Adding to functions of riparian buffers: microclimate and nutrient inputs. (14.26.572(2), .573(1)(a)).**

Fourth, we want to highlight the following changes we believe necessary for the SMP Update to comply with the SMA and SMP Guidelines:

- **Protect native salmon from net pens. Prohibit commercial net pens, including both non-native and native finfish (14.26.415(7)).** *Due to the significant risk to native salmon and to comply with the Guidelines' direction that aquaculture facilities "be designed and located so as not to spread disease to native aquatic life [or] establish new nonnative species which cause significant ecological impacts," all net pen finfish aquaculture must be proscribed in Skagit County waters. WAC 173-26-241(3)(b)(i)(C). These waters offer some of the most productive native salmon fisheries remaining in the state and must therefore be protected from the high risk of impacts from net pens.*
- **Limit excess administrative discretion. Eliminate excessive administrative discretion by requiring a variance for buffer reductions (14.26.735(2)).** *The draft's allowance for buffer reductions up to 25% without any variance review and 25%-50% without public notice and review would circumvent the public process that the Guidelines require for substantial*

shoreline development. WAC 173-27-110. The Guidelines require public notice and a 30-day comment period for any development that is not exempt from the SMA's procedural requirement. Id. *This includes variances that grant relief from the specific bulk, dimensional or performance standards set forth in the applicable master program…." WAC 173-27-030(17), -170. The SMP Update must be revised to ensure that authorizations for different dimensional standards like buffer reductions are processed as variances and that they thus involve public notice and opportunity for comment.*

- **Protect critical saltwater habitats like eelgrass. For consistency with the Guidelines' requirements to protect critical habitats like eelgrass, (1) aquaculture must be prohibited from eelgrass and macroalgae beds (14.26.415(4)); and (2) overwater structures must be located at least 25 feet from the nearest edge of eelgrass and macroalgae (14.26.420(4)(a)).** *The Guidelines direct that aquaculture should not be permitted in areas where it would result in a net loss of ecological functions, adversely impact eelgrass and macroalgae, or significantly conflict with navigation and other water-dependent uses. WAC 173-26-241(3)(b)(i)(C). In addition, the Guidelines mandate that "[l]ocal governments shall protect kelp and eelgrass beds…" which prohibits overwater structures intruding into critical saltwater habitats absent an enumerated exception. WAC 173-26-221(2)(c)(iii)(C). In addition, the Guidelines require buffer zones around critical saltwater habitats to separate them from incompatible development (WAC 173-26-221(2)(c)(iii)(B) and this would also be consistent with WDFW requirements at WAC 220-660-380(3)(b).*[2]

- **Eliminate unnecessary armoring. The draft must be revised to eliminate boulders from the suite of "soft" armor options promoted by the SMP Update (14.26.480(1)) and preclude armoring for new non-water dependent development (14.26.480(2)(c)(ii)).** *The SMP Update currently includes hard elements like boulders and logs as "soft" shoreline stabilization yet the Guidelines identify such materials as "hard" stabilization. The Guidelines identify "less rigid materials, such as biotechnical vegetation measures or beach enhancement" as "soft" structural measures. WAC 173-26-231(3)(a)(ii). In addition, the Guidelines state that "[n]ew development should be located and designed to avoid the need for future shoreline stabilization to the extent feasible." WAC 173-26-231(3)(a)(iii).*

- **Protect riparian buffers. Riparian buffers must be established equal to one site potential tree height, consistent with the most current, accurate, and complete scientific and technical information available from the Washington Department of Fish and Wildlife's**

[2] The County's Shoreline Analysis Report, at page 204, recommends that dock and pier standards be consistent with WDFW design standards to the extent practicable.

2020 report titled Ecosystems, Volume 2: Management Recommendations. 14.26.573(1)(c).

- <u>**Tree protection**</u>**. The draft must be revised to delete the authorization for timber cutting in the shoreline buffer and to remove the new statement that "temporary access roads" are not "development." (14.26.574(4)(e), 14.26.445(1)(d)).** *The Guidelines require the conservation of adequate shoreline vegetation to protect property, human safety, visual qualities of the shoreline, and plant and animal species and their habitat, and the Update thus must protect and restore the ecological functions and ecosystem-wide processes performed by vegetation along shorelines. WAC 173-26-221(5)(b). The authorization for timber cutting and the exemption for road development conflict with this provision by expressly allowing unjustified timber cutting.*

- <u>**Climate change and sea level rise**</u>**. Policies must limit development in flood prone areas. We recommend the following:** (*1) new lots should be designed and located such that the buildable area is outside the area projected to be inundated by 2100; (2) Where lots are large enough, new structures should be outside areas likely to be flooded AND outside areas where wetlands and aquatic vegetation will likely transition; and (3) new and substantially improved structures should be elevated above the likely sea level rise elevation in 2100.*

- <u>**Limit saltwater intrusion**</u>**. Protections should be adopted for safe drinking water, such as:** *(1) no wells drilled within 200 ft of the ordinary high water mark in areas of known seawater intrusion; and (2) wells to be drilled within 1000 ft of marine shorelines should have a hydrogeological study prior to drilling to ensure that the new well does not exacerbate seawater intrusion or compromise further wells subject to seawater intrusion.*

- <u>**Impervious surface**</u>**. A maximum 10% impervious surface limit for rural conservancy lands (Table 14.26.310-1 Dimensional Standards)**. *The draft's authorization for 25%-30% impervious surface conflicts with the Guidelines' statement that "[s]cientific studies support density or lot coverage limitation standards that assure that development will be limited to a maximum of ten percent total impervious surface area within the lot or parcel, will maintain the existing hydrologic character of the shoreline. WAC 173-26-211(5)(b)(ii)(D).*

- <u>**Nonconforming**</u>**. Nonconforming single-family residences must be characterized as nonconforming structures (14.26.510(1)).** *The draft's characterization of single-family residences that do not conform to the SMP as "conforming" conflicts with the SMA* *regulation's definition of "nonconforming structures" as "an existing structure that was lawfully constructed at the time it was built but is no longer fully consistent with present regulations such as setbacks, buffers or yards…." WAC 173-27-080(1)(b).*

- **Rural Conservancy SED shoreline.** *Development in the Rural Conservancy SED should be limited to water-dependent uses to protect those shorelines.*

Last, the SMP Update does not appear to establish the tracking mechanism required by the Guidelines to assess shoreline impacts that occur in the future so they can be addressed by the County. WAC 173-26-191(2)(a)(iii)(D). As noted by the County's Cumulative Impacts Analysis (page 9) and Restoration Plan (page 64), this mechanism must track shoreline conditions, permit activity, and policy and regulatory effectiveness. This component must be added to the SMP Update prior to its adoption. In addition, since the County's shoreline analysis for the SMP Update was drafted in 2011, this tracking mechanism must use 2011 as the baseline for development impacts and track all shoreline development that has occurred since that time.

Sincerely,

/s Marlene Finley
Marlene Finley, President
Evergreen Islands

Rein Attemann, Puget Sound Campaign Manager
Washington Environmental Council

Harold R. Rooks, Jr, Chair
Guemes Island Planning Advisory Committee

Jennifer Rogers

From: Lynn Lennox <planetblanchard@gmail.com>
Sent: Monday, February 28, 2022 4:15 PM
To: PDS comments

Subject: Shoreline designation in Blanchard

To Whom it May Concern,

Why has Skagit County proposed a change of McElroy Slough/Colony Creek to a Shoreline of the State? What criteria were used? Current regulation states that mean annual flow of 20 cfs is considered a shoreline, and McElroy doesn't come close to that. Currently it is designated as a fish stream, which seems more accurate.

Thank you for your consideration of this specific area and any data you are able to provide.
Sincerely,
Lynn Lennox

Jennifer Rogers

From: Molly Doran <mollyd@skagitlandtrust.org>
Sent: Monday, February 28, 2022 5:23 PM
To: PDS comments
Subject: Skagit County's Shoreline Master Program Update

SKAGIT LAND TRUST
Saving Land for Tomorrow

February 28, 2022

Skagit County Commissioners

Regarding: Skagit County Shoreline Master Program

Dear Commissioners

We appreciate the opportunity to comment on the revision and update of Skagit County's Shoreline Master Program (SMP). Skagit Land Trust encourages the adaptation of county planning documents and procedures to take climate change into account. Further modifying the SMP now to begin to meet the reality of climate change will help avoid the need for emergency revision before the next required eight-year review and avoid costly mistakes.

We understand this would be a significant addition, however due to counties and municipalities who have incorporated sea level rise considerations in their SMP's, there are now case studies and guidance on how this can be done. The Department of Ecology's publication, Lessons Learned from Local Governments Incorporating Sea Level Rise in Shoreline Master Programs (July 2021, Publication 21-06-014) is an excellent resource. WAC 173-26-090 encourages jurisdictions to consider new information and consult Ecology guidance on emerging topics such as sea level rise. **We understand the Department of Ecology will be offering grants to counties to incorporate consideration of climate change in their SMPs. We urge Skagit County to take advantage of this opportunity as soon as possible.**

Climate Change and Sea Level Rise

The draft SMP portrays a welcome emphasis on protecting the ecological integrity of shoreline environments and protecting shoreline processes. This emphasis makes all the more striking the near complete omission of attention to climate change in relation to changes in river flooding, sea level rise, related storm surges and inundation of shoreline areas. Given the science that sea level rise (SLR) and other impacts of climate change are a certainty, planning should begin now. Skagit County sits squarely in an area being affected. **A first step towards adaptation to climate change is reducing vulnerability and exposure to areas that are now, and will be, affected.**

We are already seeing impacts of a changing climate. On or near Skagit Land Trust properties we have witnessed sluffing of marine bluffs whose erosion is quickening with wet winters and more storm events –this sluffing threatens certain roads on Guemes. With increasingly dynamic flood events, some homes upstream of our properties on the Skagit River and its tributaries have destabilized and become hazards that had to be removed. In the 2021 fall floods, 90% of our Skagit River lands had large portions under water. These are all properties that formerly had development rights on them. Several conservation areas that were completely under water, had historically been platted for residential housing developments. With climate change, the frequency and quite likely the size of floods is increasing. We also saw in January king tides driven higher by low barometric pressure. Some dikes overtopped or came close to over-topping and some low elevation marine areas flooded. As sea levels rise, coastal flooding will increase, which can lead to regular storm events becoming more damaging in vulnerable areas.

Both climate change and management decisions will have a significant impact in our area. Sea level rise and climate change impacts will only increase. If we do not address these impacts through planning, there will be greater future impacts to shoreline ecological values and functions, homes, infrastructure, and agricultural lands. The longer we delay, or use dated parameters, the more costly the fixes will be. This is in addition to dealing with problems from decisions made decades ago. Well-planned avoidance is by far the least expensive strategy, the least risky to community members, and best for the environment.

Reducing global greenhouse gas emissions (GHG) over the coming decades will reduce the rate of SLR but not prevent a significant rise from happening. Recent studies, including NOAA's 2022 Sea Level Rise Technical Report, have found that the actual rate of SLR happening now is on the upper end of projections from a decade ago and likely to be between 18 inches and 3 feet by 2100 depending on the reduction of GHG emissions over the next several decades. While we recognize that counties and municipalities are not required under state law to consider the effects of climate change in revising their SMPs, this will quite likely be a requirement in the future. Whether it becomes one or not, the effects on Skagit County's shorelines will be increasingly impossible to ignore.

Suggestions on including sea level rise in the SMP

State law does not explicitly require Skagit County to address SLR in the SMP update, but it is encouraged, and the language of RCW 90.58.020 about preferred shoreline uses supports its inclusion. **The guidelines for master programs at RCW 90.58.100(e) urge that those preparing SMPs, "Utilize all available information regarding hydrology, geography, topography, ecology, economics, and other pertinent data."** The evidence for climate change and its present and likely future effects, including on river flows and flooding and on sea level rise, are certainly pertinent to preparing an adequate SMP for Skagit County.

In the spirit of the Shoreline Management Act, addressing SLR and a changing climate will help protect statewide interests, preserve the natural character, resources, and ecology of the shoreline, and elevate long-term over short-term benefits. To not address SLR means falling short of meeting all of these.

- **We urge you to tap into the expertise of the Skagit Climate Science Consortium (www.skagitclimatescience.org) to review the draft SMP and suggest how it might be modified in light of what will be very different conditions in the future.**

- **Conducting a sea level rise vulnerability assessment is a critical step**.

Sea level rise has serious implications for agricultural and other low elevation lands and wetlands.

Projections of SLR in Skagit County indicate a significant area of low elevation Skagit County, and in particular agricultural land, is at risk of either being inundated or rendered economically not practical due to increased flooding and drainage issues. Dikes and levees are a short-term and intermediate term solution for some areas but are not workable for all areas that will be affected. Building more seawalls as the sea rises could also squeeze out critical estuarine habitat on the waterward side. Many types of seawalls would interrupt drift cell activity which build our beaches and berms protecting many of our natural and residential shorelines. Innovative and creative solutions need to be discussed and tried. Ways to protect farmland should be identified and plans developed to preserve these lands functionally and cost effectively while also protecting other ecosystem services and shoreline functions. Since our county's infrastructure runs through our agricultural valleys and in shoreline areas that are prone to inundation and SLR, infrastructure may need to be moved or elevated. New technologies should be considered that have a chance of lasting for the next century and that fit with the changing environment.

- **The County should begin planning now and acknowledge the need in the Goals, Objectives, and Policies of the SMP.**

Goals for residential development should reflect climate-change projections.

Residential development, as noted in the SMP draft at 6C-15.2, "should be located …to avoid [frequent flood areas] and storm tides or surges…without placement of extensive flood hazard management facilities or hard shoreline stabilization.".

- Language should be added regarding avoiding construction in tidal and storm surge areas **at elevations projected as reasonably likely to be impacted for some specified period into the future.** For example, to "**avoid SLR and storm surge impacts for the next 50 years" or, alternatively, "for the lifetime of the planned structure."**

Armoring of Marine Shorelines (6C-16.1 Shoreline Stabilization Structures).

While the draft SMP is stricter than the current regulations, there are still too many loopholes allowing this ecologically destructive practice that also impacts other landowners' shorelines. Effects from hard armoring to shoreline values and functions are significant, and SLR will exacerbate them. Recent studies have especially singled out this use as a major driver of habitat loss for forage fish species, in turn impacting salmonids, orca, and seabirds. It is also easier to avoid developing in the wrong location now, than deal with future impacts of SLR on these properties.

- The draft proposes "limited use" of hard armoring, but this standard is too vague and permissive. We suggest language to this effect: **"Use of hard armoring is prohibited except where there is no reasonable alternative to protect a structure existing"** as of the adoption of this code amendment**.**

Stronger Standards Needed for New Hard Armoring and New Development

The SMP draft at 6C-16.2 calls for shoreline stabilization structures to be designed and located to minimize and mitigate impacts to the shoreline. **There needs to be stronger mitigation language to meet the requirements of No Net Loss.** The no net loss standard is designed to halt the introduction of new impacts to shoreline ecological functions resulting from new development. Both protection and restoration are needed to achieve no net loss. Every new or expanded foot of **hard armoring** leads to loss of shoreline function and values. **Mitigation actions contemplated in the plan would reduce those impacts but not eliminate them.** Any new or expanded hard armoring installed should be fully mitigated through the removal of another existing hard armor section on the shoreline or by other specific habitat restoration actions sufficient to provide for No Net Loss of shoreline values and ecological functions. Limiting new hard armoring in the face a climate change and sea level rise is critical. **Suggestions for modifying the SMP Development Regulations to address this issue are the following:**

- 14.26.320 (1)(a) – New Development must be located / designed to avoid the need for future shoreline stabilization to the extent feasible. This language in the current draft could be used to avoid armoring in the future as SLR increases but should be more explicit. **We suggest adding, " to the extent feasible, during the lifetime of the structure considering best available science including projections of sea level rise**.

- 14.26.470(4)(b) Residential Development Standards

  We suggest this language**: "Residential development must be located and designed to avoid the need for flood hazard reduction measures and for tidal flooding and storm surge protection measures, including shoreline stabilization."**

- 14.26.480 (2)(a) Shoreline Stabilization Structures (When allowed)

We suggest this language **for i: New hard shoreline stabilization structures are prohibited except…to protect a primary structure existing at the date of adoption of this Shoreline Management Plan update.**

- 14.26.480 (2)(c) i – **should be edited to mirror the above language as well.**

- 14.26.480 (2)(c) ii – allows new non-water dependent development, including single family residences, to be built in certain circumstances where new hard armoring would be needed to protect them. We suggest this language:

    - **No new non-water dependent that will require protection from hard armoring should be built after adoption of the SMP code update.**

Other Recommendations

The proposal also includes changing the shoreline variance requirement to allow buffer reductions of between 25% and 50% to be done via administrative review rather than requiring a shoreline variance through a hearing examiner. However, required setbacks are a critical way to avoid shoreline deterioration and help avoid future requests for armoring shoreline. **We oppose this change in process which eases reviews, at a time climate change is hastening shoreline erosion.** It is most cost effective to ensure development happens in the right places and in the right way, now, then to have to fix problems in the future.

The Planning Commission recommendations include that logging roads within the shoreline zone be exempt from the requirement of submitting a substantial development permit. We do not support this change due to the following: Forest practices under the Forest Practices Act are already exempt because they are adequately covered by that Act. However associated logging roads are not exempt from this review. Ecology's Shoreline Permitting Manual Guidance for local governments states "The development of roads, trails and bridges and placement of culverts associated with forest practices are typically considered to be substantial development and require substantial development permits."

In summary, we are pleased to see the overall progress and improvements in the County's Shoreline Management Program Draft. However, we urge the County to begin addressing the effects of climate change on the development, protection, and restoration of shorelines through the SMP. The next required update of the SMP is eight years away. It is important that Skagit County not wait so long to face this very significant reality. **Adding steps the County will take to plan and guidance in the updated SMP is an excellent place to start.** Public support for climate and sea level rise planning is strong and continues to increase as Skagit County residents accept and understand that sea level rise is an issue that needs addressing. The County's leadership is imperative.

Thank you for the opportunity to give input.

Molly Doran

Executive Director

Skagit Land Trust

1020 S 3rd

Mount Vernon, WA 98273

Jennifer Rogers

From: Arie & Joe Werder <jawerder@gmail.com>

Sent: Monday, February 28, 2022 7:11 PM

To: PDS comments

Subject: Skagit County's Shoreline Master Program Update

Hello,

We've noticed that there has been an added designation of shoreline to McElroy Slough and Colony Creek. We are confused as to why this change has been made. We are wondering if there has been a mapping error. We are hoping that you can take another look and explain these changes to us as this area doesn't seem to fit the description of shoreline. Please keep us informed of details regarding this change to our community.

Thank you,

Arie and Joseph Werder

Change #1 regarding replacement of legally existing residences:

- **Add redevelopment or replacement to "How do I use this document?" (4) on page 4: What if you just want to repair, redevelop, or expand an existing structure or modify an existing use?**
- **Add redevelopment or replacement to 14.26.620 (3) p210-211:**

14.26.620 (3)(a) Minor. Redevelopment, enlargement. or expansion by the addition of space to the main structure, or by the addition of space to an appurtenant structure, may be approved by the Administrative Official if all of the following criteria are met:

(3) Redevelopment, enlargement or expansion. A pre-existing residential or appurtenant structure that is nonconforming with respect to dimensional standards may be redeveloped, enlarged, or expanded in accordance with the following provisions.

(a) Minor. Enlargement or expansion by the addition of space to the main structure, or by the addition of space to an appurtenant structure, may be approved by the Administrative Official if all of the following criteria are met:

(i) any redevelopment or enlargement does not extend farther waterward than the existing primary residential structure or farther into the minimum side yard setback;

(ii) any redevelopment or enlargement does not expand the footprint of the existing structure by more than 200 square feet;

(iii) any redevelopment or enlargement does not cause the existing structure to exceed the height limit, or in the case of an existing over-height structure, the redevelopment or enlargement does not increase the structure's existing height;

- **Remove 14.26.620 (4) p211.**

(4) ~~Replacement is authorized consistent with the provisions of 14.26.650(4) for replacement of other pre-existing structures.~~

Discussion/reference:

The Planning Commission recognizes the importance for the ability to maintain, repair, or replace any lawfully established structure as recorded in Motion #12 in the Tuesday, November 30, 2021 Skagit County Planning Commission's Recorded Motion Regarding Skagit County Shoreline Master Program Comprehensive Update and Periodic Review, however, the draft code has yet to be changed.

Change #1 regarding replacement of legally existing residences (continued):

RCW 90.58.030 excludes single-family residences from being considered substantial developments:

> The following shall not be considered substantial developments for the purpose of this chapter:
> …
> (vi) Construction on shorelands by an owner, lessee, or contract purchaser of a single-family residence for his own use or for the use of his or her family, which residence does not exceed a height of thirty-five feet above average grade level and which meets all requirements of the state agency or local government having jurisdiction thereof, other than requirements imposed pursuant to this chapter;

RCW 90.58.620 regarding new or amended master programs allows for redevelopment with no net loss of shoreline ecological functions. Also noted in the findings:

> (1) The legislature recognizes that there is concern from property owners regarding legal status of existing legally developed shoreline structures under updated shoreline master programs. Significant concern has been expressed by residential property owners during shoreline master program updates regarding the legal status of existing shoreline structures that may not meet current standards for new development.

The intent of the Critical Areas Ordinance (CAO) is to prevent negative impact and likely disturbance to critical areas, not to prevent reasonable use that is unlikely to disturb critical areas.

There is no "best available science" indicating that replacement of a structure causes a net loss of shoreline ecological functions. The Stormwater Pollution Prevention Plan (SWPPP) requirement prevents negative impact from construction.

The current (2018) version of the Critical Areas Handbook recommends exempting modifications to existing legal structures, including replacement:

> "Allowed uses or activities" are those uses or activities that are unlikely to result in a critical areas impact because of other regulations or previous reviews. These activities are subject to review by the city or county, but do not require a separate critical areas review or report. Since these activities are generally not "exempt," the critical areas standards continue to apply and the underlying permit could be conditioned to ensure that the activity complies with critical areas protection. Some jurisdictions use the term "partial exemptions" to note that these activities are exempt from the critical areas review process, but not the protection standards. Allowed uses or activities that may not need to complete a new critical review might include:
> …
> • Modification of existing structures. Structural modifications or replacement of an existing legally constructed structure that doesn't alter or increase impacts to a critical area or buffer and doesn't increase risk to life or property.

Change #2 regarding consistency between sections:

- **Change floor area to footprint n 14.26.515 (3) (b) and (d), to be consistent with code 14.26.620 (3)(a)(ii)**

Discussion/reference:

14.26.515 (3) (b) and (d) p218

(b) The project does not expand an existing single-family residence by more than 200 square feet of ~~floor area~~ footprint and does not adversely impact or encroach into critical areas or their buffers; or

(d) The project does not expand an existing structure, other than a single-family residence, by more than 200 square feet of ~~floor area~~ footprint, does not alter the use or increase septic effluent, and does not adversely impact or encroach into critical areas or their buffers; then

14.26.620 (3)(a)(ii) p210

(ii) the enlargement does not expand the footprint of the existing structure by more than 200 square feet;

Change #3 regarding letters of exemption:

- **Change 14.26.720 (3)(a) p218**
- **Requiring a letter of exemption for activity that does not require federal agency approval adds unnecessary work, time, and cost.**
- **To be consistent with WAC 173-27-050 a letter of exemption should only be required if WAC 173-27-050 (1) (a) or (b) apply**

14.26.720 Exemption, Developments Not Required to Obtain Shoreline Permits or Local Review and Developments Not Subject to the SMA

(3) Letter of Exemption.

(a) A letter of exemption is required for all development qualifying for a Substantial Development Permit exemption.

(b) Contents. Consistent with WAC 173-27-050, a letter of exemption must contain the following:

Discussion/reference:

Per WAC 173-27-050 (1), the letter of exemption is only necessary when the review requires approval by federal agencies.

Per WAC 173-27-050 (3), Local government may specify other developments not described within subsection (1) of this section as requiring a letter of exemption prior to commencement of the development.

WAC 173-27-050 Letter of exemption.

Some projects conducted on shorelines of the state also require review and approval by federal agencies. Ecology is designated as the coordinating agency for the state with regard to permits issued by the U.S. Army Corps of Engineers. The following is intended to facilitate ecology's coordination of local actions, with regard to exempt development, with federal permit review.

(1) The local government shall prepare a letter of exemption, addressed to the applicant and the department, whenever a development is determined by a local government to be exempt from the substantial development permit requirements and the development is subject to one or more of the following federal permit requirements:

(a) A U.S. Army Corps of Engineers section 10 permit under the Rivers and Harbors Act of 1899; (The provisions of section 10 of the Rivers and Harbors Act generally apply to any project occurring on or over navigable waters. Specific applicability information should be obtained from the Corps of Engineers.) or

(b) A section 404 permit under the Federal Water Pollution Control Act of 1972. (The provisions of section 404 of the Federal Water Pollution Control Act generally apply to any project which may involve discharge of dredge or fill material to any water or wetland area. Specific applicability information should be obtained from the Corps of Engineers.)

Jennifer Rogers

From:	Hal Rooks <hsredfield@gmail.com>
Sent:	Tuesday, March 1, 2022 10:19 AM
To:	PDS comments
Subject:	Skagit County's Shoreline Master Program Update - additional late edits
Attachments:	Comments on SMP to BoCC. 3.1.2022.pdf

March 1, 2022

Re: ***Supplemental Comment Letter from Evergreen Islands, Washington Environmental Council, and Guemes Island Planning Advisory Committee.***

My name is Hal Rooks; I am the chairperson of the Guemes Island Planning Advisory Committee (GIPAC) and am providing GIPAC's comments on the Shoreline Master Program Draft before you.

GIPAC provided more extensive comments in a letter along with Evergreen Islands and the Washington Environmental Council. With the limited time we have today, I'd like to focus my comments on three issues we want to bring to your attention:

1. Rescind the Skagit County attorney's 2019 legal opinion that Skagit County cannot regulate wells drilled on Guemes Island if those wells are not linked to a development permit. Other counties do regulate **all** well drilling and in fact, the WA Dept of Ecology referred us to neighboring Island County for their policies, which Ecology supports.

We requested a copy of the attorney's legal opinion via a public records request, but this was denied. From what we understand about the opinion, we believe it is flawed because the fragile nature of Guemes Island's groundwater supply is already recognized in a variety of ways in the Skagit County Code. Special regulations apply to wells, alternative water supplies, land division, and land use permits—because Guemes Island is designated as a "sole source aquifer," a "seawater intrusion area," and an "aquifer recharge area." In addition, the entire island is a "critical area," as defined in the Critical Areas Ordinance (SCC 14.24) by virtue of its designation as both an aquifer recharge area and a seawater intrusion area.

2. Because of Guemes' documented history of seawater intrusion, we believe the county should require that a qualified hydrogeologist review and assess the

impact of drilling <u>all</u> wells anywhere on the island. We believe such a review is already required on Guemes because it is a critical area and because SCC 14.24.060 and 14.24.070 require it. But, because the County has chosen not to enforce these provisions, we have introduced a code amendment that would require this, and we believe the county should recover the cost of the hydrogeological review from the residents wanting to drill wells.

3. We favor limiting excessive administrative discretion concerning a variance for buffer reductions (14.26.735(2))**.** *The draft's allowance of buffer reductions between 25% and 50% without Hearing Examiner review conflicts with the variance standards in the SMA regulations WAC 173-27-170*. We believe giving this much discretion to County staff takes away the voice of the people who might be directly impacted by these decisions — neighbors and other members of the public.

Thank you for your attention to these issues.

Hal Rooks
Chair, Guemes Island Planning Advisory Committee
1219 10th St.
Anacortes, WA 98221

Jennifer Rogers

From:	dyvon.havens@gmail.com
Sent:	Tuesday, March 1, 2022 10:25 AM
To:	PDS comments
Subject:	Shoreline Master Plan
Attachments:	Jep letter.Commrs.Wells.docx

Below, and also attached, is a letter to the Skagit County Board of Commissioners re: the Shoreline Master Plan.

March 1, 2022

To: Skagit County Board of Commissioners

Good day,

I would like to talk with you about the Shoreline Master Plan (SMP) from the position of a county resident and a Guemes Island homeowner for over 30 years.

Over here on the Island, many of us are concerned about our future supply of water and over-drilling, what you call 14.26.541. So far, you folks are so busy with dealing with the huge growth going on all over the county that no one has enforced any of the requirements for drilling a well (14.26.543). That's not so good as far as long-term planning goes, which should be addressed in the updating of our SMP.

Now, you folks are having to deal with the whole county, so rules that apply here and occur here might not apply in other parts of the county and work there. Say, like the saltwater shorelines are different from the fresh water lakes or the Skagit River and all its tributaries.

Guemes Island being a sole source aquifer, plus a critical area, maybe it's about time to address the well-drilling requirements. The easiest way I see is no well drilling on all the Island until the landowner pays, themselves, for a hydrogeological study, with an engineer's stamp and submits it to you for approval. God knows you don't have to worry about someone trying to sneak one in on the sly—everyone here minds everyone else's business 24/7.

Now if for some reason someone's well application fails, then they can have a go at rainwater catchment. Heck, right over in San Juan county they have been doing that for years.

These island folks are a real pain in the you know where, and they are never going to shut up. I would, if I were you, make them pay for upholding the law with their own money. Just like all the other permits, they pay and they do the work. That's what I'd do if I were you.

Thanks for your time.

Sincerely,

Joseph Burdock
5117 South Shore Drive
Anacortes WA 98221
(360) 961-1220

P.S. Could you keep the variance laws as they are and let the public ask questions. You folks are giving out variances like my grandmother gave us kids candy!

Jennifer Rogers

From: Wende D <dolstads@hotmail.com>
Sent: Tuesday, March 1, 2022 3:24 PM
To: PDS comments
Subject: Skagit County's Shoreline Master Program Update

##
CAUTION: This email originated from an external email address. Do not click links or open attachments unless you recognize the sender, you are expecting this email and attachments, and you know the content is safe.
##
These comments may, or may not relate to the shoreline Master Plan. But just in case they do relate, i wanted to send them in prior to the deadline.

Regarding the proposed rock quarry/mine on Butler hill at the end of Delvan Hill Road in Sedro-Woolley:
I would like to see mining banned or extremely limited on Butler Hill at the end of Delvan Hill Road.
The current owners, the Weide family, previously had a small scale logging operation on this property for the past 40 years or so. Since the scale of logging and the use of Delvan Hill Road by logging trucks was minimal, the operation was tolerable. At times the trucks ran, and for periods of time the trucks did not run at all. Occasionally the trucks carried rocks that were mined at what might be referred to as Sunny Hill. Sunny Hill is a different location then the new mine that is under consideration. These rocks were used to build roads on the Weide property and I suppose also occasionally sold. Primarily the work was related to logging, including a saw mill on the property.
As I have expressed, in writing to the Skagit County County Commissioners previously, mining in this area is not compatible with the residential area that would need to be crossed to move the material from the mine.

Thank you for considering the families living on Delvan Hill Road.
Wende Dolstad
7650 Delvan Hill Rd
Sedro-Woolley
Dolstads@hotmail.com

Sent from my iPad

Jennifer Rogers

From: Betsy D. Stevenson
Sent: Wednesday, March 2, 2022 7:57 AM
To: Jennifer Rogers
Subject: FW: Comment on SMP in light of climate change

From: Terri Wilde <wildefoods@yahoo.com>
Sent: Tuesday, March 1, 2022 10:42 PM
To: Betsy D. Stevenson <betsyds@co.skagit.wa.us>
Subject: Comment on SMP in light of climate change

Betsy Stevenson, AICP, Project Manager
Skagit County Planning & Development Services
(360) 416-1323
betsyds@co.skagit.wa.us

To all concerned,
I believe the Shoreline Master Program should deeply consider the recent decline in salmon to inform a more updated approach that will be based on the new science and physical changes in both the ecosystem and climate. Frankly the direness of the situation was less clear in 2011 when the current process began. Efforts to protect and restore natural habitat should be encouraged. I also believe that more attention needs to be given to chemical pollution, including "forever chemicals" and herbicides and pesticides used in both forestry and agriculture. Thank you for your hard work. I truly believe that the decisions made now will have significant importance, as we are teetering with little time left to prevent great loss.

Also I believe the dangers of in-water fish pen farming have proven to be too detrimental. Clearly Cook Aquaculture should never be allowed to do business in Puget Sound again after their tragic and untold harmful net breach and damaging regular practices. I would recommend prohibiting businesses who have failed basic safety protocols. I would reccomend banning in water fish farming in general.

Thank you,
Terri Wilde
Skagit County

Skagit County Drainage and
Irrigation District Consortium, LLC
2017 Continental Place, Suite 4
Mount Vernon, WA 98273

Skagit County Dike District No. 17
P.O. Box 2926
Mount Vernon, WA 98273

March 31, 2022

Sent via e-filing

Skagit County Planning & Development
Mr. Hal Hart, AICP, Director
Ms. Betsy Stevenson, AICP, Senior Planner, Team Supervisor
1800 Continental Place
Mount Vernon, WA 98273

Skagit County Planning Commission
1800 Continental Place
Mount Vernon, WA 98273

Re: Comments, Skagit County Shoreline Master Program Comprehensive Update and Periodic Review

Dear Skagit County Board of Commission:

This is written on behalf of the Skagit County Drainage and Irrigation District Consortium, LLC, a Washington limited liability company, comprised of twelve dike, drainage, and irrigation improvement Special Purpose Districts in Skagit County ("Consortium") and Skagit County Dike District No. 17, also a Special Purpose District ("Dike District No. 17"). The Consortium and Dike District No. 17 have reviewed the Skagit County Shoreline Master Program public review draft ("SMP") and its effect on their obligation to protect the people, property, and infrastructure in their respective districts as well as in the greater Skagit County community. Please accept the following comments in response to the proposed SMP. We ask that our comments be included in the record and considered in the public hearing as the current, official position of the Consortium, and that of each of its Member Special Purpose Districts, together with Dike District No. 17.

Background.

The Consortium, formed on December 19, 2018, is comprised of the following twelve Skagit County Special Purpose Districts:

- Dike District 3
- Dike, Drainage, and Irrigation Improvement District 5
- Dike District, Drainage, and Irrigation Improvement District 12

- Drainage and Irrigating Improvement District 14
- Drainage and Irrigating Improvement District 15
- Drainage and Irrigating Improvement District 16
- Drainage and Irrigation Improvement District 17
- Drainage and Irrigating Improvement District 18
- Drainage and Irrigating Improvement District 19
- Drainage and Irrigating Improvement District 22
- Consolidated Dike, Drainage, and Irrigation Improvement District 22
- Dike, Drainage and Irrigation Improvement District 25

Each of the Consortium's Member Districts, as well as Dike District No. 17, are Washington Special Purpose Districts with a long history in Skagit County, all having been authorized and formed pursuant to state law. Collectively we serve and protect approximately 60,000 acres of prime farmland, residential, light industrial, commercial development, infrastructure, medical facilities and city and county improvements with an assessed property value of over four billion dollars with billions of additional dollars invested in dike, levee, and drainage infrastructure.

We are both obligated and committed to sustain our county's dike and levee protection. In addition, we work independently, as well as collectively, on a number of land (including shoreline) and water use policies, always striving for improved environmental quality and enhanced improvements. We also proactively work with Skagit County and the Dike District Partnership to develop Natural Hazard Mitigation Plans and plan for future development changes so as to reduce the risk from natural hazards, including that of flooding. It is through this lens that we have reviewed and considered the SMP.

We made the following comments on the SMP during the public comment period. We believe that Skagit County staff and Planning Commissioners were responsive to our comments and the final draft of the SMP adequately addressed our concerns. As you review, potentially modify, and approve the final SMP document and we hope that you consider these comments.

Comments to the SMP

The Consortium, its Member Districts, and Dike District No. 17 submit the following comments with respect to the SMP:

1. About this Document, Goals and Policies of the Shoreline Master Program. In addition to balancing development, public access, and shoreline protection we submit there are additional considerations to balance, including those obligations the Special Purpose Districts owe to those residing and/or owning property and improvements within our Districts, particularly relating to the protection of people, property, and infrastructure. We request that the SMP's opening recital include a statement that the SMP also balances the management of flood protection and control as well as drainage.

2. Section 6B-4. Rural Conservancy. The definition of Rural Conservancy together with the supporting maps depicting the shoreline designation should include those locations in which the Rural Conservancy designation extends landward of existing dikes, levees, and tidegates. These areas are reflected in the attached annotated maps, incorporated herein by this reference. As noted in the attached maps, the areas landward of existing tidegates are managed by Special Purpose Districts and should not be mapped as a shoreline. In other instances, areas have been restored and the area's classification has changed to natural. Specifically, these restored areas, from east to west, include Fisher Slough, Wiley Slough, and Fir Island Farm.

The mapped Rural Conservancy boundaries should also specify whether dikes, levees, and tidegates fall within the shoreline designation or, alternatively, whether they fall outside of the shoreline designation. If the shoreline designation is intended to include a footprint of the existing dikes, levees, and tidegates, there should be a clear statement that the inspection and routine maintenance of the existing dikes, levees, and drainage infrastructure are exempt from the SMP. Also, dike, levee, and drainage infrastructure repair and restoration, and certainly all flood fighting activities, should also be exempt from the SMP.

3. 14.26.350 Flood Hazard Reduction.

(1) Applicability. The Applicability Section of 14.26.350 is in need of additional clarification and certainty relating to flood hazard reduction. The following details and exemptions should be included in Section 14.26.350:

i. The use of tidegates as a specific hazard reduction measure;

ii. The exemption of inspection, maintenance, repair, and restoration of structural measures;

iii. The exemption of existing marine dikes operated and maintained by Special Districts

iv. The exemption of those levees that are enrolled in the PL84-99 Program; and

v. An affirmative statement should be included stating the Special Purpose Districts have the authority to engage, undertake, and complete actions and work needed to prevent and reduce flood damage and hazard reduction measures.

(2) Application Requirements. Section 14.26.350(2) should clearly distinguish and address the difference between "new" and "existing" reduction measures in order to maintain Skagit County's dike and levee system viability repair, maintenance, and restoration. Seepage berms, erosion protection, dike leveling, dike and levee restoration and maintenance, and other similar measures to reduce flood risk should be defined as "existing" work, not falling within the scope of the SMP. These flood risk reduction measures are subject to the respective Special

District requirements and that of the Army Corps of Engineers and should not also fall within the SMP.

(3) <u>Development Standards</u>. Is the Skagit County Code reference set forth in Section 14.26.350(3)(d) intended to reference SCC 14.26.370 rather than .360? With respect to the substance of Section 14.26.350(3) we are very concerned about the consequences of requiring public access to new public structural flood hazard reduction measures, including dikes and levees as provided for in Section 14.26.350(3)(b). Eighty percent of the land on which our dikes and levees are constructed is owned by private landowners. Understandably, private landowners are very likely to be opposed to providing public access to their land. Public access triggers additional maintenance obligations for the landowner together with additional risk and liability. As with private landowners, the Special Purpose Districts would also incur risk and liability should public access be permitted to the land that they own – purchased and maintained at the expense of those that own property within their Member Districts. Restricted access also provides partnership opportunities that would not otherwise be possible, for example the setback levees constructed in Special Purpose Districts No. 3 (SF Dike Setback), District No. 3 (Fisher Slough) and consolidated Dike District No. 22, (Fir Island) are partnering together on habitat restoration and levee setback opportunities. This valuable work would not be possible if the access were open to the public.

With respect to subsection (e) of Section 14.26.350, each of the drainage Member Districts of the Consortium have pragmatic permits for dredging work and currently obtain shoreline exemptions for this work. Section 14.26.350(3)(e) should include a specific exemption for such work.

4. <u>Flood Fighting Exemption</u>. The SMP should include a specific exemption providing that all flood fighting activities are exempt from the scope of the SMP. Such activities are essential to flood control and flood protection. The Member Districts and Dike District No. 17 have statutory powers, and obligations, to undertake such activity for the protection of our community. Working with the Army Corps of Engineers, it is imperative that the Dike Districts have the ability to safely carry out flood fighting measures and activities.

<u>Conclusion</u>.

In summary, we ask that the Skagit County Planning & Development Services and the Skagit County Planning Commission adopt and include in the SMP the comments set forth in this letter. The Consortium, its Member Districts, and Dike District No. 17 protect major population centers and critical infrastructure in Skagit County. They are responsible for the operation and maintenance of levees protecting the cities of Burlington, Mount Vernon, and La Conner, Interstate 5, medical facilities, governmental agencies, infrastructure, BNSF, major oil and gas pipelines, and the water intake for the city of Anacortes, which also serves Naval Air Station Whidbey Island and several major west coast refineries. Flood risk reduction, including the inspection, maintenance, repair, and restoration of existing dikes/levees and drainage infrastructure, is critical for our community. We ask that these measures be considered and balanced with the other objectives of the SMP.

Thank you for your consideration. Should you have any questions or comments with respect to our collective comments, please do not hesitate to contact us.

Sincerely,

SKAGIT COUNTY DRAINAGE AND
IRRIGATION DISTRICT CONSORTIUM, LLC

By: ______________________
Jenna Friebel, its Executive Director

SKAGIT COUNTY DIKE DISTRICT NO. 17

By: ______________________
Daryl Hamburg, its Director of Operations

Main Office: 360.466.3163
Facsimile: 360.466.5309

Swinomish Indian Tribal Community

A Federally Recognized Indian Tribe Organized Pursuant to 25 U.S.C. § 476
* 11404 Moorage Way * La Conner, Washington 98257 *

March 31, 2022

Skagit County Planning and Development Services
Hal Hart, Director
Shoreline Master Program Comprehensive Update & Periodic Review
1800 Continental Place
Mount Vernon, WA 98273

Dear Hal:

Please accept the following comments on Skagit County's Draft Shoreline Master Program ("SC SMP") on behalf of the Swinomish Indian Tribal Community ("SITC," "Swinomish" or the "Tribe) and the Skagit River System Cooperative ("SRSC"). Swinomish and SRSC appreciate the work invested in this effort by many individuals in the Skagit County ("County") government and in the larger community. However, Swinomish and SRSC continue to have many concerns with the SC SMP and supporting analyses, including those set forth below and thus do not believe that the SC SMP in its current form meets either the letter or spirit of the Shoreline Management Act and implementing regulations. These concerns are in addition to those previously articulated by Swinomish and SRSC at earlier junctures in the County's SMP development process, as well as the extensive comments submitted on June 22, 2021. *All of those previous comments are incorporated herein by reference*.

We would like to reiterate from our June 2021 letter that, given the Swinomish Tribe's sovereign status, legally protected rights and interests in its Treaty-reserved resources, as well as its and SRSC's unique subject-matter expertise, the County must engage in consultation not only in the preparation but also the implementation of its SMP. Additionally, we note that despite prior requested consultation the County has not, to-date, reached out in response to this request to begin the process of engaging in consultation.

Background on Swinomish Indian Tribal Community and Skagit River System Cooperative

The Swinomish Tribe is a federally recognized Indian tribe and present-day successor in interest to certain tribes and bands that signed the 1855 Treaty of Point Elliott ("Treaty") with the United States.[1] Among the rights reserved by the Tribe in this Treaty are various fishing, hunting

[1] Treaty of Point Elliot, Jan. 22, 1855, 12 Stat. 927 (1859).

and gathering rights.[2] The Swinomish Reservation is located on Fidalgo Island in Skagit County, Washington, at the mouth of the Skagit River. Since time immemorial, the Swinomish Tribe and its predecessors have occupied and utilized vast areas of land and water in northern Puget Sound to support the Swinomish way of life. Fish and fish habitat are crucial to the cultural, spiritual, subsistence and commercial activities of the Swinomish Tribe, and the Tribe exercises Treaty-reserved fishing rights in our "usual and accustomed" fishing areas (U&As), which include an extensive portion of marine waters of the Salish Sea in the northern Puget Sound, the entirety of the Skagit River and its tributaries, and the Samish River system.[3] The Tribe's Treaty-protected hunting and gathering rights also extend throughout the Skagit River basin and coastal areas affected by the SC SMP, among other places.

The Skagit River System Cooperative (SRSC) provides natural resource technical services for the Sauk-Suiattle Indian Tribe and the Swinomish Indian Tribal Community. On behalf of these two sovereign nations, SRSC works to actively improve fisheries availability within their usual and accustomed fishing areas. These areas include the Skagit and Samish River basins, and were ceded to the United States through treaties signed in 1855.

Majority of Swinomish, SRSC comments inexplicably not addressed by Planning Commission or County staff.

It is very concerning to the Tribe and SRSC that the County has set aside and simply not addressed the majority of our detailed comments throughout the Planning Commission process. Our analysis indicates that, based on the manner in which comments were broken down into individual "comment subjects," our June 22, 2021 letter included 78 individual "comment subjects" only some of which were included in the County staff's comment summary *Planning Commission Public Comment Matrix.*[4] Of those, the County has offered a response to 22 comment subjects. Of the 22 responses, the County recommended a change for 3 subjects (lighted signage, protection of cultural resources, prohibit all non-native finfish net pen aquaculture). The County indicated a "comment noted" on 5 of our comment subjects; and indicated "change not recommended" on 13 of 22 comment subjects. However, and concerningly, there were 56 of our "comment subjects" that were not addressed by the Planning Commission or the County staff.

We believe this has occurred in part because, very early in the process, comments were distilled into a matrix, and that has been the format for County responses to comments ever since. If a comment did not make the matrix, it was not addressed by the Planning Commission or County staff. As a result, and with no explanation provided, the Planning Commission simply

---

[2] *Id*. Article 5 provides, in part, that "[t]he right of taking fish at usual and accustomed grounds and stations is further secured to said Indians, in common with citizens of the Territory, and of erecting temporary houses for the purposes of curing …"

[3] See, *United States v. Washington*, 384 F. Supp 312 (W.D. Wash. 1974)(the "Boldt decision"); *United States v. Washington*, 459 F. Supp. 1020 (W.D. Wash. 1978)(Swinomish usual & accustomed fishing places). The term "fish," as used here and throughout these comments (unless the context suggests otherwise) is understood to include all species of fish, including shellfish. See also, *United States v. Washington*, 873 F. Supp. 1422 (W.D. Wash. 1994)(the "Rafeedie decision").

[4]https://www.skagitcounty.net/PlanningAndPermit/Documents/SMP/Skagit%20County%20SMP%20Public%20Comment%20Matrix%20Final%2012-7-21.pdf

walked line by line through the matrix at its meetings, without any mention of 56 of the Tribe's and SRSC's comments.

Best scientific and technical information not utilized

In our June 2021 letter, the Tribe and SRSC referenced numerous peer-reviewed technical and best science studies on a variety of topics, including climate change. We noted the SMA requirement that SMP updates be based "on an analysis incorporating the most current, accurate, and complete scientific or technical information available."[5] We also provided hard copies of all of those reference materials to ensure that they would be included as part of the record. We have not seen indications that those technical materials were addressed and incorporated into the staff analysis and recommendations that were part of the materials provided to Planning Commission and the Board of Commissioners ahead of deliberations.

Importantly, new technical information that should be incorporated into shoreline development regulations continues to emerge. A few weeks ago, NOAA's Ocean Service published an alarming report about the near- and long-term likely sea level rise projections for the country[6]. This new, best science report on climate change impacts to shoreline areas from sea level rise will certainly affect existing and future shoreline developments. If the Skagit SMP is to be a contemporary document, it must certainly incorporate current knowledge of climate change and sea level rise science to support coordinated development of the shoreline.

Inadequate protections for key critical habitat and aquatic resources.

<u>**Overarching Issues**</u>

1. Shorelines of Statewide Significance are not sufficiently protected (i.e. permissive to aquaculture, too little protection on marine feeder bluffs)[7].
2. The SMP fails to use "most current, accurate, and complete scientific and technical information available). There have been no updates to sources in years of SMP languish. The SMP includes nothing concerning the effects of climate change.
3. The SMP cannot ignore climate change, and resulting significant impacts like sea level rise. The SMP relies on outdated, inaccurate, incomplete scientific information[8].
4. The policies do not achieve No Net Loss.

<u>**Specific SMP comments**</u>

Mandatory Changes

These issues are mandatory under the SMA and their exclusion from the SMP will undoubtedly result in further delay of this vital update that is already a decade overdue. The County's failure to address the items is a fundamental flaw in the SMP.

---

[5] WAC-173-26-201(2)(a). "To satisfy the requirements for the use of scientific and technical information in RCW 90.58.100(1), local governments shall … base master program provisions on an analysis incorporating the most current, accurate, and complete scientific or technical information available."

[6] https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html

[7] WAC- 173-26-251(3)

[8] Id.

1. The SMP fails to use "most current, accurate, and complete scientific and technical information available), and little update to sources occurred in years of SC SMP languish.[9] The SMA's protective policies should be understood broadly rather than narrowly, as should Ecology's rules to implement the Act. The SC SMP must incorporate "most current, accurate, and complete Scientific information" including consideration of climate change impacts.

2. SMP does not acknowledge the ambulatory nature of the OHWM, its expected landward migration in marine and fluvial systems under climate change and SLR, or its jurisdictional impacts of these events on Shoreline Environment Designations. (This comment has not been addressed to date by the PC, BOCC, or staff).

3. Policy statement 6G-1 undermines the requirements of the Act; this section uses 'should' but county must use "shall" to meet No Net Loss achievement at programmatic and project level. (This comment has not been addressed to date by the PC, BOCC, or staff).

4. Mitigation plans must recognize the need to account for failure, climate change, temporal dimensional of lost ecosystem services when mitigation is delayed, and for uncertainty.

5. The Water Pollution Control Act must be complied with in the SMP. The SMP should reference that document to ensure those water quality standards are met.

6. New aquaculture should not be permitted in Shorelines of Statewide Significance unless it satisfies policies of RCW 90.58.020. (This comment has not been addressed to date by the PC, BOCC, or staff).

7. The SMP allows dredging in typed streams, CMZs, and floodways if is deemed an agricultural activity/maintenance dredging. That would be in violation of state and federal dredging rules. The SMP must only allow dredging when otherwise allowed, as stated in Policy 6C-8.1. (This comment has not been addressed to date by the PC, BOCC, or staff).

Recommended Changes

Skagit County should exercise its discretion on the following subject areas and adopt enhanced protections for Shorelines rather than weakening already inadequate protections that will fail to accomplish salmon recovery. In addition to the four comments identified above that have thus far gone unaddressed by the Planning Commission, Board of Commissioners, and Skagit County staff, below we reiterate the additional 52 of our "comment subjects" that have not been addressed in this SC SMP process.

Shoreline Jurisdiction

[9] WAC-173-26-201(2)(a); Department of Ecology, *SMP Handbook,* Ch.2, Basic Concepts (Publication No. 11-06-010, Rev 12/2017) "At a minimum, local governments must: Make use of all available scientific information, aerial photography, inventory data, technical assistance materials, manuals and services from reliable sources of science."

1. County selected the minimum (not maximum) extent of jurisdiction allowed. We recommend jurisdiction include full 100-year floodplain; Channel Migration Zone (CMZ) references removed from 2016 to 2020 drafts but should be replaced.
2. SC SMP limits jurisdiction to critical areas and their buffers 'located wholly within' shoreline jurisdiction; again, it is minimum not maximum protection. We recommend SC SMP jurisdiction (especially for statewide significant shorelines) should include CAO/buffers partly within shorelines.
3. County should commit to publicly available maps and GIS products depicting floodplain, floodway, wetlands, feeder bluffs, landslide hazard areas, CMZs.

Shoreline Environment Designations

4. SMP does not fully make use of SEDs to ensure an adequate level of protection to shoreline resources and recommend adding "Priority Aquatic" SED.
5. Specific map revisions suggested in Appendix A were not addressed.

6. Shorelines of Statewide Significance – SC SMP fails to meet the heightened standards for protecting these special shorelines; there should be a separate section under General Regulations that highlights and provides regulations for the considerable expanse of areas that are Shorelines of Statewide Significance.
7. Shorelines of Statewide Significance – SC SMP should specify Swinomish Tribe among those to be consulted with expertise/status rights as an adjacent jurisdiction.
8. Shorelines of Statewide Significance – SC SMP should ensure "long term over short term benefit."
9. Mitigation – We applaud some progress in 14.26.305(4)-(6) to address importance of mitigation in NNL, but some statements obscure the import of NNL applicability to ecological function, processes, and values on local and ecosystem scale.
10. Mitigation - The mitigation sequence does not convey the "top priority" for avoiding the impact altogether.

Provisions waterward of OHWM

11. We are concerned that the County is abandoning efforts to delineate the CMZ and incorporate those into the SC SMP; CMZ terminology from Feb 2021 to Apr 2021 drafts is replaced with 'floodplain' which refers back to FEMA floodplain developed in the 1980s.

Flood Hazard Reduction

12. Restore CMZ references in Flood Hazard Reduction section.
13. Clarify "reasonably foreseeable" to a less subjective definition (suggested 75 years).

Vegetation Conservation

14. Native vegetation (retention and planting) in the shoreline is not emphasized; recommend changes to prioritize shoreline planting and retention.
15. Unclear language between 'vegetation retention' and 'tree retention.'
16. The proposed 3:1 replacement ratio is insufficient (temporal lag, failure rates) for replacing lost mature tree with 3 small seedlings.

17. Need assurance that trees planted are maintained and monitored, including thru change in ownership - need requirement for maintenance, monitoring, deed notice, surety.
18. Policy 6G-3.2 prioritizes conifers, but that policy is not carried thru to regulations; recommend specifying conifers be emphasized and/or specified in code/prioritized lists of vegetation.

Water Quality and Nonpoint Source Pollution

19. Concerns about recent research/science recognizing pollution and runoff/contaminants of emerging concern; we recommend identifying Water Pollution Control Act and restricting tire crumbs in the shoreline.
20. Water quality below agricultural areas is poor; recommend SC SMP ensure, at a minimum, WA State WQ Standards for Dissolved oxygen, temperature, fecal coliform, other pollutants are met.

Aquaculture

21. Concerns regarding commercial finfish net-pen operations (both native and nonnative) due to disease, fish escape, ecosystem impacts, lighting; impacts to native wild fish; new science questions why pens are even "in" the water; recommend prohibition of 'commercial finfish net pens (native and non-native) in marine waters."
22. Strengthen the requirements for review and permitting rather than minimizing the instances where review/permits are triggered to minimize impacts to environment and eelgrass.
23. Concern about a potential loophole between 'new' aquaculture and 'expanded' aquaculture; SRSC commented on this in 2013 and 2016 and needs a clear definition; SC SMP allows areas left fallow for many years to be 'expanded' and not 'new' with accompanying eelgrass other impacts.
24. Add a regulation to accommodate Eelgrass that has grown into areas previously not vegetated (SLR prediction); add a regulation for operations expansion/change/new proposals to be permitted as 'new.'
25. Revise Policy 6C-2.1 to more accurately capture the qualified embrace of aquaculture in Ecology's regulations by including 'when properly managed' statement.

Boating Facilities

26. Mooring buoys - Derelict and unpermitted buoys present a navigational hazard/shellfish bed damage if they lose buoyancy; Recommend labels with SMP permit # and remove those that are in disrepair.
27. Mooring Buoys – Installations must prevent dragging anchor chains, such as anchored with a helical screw and mid-water float to avoid scour of bed.
28. Mooring Buoys - County should track the location and density of buoys and under SC SMP monitoring report net change in mooring buoy density.

Dredging

29. Clarify reference to Fish and Wildlife Habitat Areas since 'officially designated fish and wildlife areas" is not defined.
30. Provide vetting for dredging called 'restoration and enhancement' to ensure it provides benefits to fish and wildlife habitat.

31. Additional agencies have jurisdiction over agricultural activities but SC SMP only offers
the NW Clean Air Agency; Recommend adding WA Ecology, FEMA.
32. There are types of agricultural activities that are not exempted under 90.58.065, but SC SMP does not require substantial development permit for these activities.
33. Definitions of 'channelization' is unclear; definition for 'debris' is not offered; recommend a new offered definition for 'channelization.'
34. The term "maintenance dredging" is undefined and confuses agricultural, ditch, and stream dredging with large scale navigation dredging like in the Swinomish Channel.

Residential Development

35. Beach stairs should be an accessory development and not an appurtenance; recommend clarifying the separate treatment of accessory (suggest beach stairs, trams, docks) and appurtenant (septics, garage, deck, fence).
36. Location of appurtenances should be landward to extent feasible.
37. Location of crossing structures should minimize new culverts and bridges in the shoreline

Structural Shoreline Stabilization

38. Hard shoreline stabilization definition doesn't represent what is seen in practice; recommend including 'log timber piles, sheet piles, blanket application of angular rock including spalls and riprap.'
39. Boulders should not be listed under soft shoreline stabilization. Without a clear definition in this code for "soft shoreline stabilization", the inclusion of 'boulders' will allow shoreline stabilization measures to be permitted as 'soft shoreline stabilization' that do not follow the most current, accurate, and complete scientific and technical information available. They may be a supporting element of a soft shoreline stabilization project, but should not serve as a primary feature which is implied in this code.
40. "When allowed" should include 'when they comply with SCC 14.34 Flood Damage Prevention."
41. Upland land use has effects on the need for structural shoreline stabilization; Recommend requirement for land use divisions designed that future development of created lots will not require stabilization from geologic or hydrologic conditions within 75 years.

Transportation Facilities

42. Recommend avoiding "stream adjacent parallel roads."

Critical Areas

43. Offers increased specificity for Review and Assessment Reports - who is qualified to prepare, and review.

Fish & Wildlife Habitat Conservation Areas, Buffers

44. Lower Skagit basin has 112 miles of impaired (T) WQ; the SC SMP fails to account for the substantial extent of impaired waters that limits salmon recovery.

45. SC SMP fails to provide comprehensive, integrated approach to vegetation conservation; Recommend restricting variances and buffer averaging along salmon streams or tributaries to salmon streams or a 2004 TMDL stream to achieve NNL.
46. Establish protective dimensions for riparian and other buffers, require assessment to include density & diversity of trees, SPTH, current width of buffer.
47. Expand the intent of buffers to include these 'basic riparian forest functions" including migration corridors, watering rearing, refuge areas; providing organic inputs; reduce fine sediment; regulate the microclimate.
48. Add language that riparian areas shall maintain and work to restore 1 SPTH and restore the function and values of the CMZ.
49. Buffer averaging should only be allowed with a habitat conservation area site assessment.
50. Buffer averaging should be restricted on streams with existing water quality impairment.
51. SC SMP table at end of 14.26.574 Performance Based Riparian Standards - where does this table come from what scientific info does it use. Ecology requires local govt to 'show its work' when accounting for buffer variances.

Setbacks

52. We recommend a setback from a marine feeder bluff of 50 feet from the top of slope (or 2x height of slope whichever is greater) for new construction

Shoreline Variances

The County's approach includes excessive discretion in administrative officials, no accountability to ensure no net loss is achieved, and fails to account for the degraded riparian habitat buffers and legally temperature-impaired water quality in 112 miles of salmon streams. And yet, the SC SMP allows for significant shoreline variances. We recommend no variances on legally impaired water quality streams; variances must be determined essential by the administrative official and required to provide written justification including cumulative impacts analysis.

New Issues, Comments, and Proposed Code Revisions prompted by February 15, 2022 Draft

We have thus far highlighted those issues that we commented on in June 2021 that went unaddressed by the County in their review. Here, we provide new commentary on the several revisions to the draft SC SMP that were included in the SC SMP draft dated February 15, 2022.

1. ***SCC 14.26.130(5)***

   This provision was added to the draft SMP stating that "As provided in RCW Title 85 and through the US Army Corps of Engineers PL84-99 Program, the provisions of this SC SMP do not affect the authorities and powers of diking and drainage districts". Agriculture is addressed in Policy sections 6C-1 and SCC 14.26.410 making this code redundant. Additionally, even exempt activities exempted as "ongoing agriculture" need to meet the requirements of the SMA for no net loss, so the SC SMP may affect districts' activities even in situations where no substantial development permit is required. To avoid confusion, SC 14.26.130 (5) should be stricken.

2. ***Imprecise terminology in Aquaculture provision***

New provision SCC 14.26.415(7)(b) was added to the SC SMP, but we are extremely concerned that imprecise terminology will lead to misinterpretation of this provision. The provision states that "A conditional use permit is required for new commercial net pen aquaculture operations proposing to propagate a native finfish species". We are concerned with the ecological impacts and risks associated with net pen aquaculture, and 'propagation' of fish is an extremely narrow task within the realm of net pen aquaculture. 'Aquaculture' means the propagation, rearing, enhancement, and harvest of aquatic organisms. 'Propagation' is the breeding or reproduction of animals, and oftentimes is not even part of an aquaculture operation where purchasing or mail order of live stock is possible. We strongly encourage this code is revised to eliminate the term 'propagation' and replace it with 'aquaculture' and rely on the definition of 'aquaculture' included in SCC 14.26.415.

3. Recommend that Light-Blocking Canopies be used only seasonally when boat is in use

Table 14.26.420-1 was modified, removing the specification that boat canopies must use light-permeable fabric. The reasoning discussed at Planning Commission meetings for removing the specification for light-permeable fabric is that a boat itself is not light permeable, and utilizing light permeable fabric reduces the effectiveness of a canopy protecting a boat from harsh sunlight. We recommend the new SMP code encourage removal/storage of the canopy during seasons of the year when the boat and canopy will not be in use. This would meet the desire to protect the boat during boating season, yet reduces shoreline impacts and provides for fuller ecological function on the lakebed for much of the year.

4. Retain April 2021 provision SCC 14.26.445(1)(d) regarding 'temporary access roads'

The 2021 drafts of the SC SMP clarified that a forest practices that only involves timber cutting is not a development under SMA and does not require a substantial development permit or exemption. The February 15, 2022 draft SMP appended a statement to this provision, stating "This includes the construction of temporary access roads. All such temporary access roads must be properly abandoned following harvest." Skagit County should strike the new statement in SCC 14.26.445(1)(d) that exempts temporary access roads from the definition of development and retain the April 2021 provision.

This added provision clearly violates the SMA definition of a development. In RCW90.58.030(3)(a), "development" means "…filling;…placing of obstructions;…or any project of a permanent or temporary nature which interferes with the normal public use of the surface waters overlying lands subject to this chapter at any state of water level." A substantial development means any development which the total cost or fair market value exceeds $5000. The RCW identifies several activities (items i-xiii) that "shall not be considered substantial developments for the purpose of this chapter" and none pertain to forest practices nor developments of a temporary nature. This provision added to the February draft provides an exemption to the SMA that is not allowed in the RCW.

We are concerned about the impacts of a temporary access road that includes filling (surfacing, grading, importing non-native materials) within the floodplain and installation of crossing structures (culverts, bridges) within the floodplain. A temporary road constructed for use in Forest Practices that includes fill and/or culverts is clearly a Development under state law, yet this provision exempts that development from adequate review.

Washington Forest Practices allow a temporary road to be in place for the duration of a permit, which is 3 years, and this Skagit SMP provision does not reduce or minimize this duration. The drafted provision would allow a temporary access road, fill, and culverts to remain in place for up to three years, with no SMP review of impacts nor mitigation sequencing.

The drafted provision indicates that a temporary road must be properly abandoned, but there is no indication or guidance on proper abandonment. Further, without the oversight of a shoreline SSD or exemption, there is no agency nexus with Skagit County or DNR to ensure that road building and road decommissioning within the protected riparian corridor are properly implemented.

The definition of Forest Practices in the WAC 222-16-010 indicates that any activity conducted on or directly pertaining to forest land and related to growing/harvesting/processing lumber or removing forest biomass including but not limited to road and trail construction (among many other activities) are considered Forest Practices. This WAC identifies activities that are NOT forest practices, and includes the harvest of ‘berries, ferns, greenery, herbs….and other products which cannot normally be expected to result in damage to forest soils, timber, or public resources. The types of activities that Skagit County are trying to exclude from their definition of Forest Practices and from the requirements of developments under the SMP are the harvest and retrieval of trees, logs, and timber. These types of harvest activities most certainly would affect damage to forest soils, timber, and public resources, and their exclusion by Skagit County is not supported by the WAC.

The language in the Feb 2022 DRAFT SMP 14.26.445 is counter to the staff recommendations, who recommended that SCC 14.26.445 be retained as previously written. Staff recommendation relies on a 2017 state guideline change (WAC 173-26-241 Shoreline Uses, (3)(e) and clarified that forest practices that only involve timber cutting are not considered development under the SMA and do not require shoreline review.

Skagit County should strike this added provision and restore the code to its previous (April 2021) version.

5. ***Buffer Width Decreasing Variance procedure eliminates public review, has impacts***
The new SCC 14.26.574(3) allows an applicant’s request to reduce a buffer width by up to 25% to be a decision by the Administrative Official as described in County Code, and no variance permit process is required.

Buffers serve a variety of purposes that benefit both the natural environment and the people who reside there. Buffers preserve a vegetated corridor and provide a variety of ecosystem services including shade, habitat structure, runoff filtration, and provide nutritious inputs that form the foundation of the food web.

Buffers allow bank integrity to develop through root reinforcement. And importantly, buffers provide a physical separation from the dynamic shoreline and provides protection for the built environment from flooding and erosion. Reductions of these protective buffers should be granted after careful consideration of the grounds for justification, risks and impacts.

We are concerned about the reduced evaluation and increased staff discretion to grant a buffer reduction of up to 25%. It reduces the opportunities and notice for public review. Previous SC SMP drafts maintained that a buffer reduction was a variance permit procedure, offering a clear opportunity for public review and comment to articulate concerns and potential impacts to natural resources and view corridors. That opportunity for review is not secured through a staff level decision to a single family residential exempted permit.

Accounting for buffer reduction in the metrics for No Net Loss are unclear and risks unmitigated impacts to the shoreline. There are clear guidelines for what circumstances would allow for a buffer reduction under a variance permit process, as detailed in the draft SC SMP under 14.26.735, and includes: an appraisal of how application of the standard dimensions interfere with reasonable use of the property; the proposed design will not cause adverse impacts to the shoreline environment; the proposed buffer reduction is compatible with other authorized uses within the area; the variance will not constitute a special privilege not enjoyed by others in the area; and the public will not suffer substantial detrimental effect. These lead to a transparent process that affords necessary accommodation to property owners while also clearly considering the impacts to the natural environment and the community.

However, the grounds for granting a buffer reduction as a staff decision are not articulated nor is there transparency in the grounds for decision making. The County should retain allowable buffer reductions only as a clear and transparent variance permit process, where there are clear standards to demonstrate need and adequate mitigation that is monitored for success with accountability measures.

The Draft Skagit SMP fails to offer necessary habitat, natural resource protections for Treaty resources, including ESA-listed salmon.

The Swinomish Tribe and SRSC appreciate the opportunity to provide detailed comments on Skagit County's proposed Shoreline Master Program Comprehensive and Periodic Update. We very much would have liked the County to have put forward a SMP Update that recognizes and effectively protects the significant shorelines within Skagit County and especially the Skagit River watershed, as well as the importance of them to the Treaty Tribes like Swinomish that have called these lands and waters home since time immemorial. We think the Skagit River basin, the imperiled wild salmon that are home to it, and the critically endangered Southern

Resident Killer Whales that depend upon Skagit River salmon as a primary source of prey deserve much more than what the County has proposed in this SC SMP Update.

The unfortunate reality is that the County's SMP Update weakens protections that are already inadequate to recover salmon, or protect or recover the degraded habitat they depend upon. This is particularly true with respect to the County's failure to acknowledge, let alone address in any meaningful way, the impacts associated with climate change and the County's failure to provide any mechanism to address water quality and excessive stream temperatures. The County's proposal to allow variances of up to 50% for riparian habitat – a key limiting factor identified in the 2005 Skagit River Chinook Recovery Plan – not only fails to require meaningful protection, but also actively worsens the problem.

The County cannot credibly claim that it supports salmon recovery and on the one hand, purport to recognize that "the entirety of the Skagit ecosystem is subject to a perpetual environmental servitude," and that this is "an obligation that impacts and influences virtually everything that occurs in Skagit County," and at the same time put forward shoreline policies that undeniably fail to either recognize or effectuate this otherwise laudable sentiment. If in fact the County is "extremely concerned" about the decline of salmon resources in the Skagit ecosystem, then it must heed the above comments from the Swinomish Tribe and SRSC, and rewrite the Skagit SMP Update accordingly.

The SC SMP in its current form fails to meet the standards required by the Shoreline Management Act. If the current version is adopted, it will be challenged and it will be sent back to address, at a minimum, the impacts of climate change and the significant new science developed while this SMP has languished. SITC and SRSC would prefer for the County to get it right this time to ensure the shorelines of Skagit County receive the protection they require and landowners receive clear guidance in their land use decisions. This process has gone on too long to adopt a rushed, incomplete SC SMP.

Thank you for this opportunity to provide input on the draft SC SMP. We look forward to your anticipated cooperation in adopting our proposed changes to the SC SMP and in consulting with us as local subject matter experts.

Sincerely,

Amy Trainer
Environmental Policy Director
Swinomish Indian Tribal Community

Nora Kammer
Environmental Protection Specialist
Skagit River System Cooperative

By Email

March 31, 2022

Skagit County Board of County Commissioners
1800 Continental Place
Mount Vernon, WA 98273
pdscomments@co.skagit.wa.us

Re: Incorporating Sea Level Rise into Skagit County's Comprehensive SMP Update

Dear Commissioners Browning, Janicki and Wesen:

Thank you for extending the comment period and for taking the time to carefully consider these comments on the comprehensive update to Skagit County's Shoreline Management Program (SMP). With this letter, the undersigned local conservation organizations, representing thousands of Skagit Valley residents, emphasize that:

- Skagit County has an urgent need to address the existing and impending risks that climate change, and particularly sea level rise, pose to our community's infrastructure, safety, and the environment;
- the County should join other jurisdictions that are already taking these steps–deferring this needed planning until the next update will only exacerbate the challenge;
- well-settled scientific information can be used to guide the County's planning;
- the Shoreline Management Act requires SMPs to address flooding issues and to use the most current scientific and technical information in doing so; and
- we have proposed a sampling of redlined text from the SMP update that would incorporate sea level rise considerations into development decisions.

This letter addresses each of the points above. The proposed revisions to the SMP language begin at page 7. You will also find a summary of each of the signatories to this letter in the Appendix.

A. It Is Imperative to Address Sea Level Rise Today.

Now is the time for Skagit County to begin addressing the adverse effects of climate change — particularly Sea Level Rise (SLR). The County is highly vulnerable to the effects of rising sea levels. If left unmanaged, future flooding and coastal erosion will pose considerable risks to life, safety, jobs, critical infrastructure, coastal ecosystems, homes and businesses, agriculture, the County's natural and recreational assets, and the economy. Some of Skagit's coastal roads are already failing due to erosion or flooding regularly and will not hold up under SLR, particularly with more frequent storm events. Without planning, low elevation and marine areas of the County - which the vast majority of Skagitonians transit through daily, live in or make their livelihood in - will increasingly be cut off or damaged as the impacts of climate change and SLR are felt. Not only are these low lying areas, including extensive farmland, at risk, but emergency responses are expensive and are often extremely damaging to the environment. Crisis often means a temporary solution, rather than encouraging innovation and the best use of resources. We cannot afford to lose our coastal ecosystems, infrastructure, or farmland or place people in harm's way. Skagit County needs to plan and to act now.

Across the globe, the case for planned approaches to climate change adaptation is clear. Sea level rise is one of the primary and most devastating impacts from climate change, and it, along with river and coastal flooding, is of particular importance in Skagit County. Skagit Climate Science Consortium notes:

> Increases in coastal flooding and erosion are the result of more frequent extreme high tides, higher storm surge, and the greater chance of a high tide coinciding with a flooding river. Sea level and storm surge can cause floodwaters to "back up" into the lower Skagit River potentially increasing river flooding. Already seawater backs up from the bay to about Mt. Vernon during high tides. Rising sea levels can cause storm waves to become larger and more likely to overtop dikes and erode coastal bluffs and bulkheads.[1]

As the Department of Ecology writes, "[s]ea level rise and storm surge[s] will increase the frequency and severity of flooding, erosion, and seawater intrusion—thus increasing risks to vulnerable communities, infrastructure, and coastal ecosystems."[2] Not only will our marine shorelines be impacted, but as Ecology continues "[m]ore frequent extreme storms are likely to cause river and coastal flooding, leading to increased injuries and loss of life." The 2022 NOAA

---

[1] Skagit Climate Science Consortium, Sea Level Rise, Brief Overview. Education Resources, www.skagitclimatescience.org

[2] Washington Department of Ecology, *Preparing for a Changing Climate; Washington State's Integrated Climate Response Strategy*, Publication No 12-01-004, 90 (April 2012), *available at* https://fortress.wa.gov/ecy/publications/publications/1201004.pdf.

Sea Level Rise Technical Report[3] warns that "SLR will create a profound shift in coastal flooding over the next 30 years by causing tide and storm surge heights to increase and reach further inland." "Moderate floods will be 10 times as common as they are today. Major flooding will happen five times as often."

We also note the broad community support for addressing sea level rise because it will flood homes, farms, businesses, and wildlands equally. It will not discriminate. All in its path will be harmed. So this Commission owes it to the entire County to properly plan for SLR in the SMP.

We value the Skagit and all that it has to offer, which is why Skagit County needs a program along with policies and regulations to help prepare for the challenge of sea level rise and flooding. We want county planning focused on building stronger and better prepared communities and resources, encouraging and protecting resilient coastal ecosystems, and ensuring a healthy future for generations to come.

While we appreciate the good work of Skagit County and the Watershed Company in making significant improvements from the current code, we wish to draw your attention to the glaring gap remaining – the urgent need to address sea level rise as a result of a changing climate in the Shoreline Management Plan.

B. Climate Change and Sea Level Rise Are Well-Settled Scientific Principles and Their Effects Can Be Projected with Reliable Certainty.

The science on climate change and sea level rise for our region is not new. In 1991, Ecology stated that "[a]ccelerated sea level rise is an acknowledged secondary effect of the greenhouse effect. Only the rate of acceleration is debated."[4] At that time, the US Environmental Protection Agency projected sea level rise through 2100 ranging between 1.8 and 11.3 feet.[5] More recently, a 2022 report by the National Oceanic and Atmospheric Administration, titled "Global and Regional Sea Level Rise Scenarios for the United States," refined projected rates of sea level rise and found that flooding events would increase significantly by 2050.[6] The report projects several scenarios for sea level rise in the northwestern US, with the intermediate scenario resulting in 0.6 feet of sea level rise by 2050 and 2.6 feet of sea level rise by 2100.[7]

---

[3] NOAA, NASA,US EPA, USGS, FEMA,US Army Corps, US Dept of Defense, *et al.*, *Global Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines*, NOAA Technical Report NOS 01 (2022), *available at*: https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf (hereafter "NOAA Report") (attached hereto).
[4] Washington State Department of Ecology, *Sea Level Rise in Washington State: State-of-the-knowledge, Impacts, and Potential Policy Issues*, Pub. No. 93-537 Version 2.1, 4 (Dec. 199), *available at:* https://apps.ecology.wa.gov/publications/documents/93537.pdf.
[5] *Id.*
[6] NOAA Report.
[7] *Id.* at 23.

Minor/disruptive flooding events are projected to increase in frequency in the northwest from about 4 events/year in 2020 to more than 10 events/year by 2050.[8] Additional scientific information about the anticipated effects of climate change on Washington's coasts, as well as considerations like clean water, endangered species, and human health, can be found at the University of Washington's Climate Impacts Group website[9] and Ecology's Climate Change web pages.[10]

A 2011 reported titled Skagit River Basin Climate Science Report described the local shoreline impacts from climate change, stating that:

> Increased flood risks from the combination of sea level rise and projected increases in river flooding has the potential to cause major damage to low-lying farms and urban development in the floodplain, impacting homes, businesses, water treatment plants, and transportation infrastructure such as bridges and roads. …Sea level rise may also impact the ability to drain low-lying farmland using traditional tide gates. Warmer water temperatures, more severe and prolonged low summer flows, and potential habitat loss associated with projected sea level rise are projected to negatively impact coldwater fish species such as salmon, steelhead, and trout.[11]

Thus, the science shows that it's time to act. As the NOAA report states, "[s]ea level rise driven by global climate changes is a clear and present risk to the United States today and for the coming decades and centuries."[12]

C. Additional Delays Will Lead to Greater Costs Down the Road–Skagit County Should Complete the Work it Started in 2011 to Address Climate Change and Sea Level Rise.

Although it may seem urgent to finalize the SMP since it has taken so long to get to this stage, it will be far more burdensome to the community, the environment, natural resource lands and the County to delay planning for SLR until the next update in 2028. The economic impact of allowing homes or infrastructure to be built in areas that will experience SLR impacts in upcoming years is enormous. Skagit County is well known for its agriculture, with approximately 1000 farms covering 97,700 acres.[13] The dollar value of these crops exceeded $314,447,000 in 2020. [14] Without a plan, Skagit agriculture is increasingly at risk. The answer is not as simple as

[8] *Id.* at 41.
[9] https://cig.uw.edu/.
[10] https://ecology.wa.gov/Air-Climate/Climate-change.
[11] Se-Yeun Lee & Alan F. Hamlet, *Skagit River Basin Climate Science Report*, 15 (Sept. 2011), *available at*: https://www.skagitcounty.net/EnvisionSkagit/Documents/ClimateChange/Complete.pdf.
[12] NOAA Report, at 1.
[13] USDA 2017 Census of Agriculture, County Profiles.
[14] Draft Skagit County WSU Extension 2020 Skagit County Agricultural Statistics.

building higher levees and more sea walls. The effective use of these structures will have a place in a plan, but these structures often accelerate erosion of adjacent, unprotected coastal areas, and damage coastal habitats by starving them of sediments and natural shorelines. Thus, risk reduction measures must be part of any plan. Additionally, natural shorelines should be used as a defense. Natural shorelines not only host numerous ecological environments for fish and wildlife, and are beloved for recreation locally, but also can provide long term, cost-effective buffers to our coastal communities, livelihoods, and infrastructure. In the challenging, uncertain world of climate change and Sea Level Rise, planning is the first thing to do.

Further, Skagit County has been working on the issue since 2011, when the Skagit County SMP Stakeholders task group identified climate change and sea level rise as critical issues that needed to be addressed and proposed several recommendations. In her April 15, 2016 staff report on the SMP Update, Betsy Stevenson similarly recommended that the update incorporate sea level rise into planning for residential development, shoreline erosion rates, and newly subdivided lots.[15]

Some local governments are already following Ecology's direction to address flood hazards and to reduce damage caused by floods by addressing sea level rise in their SMPs. Ecology's *Shoreline Master Program Handbook Appendix A: Addressing Sea Level Rise in Shoreline Master Programs* presents background information on projected sea level rise in Washington State and impacts and offers guidance for addressing sea level rise in SMP updates. In addition, Ecology has partnered with Washington Sea Grant to develop the Puget Sound Coastal Resilience Project that incorporates data on future sea level, high tides, and storm surges to map projected inundation in the Nooksack, Skagit, Stillaguamish, Snohomish, Nisqually, and Skokomish River deltas. Thus, information exists to support planning for SLR, and jurisdictions from the Swinomish Indian Tribal Community to the City of Anacortes are formally assessing and addressing the risks of SLR.

D. Shoreline Management Act Mandates to Use Science and Address Flooding Require the County to Address Climate Change and Sea Level Rise.

While the Shoreline Management Act ("SMA") and Shoreline Master Program Guidelines ("Guidelines") do not expressly use the term "sea level rise," it is not possible in 2022 to satisfy the SMA's requirements to use current science and address flooding without acknowledging and addressing sea level rise. The SMA instructs shoreline master programs to include "[a]n

[15] Supplemental Staff Report #1, from Betsy Stevenson to Planning Commission, regarding Shoreline Master Program Update – Comprehensive Plan Policies, Development Regulations and Shoreline Environment Designation Maps, 4-5 (April 15, 2016), *available at:* https://www.skagitcounty.net/PlanningAndPermit/Documents/SMP/Supplemental%20Staff%20Report%204-15-2016.pdf.

element that gives consideration to the statewide interest in the prevention and minimization of flood damages…."[16] The Guidelines note that the most effective means for reducing flood hazards is to prevent or remove development in flood-prone areas.[17] And in updating SMPs, the Guidelines declare that "[e]ffective shoreline management requires the evaluation of changing conditions and the modification of policies and regulations to address identified trends and new information."[18] Sea level rise certainly qualifies as an identified trend, and while scientific evidence of its existence along our shorelines could no longer be characterized in 2022 as "new," recent scientific studies have refined projections with increased specificity.

In addition, the SMA and Guidelines direct the County to incorporate scientific information and thus require the use of readily-available sea level rise information. The SMA directs the County to "[c]onsider all plans, studies, surveys…being made by federal…agencies…dealing with pertinent shorelines of the state," and, more specifically for sea level rise, to "[u]tilize all available information regarding hydrology, geography, topography, ecology, economics, and other pertinent data."[19] To implement the SMA directive to protect shoreline natural resources and the ecological functions necessary to sustain those natural resources, counties must use scientific and technical information.[20] First, counties must "identify and assemble the most current, accurate, and complete scientific and technical information available that is applicable to the issues of concern."[21] Second, once a county has amassed this information, it must "base master program provisions on an analysis incorporating" this information.[22] Nowhere do the Guidelines suggest that a county can ignore current and accurate scientific information, much less ignore it without justification. Consequently, just as the SMP acknowledges the reality of physical processes like tides and feeder bluffs, it must acknowledge the scientifically-undisputed rising sea levels that are threatening its shorelines.

Even if the Guidelines did not require the SMP Update to incorporate common sense measures to protect your community from unnecessary damage and danger due to sea level rise, residents reasonably expect this from you. Like most challenges that elected representatives face, sea level rise won't disappear by ignoring it. Instead, the risks and the expense of responding to them will merely increase as historic development patterns and practices continue. Our community cannot twiddle our thumbs any longer on the issue of sea level rise. The longer we procrastinate, the costlier it will become to undo the damages to our infrastructure, our agricultural sector, our properties, and our communities from sea level rise.

[16] RCW 90.58.100(2)(h).
[17] WAC 173-26-221(3)(b).
[18] WAC 173-26-201(2)(b).
[19] RCW 90.58.100(1)(c), (e).
[20] WAC 173-26-201(2)(c), (2)(a).
[21] WAC 173-26-201(2)(a).
[22] WAC 173-26-201(2)(a).

E. Several Revisions to the SMP Update Could Address Sea Level Rise.

Fortunately, a few simple revisions to the Update can start to address shoreline development in areas that are already being, and likely in the near future to be, affected by sea level rise. Toward that end, we propose specific language below. Note that additions are marked with underline, and deletions marked with ~~strike through~~. Please also note that we propose planning and permitting decisions based on the anticipated life for the specified type of development based on the planning horizon concept contemplated by Ecology.[23]

Policies:

Shoreline Uses and Modifications

- 6C-6.5: Essential public facilities should not be constructed in flood plains and areas of marine shorelines that are likely to be inundated by sea level rise during the anticipated life span of those facilities.
- 6C-15.3: Residential development should be located:
    - c. to avoid the need for hard shoreline stabilization and flood hazard management facilities during the anticipated life span of that development.
- 6C-15.12: New shoreline residential development should be designed, located, and constructed to ensure that it will not need to be relocated or reconstructed due to sea level rise during the anticipated life span of that development.
- 6C-16.1 ~~Limit use of hard structural stabilization measures to reduce shoreline damage~~. Use of hard structural stabilization measures will be prohibited except where there is no reasonable alternative to protect a primary structure existing as of 2022.

Critical Areas

- 6G-2.3: Protect and manage shoreline-associated wetlands, including maintenance of sufficient volumes of surface and subsurface drainage into wetlands, as well as the landward migration of wetlands as a result of sea level rise, to sustain existing vegetation and wildlife habitat.
- 6G-2.8: Limit new development in floodplains and areas of marine shorelines likely to be inundated by sea level rise during the anticipated life span of that new development.
- 6G-2.9: Regulate development within the 100-year floodplain and areas of marine shorelines likely to be inundated by sea level rise to avoid adverse impacts to shoreline

---

[23] *Sea Level Rise in Washington State*, Pub. No. 93-537 Version 2.1, at 20 (acknowledging, however, that "[p]lanning and analysis horizons for land use decisions or commitments might as well be perpetual for all practical purposes. Once a site has been 'committed' to a use, that use becomes established by tradition or legal fact."

ecological functions and to avoid risk and damage to property and loss of life.

Flood Hazard Reduction policies:

- 6I-1.5: Skagit County shall monitor the impacts of climate change on shorelands, the shoreline master program's ability to adapt to sea level rise and other aspects of climate change at least every periodic update, and revise the shoreline master program as needed. Skagit County shall periodically assess the best available sea level rise projections and other science related to climate change within shoreline jurisdiction and incorporate them into future program updates, as relevant.
- 6I-1.6: Plans, regulations, and programs related to tidal flooding and storm surge will be coordinated and integrated with the Comprehensive Plan, marine flood hazard plans, National Flood Insurance, and regulations for critical areas and the SMP.
- 6I-1.7: Non-structural flooding and storm surge hazard reduction measures are preferred over structural measures. When evaluating alternative measures, the removal or relocation of structures in the tidal flood and storm surge-prone areas should be considered.
- 6I-1.8: Tidal flood and storm surge hazard protection measures will result in No Net Loss of ecological functions and ecosystem-wide processes associated with marine and estuarine shorelines.
- 6I-1.9: Marine and estuarine ecological systems should be returned to and maintained in the future in a more natural state where feasible including by removal of structures and hard armoring blocking the upward shoreline migration due to sea level rise.
- 6I-1.10: New lots and new expanded development should be located so they will not interfere with the landward expansion and movement of wetlands and aquatic vegetation as sea level rises.

Development Regulations:

- 14.26.305(1) No Net Loss of Ecological Functions. Uses and developments on Skagit County shorelines must be designed, located, sized, constructed, and maintained to achieve no net loss of shoreline ecological functions necessary to sustain shoreline natural resources, considering sea level rise estimates.
- **14.26.310-1 Dimensional Standards.** 10% Hard Surface Limits for all uses in Rural Conservancy.
- **14.26.320 General Provisions Applicable Upland of the OHWM**
    - (1)(a) New development must be located and designed to avoid the need for future shoreline stabilization to the maximum extent feasible during the life span

of the structure and based on sea level rise projections for that time period.

- (1)(b) Land divisions must be designed to ensure that future development of the created lots will not require shoreline stabilization for reasonable development to occur or cause foreseeable risk from geological or hydrological conditions, including any change in conditions projected by 2100 due to sea level rise.

- **14.26.350 Flood Hazard Reduction**
  - (1)(c) Actions under this section must be designed to accommodate the amount of sea level rise estimated during the anticipated life span of proposed development.
  - (2)(b) That the potential adverse impacts on ecological functions and priority species, including those associated with or exacerbated by sea level rise, can be successfully mitigated;
- **14.26.380 Vegetation Conservation**
  - (2) Application requirements
    - (g) areas projected to be inundated by sea level rise during the anticipated life span of the proposed development.
- **14.26.460 Recreational Development**
  - (4)(c) Recreational developments must be located, designed and operated in a manner consistent with the purpose of the environment designation in which they are located and so that no net loss of shoreline ecological functions or ecosystem-wide processes results, considering projected sea level rise.
- **14.26.470 Residential Development**
  - (4)(a) Plats and subdivisions must be designed, configured and developed in a manner that ensures that no net loss of ecological functions results from the plat or subdivision at full build-out of all lots. New lots shall be designed and located so that the buildable area is outside the area likely to be inundated by sea level rise in 2100 and outside the area in which wetlands and aquatic vegetation likely will migrate during that time.
  - (4)(b) Residential development must be located and designed to avoid the need for flood hazard reduction measures and for tidal flooding and storm surge protection measures, including shoreline stabilization, based on sea level rise projections during the anticipated life span of the development.
  - (4)(g) Where lots are large enough, new structures shall be located so that they are outside of the area likely to be inundated by sea level rise during the

anticipated life span of those structures and outside of the area in which wetlands and aquatic vegetation will likely migrate during that time.

- (4)(h) New and substantially improved structures shall be elevated above the elevation likely to be gained by sea level rise during the anticipated life span of those structures.

- **14.26.475 Shoreline Habitat and Natural Systems Enhancement Projects**
  - (3) Application Requirements:
    - (a)(i) Plan and cross-section views of the existing and proposed shoreline configuration, showing accurate existing and proposed topography and OHWMs as estimated for 2100 based on sea level rise projections.

- **14.26.480 Structural Shoreline Stabilization**
  - (2)(a) New hard shoreline stabilization structures are prohibited, except when analysis confirms that there is a significant possibility that a primary structure built before 2022 will be damaged within three years as a result of shoreline erosion in the absence of such hard shoreline stabilization structures, or where waiting until the need is immediate results in the loss of opportunity to use measures that would avoid impacts on ecological functions.
  - (2)(c)(i) To protect a~~n existing~~ primary structure built before 2022, including a residence, when conclusive evidence, documented by a geotechnical analysis, is provided that the structure is in danger from shoreline erosion caused by currents or waves….
  - (3)(a)(ii)(A) Plan and cross-section views of the existing and proposed shoreline configuration, showing accurate existing and proposed topography and OHWMs as estimated based on sea level rise provisions over the anticipated life span of the development.
  - (3)(b)(iv) An assessment that concludes the replacement structure is designed, located, sized, and constructed to assure no net loss of ecological functions consistent with mitigation sequencing requirements in SCC 14.26.305 and incorporating sea level rise projections for the anticipated life span of the structure.

- **14.26.485 Transportation Facilities**
  - (3) Application requirements
    - (a)(iii) potential for enlargement of inundated areas, including the potential and the area projected to be inundated by sea level rise over

the anticipated life span of the facility.

- (4) Development Standards.
  - (a) Transportation facilities must be planned, located, and designed to achieve all of the following at current tidal levels and at tidal levels projected over the anticipated life span of the facilities due to sea level rise:
  - (i) Bridge abutments and necessary approach fills must be located, if feasible, landward of associated wetlands or OHWM for water bodies without associated wetlands, as they are projected to migrate during the anticipated life span of those abutments due to sea level rise, provided mid-river bridge piers are permitted.
  - (j) Roads and railroads must not measurably increase flood levels or profiles and must not restrict or otherwise reduce floodplain and floodway capacities at current tidal levels and at tidal levels projected during the anticipated life span of that development due to sea level rise

- **14.26.490 Utilities**
  - (4) Development Standards
    - (a)(ii) Locate and design the project to avoid the need for new structural shoreline stabilization or flood hazard reduction facilities over the anticipated life span of the utilities based on projected sea level rise.
    - (c)(i) Underwater utility lines must enter and emerge inland from fresh and salt water banks, dikes, beaches, or shorelands in their projected location as it migrates over the anticipated life span of the utility lines due to sea level rise.
    - (d)(ii) Permitted water crossings requiring structural abutments or approach fills must set back such facilities landward of the OHWM in the location projected for those water crossings due to sea level rise projections at the end of the anticipated life span of those crossings.

- **14.26.515 Standard Critical Areas Review and Site Assessment Procedures**
  - (4)(c) The site assessment shall include:
    - (x) the projected location of the critical area over the anticipated life span of the new development based on sea level rise projections.

- **14.26.534 Wetland Performance-based Buffer Alternatives and Mitigation Standards**

- (2) Buffer Width Averaging.
    - (e) Averaging is prohibited for wetland buffers unless the applicant demonstrates that the buffer will not be adversely affected by projected sea level rise over the anticipated life span of the development.

- **14.26.540 Aquifer recharge areas intent**
  - (1)(d) limit adverse impacts to drinking water from saltwater intrusion to the maximum extent possible as sea level rises.

- **14.26.542 Aquifer recharge areas prohibited activities**
  - (7) Drilling new wells within 100 feet of an existing well that has experienced saltwater intrusion to the extent that chloride levels exceed Washington State maximum contaminant levels.

- **14.26.562 Geologically hazardous areas site assessment requirements**
  - (2)(h) A description of the likely effect that sea level rise projected over the anticipated life span of the development will have on the geologically hazardous area.

- **14.26.563 Geologically hazardous area mitigation standards.**
  - (2)(b) A site assessment is submitted and certifies that:
    - (ii) A quantitative slope stability analysis indicates no significant risk to the development proposal and adjacent properties; or the geologically hazardous area can be modified; or the development proposal can be designed so that the hazard is eliminated, all taking into consideration the sea level rise projected over the anticipated life span of the development.

- **14.26.572 Fish and wildlife habitat conservation area site assessment requirements.**
  - (4) A description of the likely effect that sea level rise projected over the anticipated life span of the development will have on the fish and wildlife habitat conservation area.

- **14.26.574 Fish and wildlife habitat conservation area performance-based buffer alternatives and mitigation standards.**
  - (2) Buffer Width Averaging.
    - (f) Averaging is prohibited for buffers unless the applicant demonstrates that the buffer will not be adversely affected by projected sea level rise over the anticipated life span of the development.

Conclusion

Don't let Skagit County get left behind. The risk of not planning for sea level rise is far too great. With both high probability of sea level rise and the high-cost consequences, Skagit County must act now to reduce the risk to lives, to protect the economic vitality of the community and the region, and to preserve our rich ecological heritage.

Sincerely,

_/s Marlene Finley______________
Marlene Finley, President
Evergreen Islands
P.O. Box 223
Anacortes, WA 98221

____
Jeff Osmundson, President
Skagit Audubon Society

____
Rick Eggerth
Chair, Mt. Baker Group, Sierra Club

____
Rein Attemann
Puget Sound Campaigns Manager
Washington Environmental Council
1401 3rd Ave Suite 1400
Seattle, WA 98104

Molly Doran

Molly Doran
Executive Director
Skagit Land Trust

1020 S 3rd Street
Mount Vernon, WA 98273

____
Hal Rooks, President
Guemes Island Planning Advisory Committee

____
Ander Russell, Program Director
RE Sources
2309 Meridian St
Bellingham, WA 98225

cc: Joe Burcar, Department of Ecology

Attachment

APPENDIX

The organizations signing the letter above represent thousands of Skagit County residents who care about the natural and built environments. We value this area and all that it has to offer, and strongly encourage Skagit County to adopt SMP policies and regulations to help prepare our community for the challenge of sea level rise and flooding. We want county planning focused on building stronger and better prepared communities, encouraging and protecting resilient coastal ecosystems and ensuring a healthy future for generations to come.

Evergreen Islands dedicates itself to promoting, protecting, and defending Skagit County's unique saltwater island ecosystems, and to ensuring that Skagit County manage the expansion of its built environment to protect local ecological treasures.

Washington Environmental Council is a 501(c)(3) organization founded in 1967. Our mission is to protect, restore, and sustain Washington's environment for all, and we are committed to clean water protections for Puget Sound and for all Washington State waters.

RE Sources is a local organization in northwest Washington. Founded in 1982, RE Sources works to build sustainable communities and protect the health of northwest Washington's people and ecosystems through the application of science, education, advocacy, and action. RE Sources has over 20,000 supporters in Whatcom, Skagit, and San Juan counties.

Sierra Club, founded in 1892, is the largest and oldest grassroots conservation organization in the United States, with more than 3,000,000 members nationwide, and more than 100,000 members and supporters in Washington. The Mt. Baker Group (MBG) of Sierra Club's Washington State Chapter encompasses Whatcom, Skagit and San Juan Counties, collectively home to more than 10,000 members and supporters. More than 3,000 members and supporters reside in Skagit County, where MBG takes a keen interest in the efforts of elected officials to protect their constituents from the increasingly dangerous impacts of climate change.

Skagit Audubon Society is the National Audubon chapter focused on Skagit County. The society's 450 members share a mission of conserving and restoring natural ecosystems, focusing on birds, other wildlife, and their habitats for the benefit of humanity and the earth's biological diversity.

Guemes Island Planning Advisory Committee's mission is to sustain the island's rural character and natural environment.

ATTACHMENT A

Global and Regional Sea Level Rise Scenarios for the United States

NOAA

NASA

US Army Corps of Engineers

USGS
science for a changing world

RUTGERS
UNIVERSITY | NEW BRUNSWICK

FEMA

FIU | Institute of Environment
FLORIDA INTERNATIONAL UNIVERSITY

Credit ©Gary J. Kohn

Cover Image: Flooding from 15-knot northerly winds on Smith Island, Maryland, on November 23, 2015.
Credit ©Gary J. Kohn

National Oceanic and Atmospheric Administration
U.S. Department of Commerce
National Ocean Service
Silver Spring, Maryland
February, 2022

Recommended Citation:
Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A.S. Genz, J.P. Krasting, E. Larour, D. Marcy, J.J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K.D. White, and C. Zuzak, 2022: Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nos-techrpt01-global-regional-SLR-scenarios-US.pdf

Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines

Authors

William V. Sweet
NOAA National Ocean Service

Benjamin D. Hamlington
NASA Jet Propulsion Laboratory, California Institute of Technology

Robert E. Kopp
Rutgers University

Christopher P. Weaver
U.S. Environmental Protection Agency

Patrick L. Barnard
U.S. Geological Survey

David Bekaert
NASA Jet Propulsion Laboratory, California Institute of Technology

William Brooks
NOAA National Ocean Service

Michael Craghan
U.S. Environmental Protection Agency

Gregory Dusek
NOAA National Ocean Service

Thomas Frederikse
NASA Jet Propulsion Laboratory California Institute of Technology

Gregory Garner
Rutgers University

Ayesha S. Genz
University of Hawaiʻi at Mānoa, Cooperative Institute for Marine and Atmospheric Research

John P. Krasting
NOAA Geophysical Fluid Dynamics Laboratory

Eric Larour
NASA Jet Propulsion Laboratory, California Institute of Technology

Doug Marcy
NOAA National Ocean Service

John J. Marra
NOAA National Centers for Environmental Information

Jayantha Obeysekera
Florida International University

Mark Osler
NOAA National Ocean Service

Matthew Pendleton
Lynker

Daniel Roman
NOAA National Ocean Service

Lauren Schmied
FEMA Risk Management Directorate

Will Veatch
U.S. Army Corps of Engineers

Kathleen D. White
U.S. Department of Defense

Casey Zuzak
FEMA Risk Management Directorate

Table of Contents

List of Figures

List of Tables

Executive Summary

This report and accompanying datasets from the U.S. Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force provide 1) sea level rise scenarios to 2150 by decade that include estimates of vertical land motion and 2) a set of extreme water level probabilities for various heights along the U.S. coastline. These data are available at 1-degree grids along the U.S. coastline and downscaled specifically at NOAA tide-gauge locations. Estimates of flood exposure are assessed using contemporary U.S. coastal flood-severity thresholds for current conditions (e.g., sea levels and infrastructure footprint) and for the next 30 years (out to year 2050), assuming no additional risk reduction measures are enacted.

This effort builds upon the 2017 Task Force report (Sweet et al., 2017). In particular, the set of global mean sea level rise scenarios from that report are updated and downscaled with output directly from the United Nations Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6; IPCC, 2021a), through the efforts of the NASA Sea Level Change Team; updates include adjustments to the temporal trajectories and exceedance probabilities of these scenarios based upon end-of-century global temperatures. As with the 2017 report, these global mean sea level rise scenarios are regionalized for the U.S. coastline. In addition, methodology supporting the U.S. Department of Defense Regional Sea Level (DRSL) database[1] (Hall et al., 2016) is adapted for the extreme water level dataset newly developed for this report.

This report will be a key technical input for the Fifth National Climate Assessment (NCA5). These data and information are being incorporated into current and planned agency tools and services, such as NOAA's Sea Level Rise Viewer and Inundation Dashboard,[2] NASA's Sea Level Change Portal,[3] and others. Although the intent of this report is not to provide authoritative guidance or design specifications for a specific project, it is intended to help inform Federal agencies, state and local governments, and stakeholders in coastal communities about current and future sea level rise to help contextualize its effects for decision-making purposes.

Key Message #1:
Multiple lines of evidence provide increased confidence, regardless of the emissions pathway, in a narrower range of projected global, national, and regional sea level rise at 2050 than previously reported (Sweet et al., 2017).

- Both trajectories assessed by extrapolating rates and accelerations estimated from historical tide gauge observations, and model projections, fall within the same range in all cases, giving higher confidence in these relative sea level (RSL; land and ocean height changes) rise amounts by 2050.
- Relative sea level along the contiguous U.S. (CONUS) coastline is expected to rise on average as much over the next 30 years (0.25–0.30 m over 2020–2050) as it has over the last 100 years (1920–2020).
- Due to processes driving regional changes in sea level, there are similar regional differences in both the modeled scenarios and observation-based extrapolations, with higher RSL rise along the East (0–5 cm higher on average than CONUS) and Gulf Coasts (10–15 cm higher) as compared to the West (10–15 cm lower) and Hawaiian/Caribbean (5–10 cm lower) Coasts.
- The projections do not include natural year-to-year sea level variability that occurs along U.S. coastlines in response to climatic modes such as the El Niño–Southern Oscillation.

1 https://drsl.serdp-estcp.org/
2 https://coast.noaa.gov/digitalcoast/tools/slr.html
3 https://sealevel.nasa.gov/

Key Message #2

By 2050, the expected relative sea level (RSL) will cause tide and storm surge heights to increase and will lead to a shift in U.S. coastal flood regimes, with major and moderate high tide flood events occurring as frequently as moderate and minor high tide flood events occur today. Without additional risk-reduction measures, U.S. coastal infrastructure, communities, and ecosystems will face significant consequences.

- Minor/disruptive high tide flooding (HTF; about 0.55 m above mean higher high water [MHHW][4]) is projected to increase from a U.S average frequency of about 3 events/year in 2020 to >10 events/year[5] by 2050.
- Moderate/typically damaging HTF (about 0.85 m above MHHW) is projected to increase from a U.S. average frequency of 0.3 events/year in 2020 to about 4 events/year in 2050.
- Major/often destructive HTF (about 1.20 m above MHHW) is projected to increase from a U.S. average frequency of 0.04 events/year in 2020 to 0.2 events/year by 2050.
- Across all severities (minor, moderate, major), HTF along the U.S. East and Gulf Coasts will largely continue to occur at or above the national average frequency.

Key Message #3:

Higher global temperatures increase the chances of higher sea level by the end of the century and beyond. The scenario projections of relative sea level along the contiguous U.S. (CONUS) coastline are about 0.6–2.2 m in 2100 and 0.8–3.9 m in 2150 (relative to sea level in 2000); these ranges are driven by uncertainty in future emissions pathways and the response of the underlying physical processes.

- With an increase in average global temperature of 2°C above preindustrial levels, and not considering the potential contributions from ice-sheet processes with limited agreement (low confidence) among modeling approaches, the probability of exceeding 0.5 m rise globally (0.7 m along the CONUS coastline) by 2100 is about 50%. With 3°–5°C of warming under high emissions pathways, this probability rises to >80% to >99%. The probability of exceeding 1 m globally (1.2 m CONUS) by 2100 rises from <5% with 3°C warming to almost 25% with 5°C warming.
- Considering low-confidence ice-sheet processes and high emissions pathways with warming approaching 5°C, probabilities rise to about 50%, 20%, and 10% of exceeding 1.0 m, 1.5 m, or 2.0 m of global rise by 2100, respectively. These processes are unlikely to make significant contributions with 2°C of warming, but how much warming might be required to trigger them is currently unknown.
- As a result of improved understanding of the timing of possible large future contributions from ice-sheet loss, the "Extreme" scenario from the 2017 report (2.5 m global mean sea level rise by 2100) is now viewed as less plausible and has been removed. Nevertheless, the potential for increased acceleration in the late 21st century and beyond means that the other high-end scenarios provide pathways that could reach this threshold in the decades immediately following 2100 (and continue rising).
- Regionally, the projections are near or higher than the global average in 2100 and 2150 for almost all U.S. coastlines due to the effects from vertical land motion (VLM); gravitational, rotational, and deformational effects due to land ice loss; and ocean circulation changes. Largely due to VLM, RSL projections are lower than the global amounts along the southern Alaska coast and are higher along the Eastern and Western Gulf coastlines.

[4] Mean higher high water (MHHW) level is estimated over the 1983–2001 tidal epoch period and, in this case, is considered a fixed elevation that does not change with sea level rise.

[5] The extreme value statistical methods in this report do not directly resolve frequencies >10 events/year.

Key Message #4

Monitoring the sources of ongoing sea level rise and the processes driving changes in sea level is critical for assessing scenario divergence and tracking the trajectory of observed sea level rise, particularly during the time period when future emissions pathways lead to increased ranges in projected sea level rise.

- Efforts are under way to narrow the uncertainties in ice-sheet dynamics and future sea level rise amounts in response to increasing greenhouse gas forcing and associated global warming.
- Early indicators of changes in sea level rise trajectories can serve to trigger adaptive management plans and are identified through continuous monitoring and assessment of changes in sea level (on global and local scales) and of the key drivers of sea level change that most affect U.S. coastlines, such as ocean heat content, ice-mass loss from Greenland and Antarctica, vertical land motion, and Gulf Stream system changes.

Section 1: Introduction

Sea level rise driven by global climate change is a clear and present risk to the United States today and for the coming decades and centuries (USGCRP, 2018; Hall et al., 2019). Sea levels will continue to rise due to the ocean's sustained response to the warming that has already occurred—even if climate change mitigation succeeds in limiting surface air temperatures in the coming decades (Fox-Kemper et al., 2021). Tens of millions of people in the United States already live in areas at risk of coastal flooding, with more moving to the coasts every year (NOAA NOS and U.S. Census Bureau, 2013). Rising sea levels and land subsidence are combining, and will continue to combine, with other coastal flood factors, such as storm surge, wave effects, rising coastal water tables, river flows, and rainfall (Figure 1.1), some of whose characteristics are also undergoing climate-related changes (USGCRP, 2017). The net result will be a dramatic increase in the exposure and vulnerability of this growing population, as well as the critical infrastructure related to transportation, water, energy, trade, military readiness, and coastal ecosystems and the supporting services they provide.

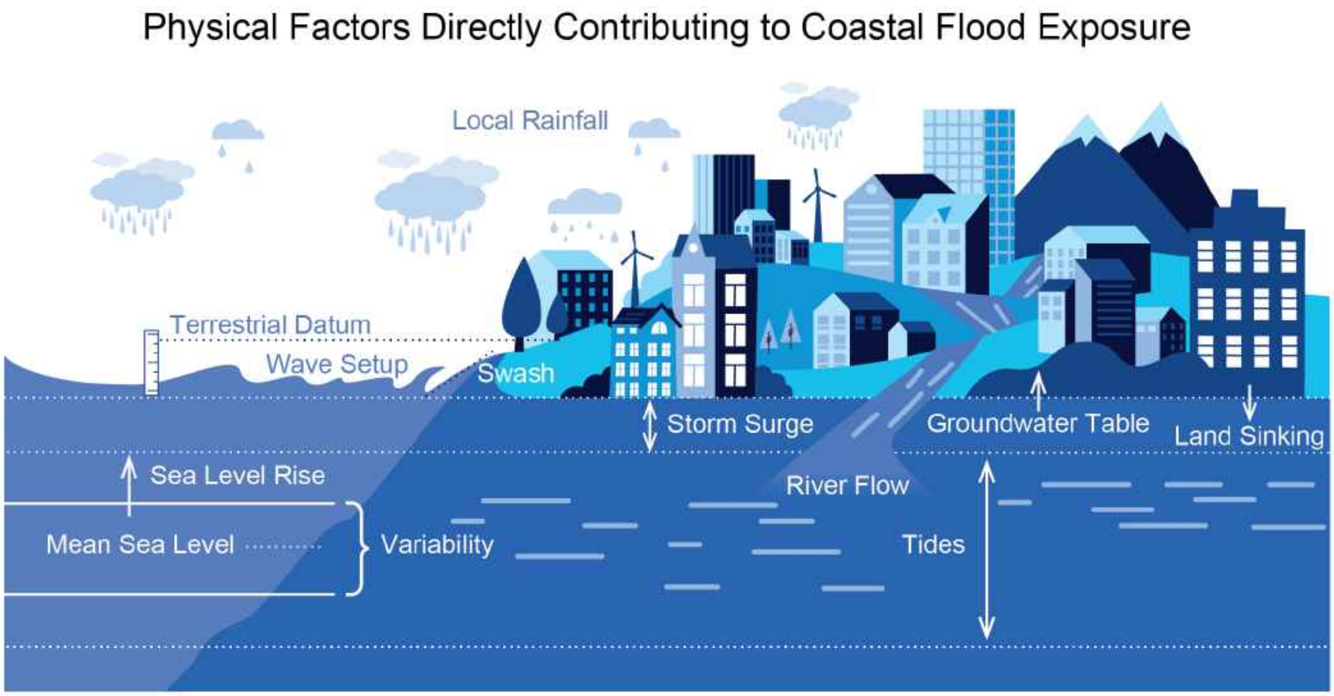


Figure 1.1: Schematic (not to scale) showing physical factors affecting coastal flood exposure. Due to the clear and strong relative sea level rise signal (i.e., combination of sea level rise and sinking lands), the probability of flooding and impacts are increasing along most U.S. coastlines.

Global mean sea level (GMSL) rise is a direct effect of climate change, resulting from a combination of thermal expansion of warming ocean waters and the addition of water mass into the ocean, largely associated with the loss of ice from glaciers and ice sheets. These processes are well understood for the recent past, and their contributions have been estimated for the 20th century (Figure 1.2a). With regard to increasing sea levels associated with climate change, the questions are when and how much, rather than if (USGCRP, 2017; Hall et al., 2019). Increases in GMSL provide an important indicator of the changing climate, but it is the sea level rise on local and regional scales—measured by the global network of tide gauges and satellites—that is most relevant for coastal communities around the world. Regional and local sea level rise has not been and will not be uniform in time or space. Rather, sea levels change locally for a variety of reasons, such as vertical land motion (VLM), which can exacerbate the effects of the rising ocean. For context, whereas GMSL has risen by about 17 cm over the last 100 years (1920–2020), with noted acceleration since about 1970, relative sea level (RSL) averaged along the contiguous United States (CONUS) has risen about 28 cm over the same period with similar onset of acceleration (Figure 1.2b).

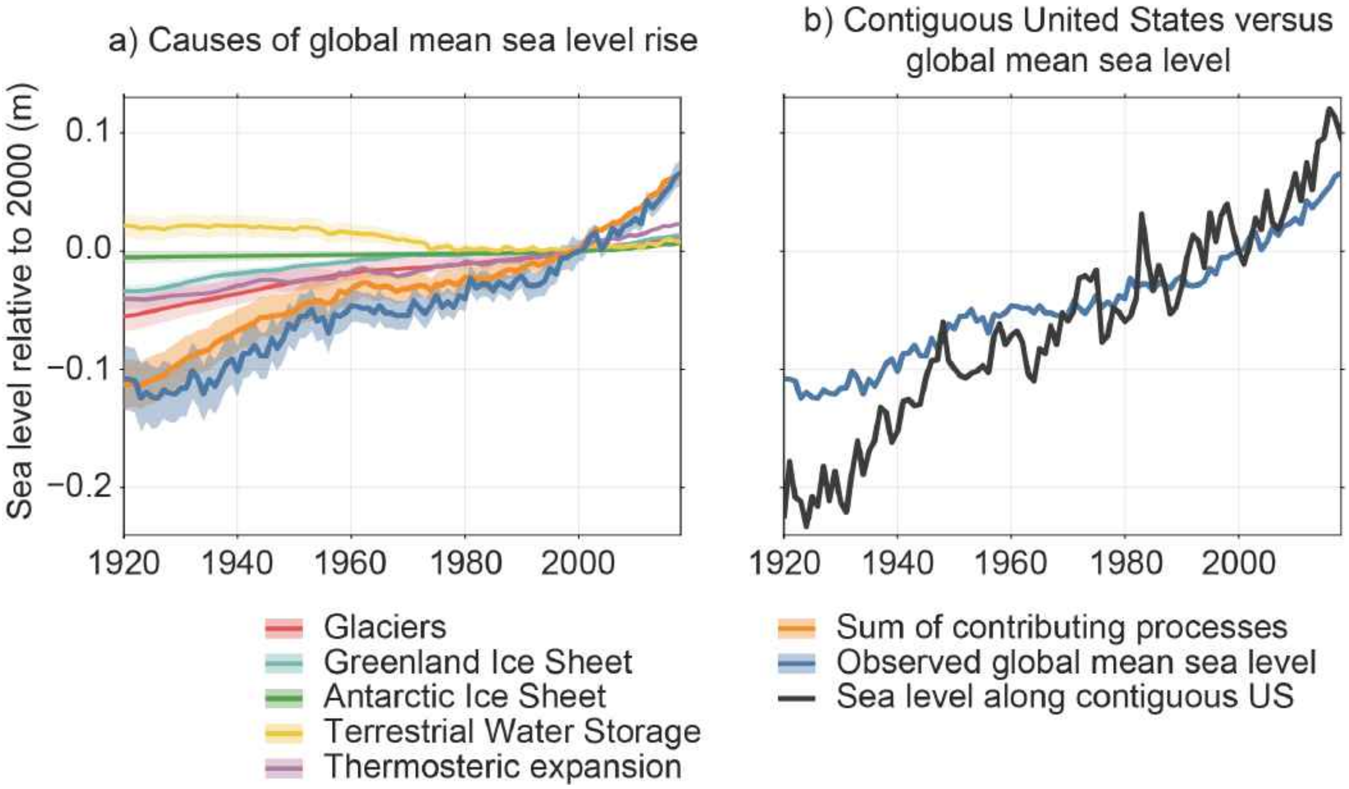


Figure 1.2: a) Observed annual global mean sea level (GMSL) change from global tide gauges (blue line), along with the sum (orange line) of contributions from thermal expansion (thermosteric) and four distinct water-mass-driven increases in GMSL. b) GMSL change (blue line) as shown in a) with the annual average relative sea level change measured by tide gauges around the contiguous United States (black line; with a linear regression estimate of 28 cm of sea level rise from 1920 to 2020). (Adaptation of Frederikse et al., 2020).

While this long-term and upward shift in mean RSL is the underlying driver of changes to the Nation's coasts, extreme water levels (EWLs) occurring against the background of this shifting sea level baseline are responsible for many of the recurring and event-based impacts. In this report, EWLs are explicitly assumed to be ocean-related changes measured by tide gauges (e.g., high tides and storm surges), which typically do not measure other contributors such as direct rainfall or river flow unless they are positioned upstream of major river systems (Moftakhari et al., 2016). Specifically, EWLs are considered as those occurring with an average event frequency between 0.01 events/year (often referred to as the 1% annual chance event) and 10 events/year. This range mostly spans the flood frequency of NOAA high tide flood (HTF) severity levels (minor, moderate, and major). HTF levels are nationally calibrated against NOAA's National Weather Service and local emergency managers' depth-severity thresholds used in weather forecasting and impact communications (NOAA, 2020) to provide a consistent coastal-climate resilience standard (Sweet et al., 2018).

Higher sea levels amplify the impacts of storm surge, high tides, coastal erosion, and wetland loss, even absent any changes in storm frequency and intensity. Because of threshold effects related to changes measured relative to a fixed elevation (Figure 1.3a), even the relatively small increases in sea level over the last several decades have led to greatly increased frequency of flooding[6] at many places along the U.S. coast (Figure 1.3b). Much of the coastline is already close to a flood regime shift, with respect to flood frequency (and presumably damages). That is, only about a 0.3–0.7 m height difference currently separates infrequent, moderate/typically-damaging and major/often-destructive HTF from minor/disruptive "nuisance" HTF (Sweet et al., 2018), whose impacts are already remarkable throughout dozens of densely populated coastal cities (Moore and Obradovich, 2020). Decades ago, powerful storms were what typically caused coastal flooding,

[6] The definition of a "flood" in this report is typically meant to refer to a water level associated with impacts rather than the occurrence of natural phenomena.

but today, due to RSL rise, even common wind events and seasonal high tides regularly cause HTF within coastal communities, affecting homes and businesses, overloading stormwater and wastewater systems, infiltrating coastal groundwater aquifers with saltwater, and stressing coastal wetlands and estuarine ecosystems.

At multiple locations along the U.S. coastline, the annual frequency of minor HTF is accelerating and has more than doubled over the past couple of decades, turning it from a rare event into a recurrent and disruptive problem (Sweet and Park, 2014; Sweet et al., 2018; USGCRP, 2018). For example, the trends in minor/disruptive HTF have grown from about 5 days in 2000 to 10–15 days in New York City and Norfolk, Virginia, in 2020; in Miami, Florida, and Charleston, South Carolina, annual frequencies have grown from 0–2 days to about 5–10 days over the same period. These increases will continue, further accelerate, and spread to more locations over the next couple of decades (Sweet et al., 2021; Thompson et al., 2021). Thus, accurate projections of ongoing and future sea level rise and assessments that integrate across processes and temporal and spatial scales are key inputs to planning efforts and a key goal of this report.

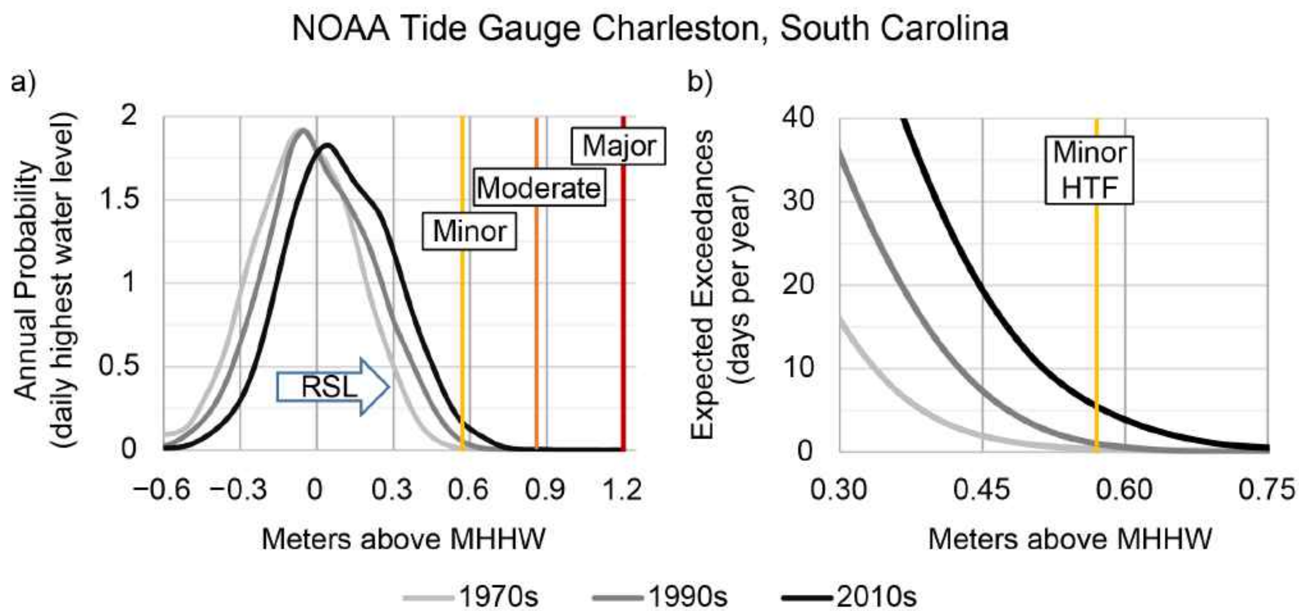


Figure 1.3: a) Annual probability density and b) annual expected exceedances for daily highest water levels relative to the 1983–2001 mean higher high water (MHHW) tidal datum showing increases in NOAA minor, moderate, and major high tide flooding (HTF) probabilities/frequencies due to relative sea level (RSL) rise at the NOAA tide gauge in Charleston, South Carolina.

The Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force (hereafter “Task Force”) was jointly convened at the direction of the White House Resilience Council in 2015 under the U.S. Global Change Research Program (USGCRP), the Subcommittee on Ocean Sciences and Technology (SOST), and the National Ocean Council (NOC). This was in recognition of the strong need and demand for authoritative, consistent, and accessible sea level rise and associated coastal hazard information for the entire U.S. coastline, coordinated across the relevant Federal agencies, to serve as a starting point for on-the-ground coastal preparedness planning and risk management activities. The goal of the Task Force, since its inception, has been to develop the necessary products through sustained and coordinated participation of key agencies, based on the best available science, including regional science and expertise when possible and appropriate. The goal has also been to incorporate those products into user-friendly mapping, visualization, and analysis tools made easily accessible through existing agency portals serving specific partners and stakeholders, as well as interagency venues such as the National Climate Assessment (NCA), the U.S. Climate Resilience Toolkit, and others.

The Task Force focused its initial efforts on the development of an interagency report (Sweet et al., 2017), providing updated GMSL rise scenarios focused primarily on 2100 and integrating these GMSL rise scenarios with regional factors contributing to sea level change to produce, for the first time, a set of RSL scenarios for the entire U.S. coastline. These scenarios were also a major technical input to Volumes I and II of the Fourth NCA (NCA4; USGCRP 2017, 2018) and have been widely used in the development of state (e.g., Florida[7] and Virginia [CCRM, 2019]) and local agency adaptation plans (e.g., Pensacola, Florida,[8] and Portland, Maine [One Climate Future, 2019]), and processes for anticipating and managing future coastal risks.

The Task Force's first report (Sweet et al., 2017) built upon the most current scenarios at that time (e.g., Parris et al., 2012; Kopp et al., 2014; Hall et al., 2016) and estimated the full possible range for GMSL rise by 2100 as being bounded by 0.3 m on the low end, representing a simple linear extrapolation of the GMSL rate since the early 1990s, and by 2.5 m on the high end, representing an extreme ice-sheet melt/discharge scenario. This 0.3–2.5 m range was discretized and aligned with emissions-based, conditional probabilistic storylines and global model projections into six GMSL rise scenarios: Low, Intermediate-Low, Intermediate, Intermediate-High, High, and Extreme, corresponding to GMSL rise by 2100 of 0.3 m, 0.5 m, 1.0 m, 1.5 m, 2.0 m, and 2.5 m, respectively. These GMSL rise scenarios were then used to derive regional RSL responses on a 1-degree grid covering the coastlines of the U.S. mainland, Alaska, Hawaiʻi, the Caribbean, and the Pacific Island territories, as well as at the precise locations of tide gauges along these coastlines.

This current report takes the Sweet et al. (2017) report as its starting point, updating the GMSL scenarios and the associated local and regional RSL projections to reflect recent advances in sea level science, as well as expanding the types of scenario information provided to better serve stakeholder needs for coastal risk management and adaptation planning. As with the 2017 report, this iteration will also serve as a key technical input to the NCA, in this case NCA5. Specific updates in this report include the following:

- While this report still uses the same nomenclature as the NOAA 2017 GMSL scenarios, it draws upon new science of the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6; Fox-Kemper et al., 2021; Garner et al., 2021) to provide updated temporal trajectories and exceedance probabilities based on different levels of global warming. One effect is that the associated RSL projections for the U.S. coastline (gridded and at individual tide-gauge locations) differ in timing and magnitude as compared to the NOAA 2017 projections.
- In addition, in leveraging this updated science, including a longer observational record, improved understanding of ice-sheet dynamical processes, and better-constrained models, this report provides a more comprehensive and detailed assessment of the distinct types and range of uncertainties associated with the GMSL rise scenarios, particularly at the high end.
- By utilizing 50-year regional sets of tide-gauge data, observation-based rates and accelerations are extrapolated to the year 2050 to identify the scenario projections aligning with current RSL trajectories.
- Lastly, gridded EWL probabilities are provided, along with methods to localize them along most U.S. coastlines, to contextualize each of the regionalized sea level scenarios across a range of flood frequencies under current standards, from recurrent tidal flooding to major storm-surge flooding, out to 2050.

To frame the remainder of this report, it is important to emphasize the distinction between describing scientific progress, in terms of current understanding and key uncertainties, and translating such advances in the scientific knowledge base into actionable science. The latter requires sustained engagement by groups such as NOAA's Office of Coast Management and the Sea Grant program with users, stakeholder groups, and associated boundary organizations regarding their specific planning and decision contexts. Our development

[7] https://floridadep.gov/rcp/florida-resilient-coastlines-program/documents/proposed-rule-development-draft-62s-7-sea-level

[8] https://storymaps.arcgis.com/stories/e812723f69ad4a618c8f5f8b08cb208e

of scenarios in this report is grounded in the principles of risk-based framing for climate assessment (King et al., 2015; Weaver et al., 2017; Sutton, 2019; Kopp et al., 2019) and is consistent with adaptation pathways approaches for long-term planning. What we thus aim to provide are screening-level (suitable for first-order assessment) products appropriate for framing and bounding important problems in coastal risk assessment and management, along with contextualization of the underlying science and illustrative case studies. For example, consistent with this purpose, this report aims to provide the underlying scientific information to develop both planning- and bounding-type scenarios across the full spectrum of coastal risk; that is, 1) planning scenarios intended to frame near- to mid-term decision contexts and/or longer-term decisions with high-risk tolerance or ability to adjust plans, which address the question, What is most likely to happen? and 2) bounding scenarios designed to set the envelope of possible future outcomes, which can be used to stress-test long-term objectives, gauge the "when, not if" a given level of sea level rise might be reached, and address the question How bad could things get? *What this report does NOT provide is official guidance nor design specifications for a specific project.*

Section 2 describes advances in the understanding of the drivers of mean sea level since the 2017 report, discusses the use of observations for a near-term trajectory assessment, and provides the updated GMSL rise scenarios and their associated regional RSL projections. Section 3 focuses on high-frequency EWLs, including a regional frequency analysis of historical NOAA tide-gauge data to develop a set of EWL probabilities for assessing and projecting (to 2050) across a range of flood levels. Section 4 applies these scenarios and projections in illustrative use-case examples. Section 5 provides a summary of the report findings, as well as conclusions and next steps.

Section 2: Future Mean Sea Level: Scenarios and Observation-Based Assessments

Since Sweet et al. (2017), the observations and available data records of both sea level change and the associated processes have increased in number and length. In part due to these observations, our understanding of the drivers of sea level change has improved. There have also been significant advances in modeling how these processes will cause sea level to change in the future. This has led to an improved understanding of the possible trajectory of future sea level rise. In this report, these advances are reflected both in an update to the GMSL scenarios and a change in approach from Sweet et al. (2017). The primary change in approach is in separating this section into two different time periods: 1) near term (2020–2050) and 2) long term (2050–2150). There is also a section discussing divergence of the GMSL scenarios and tracking that is particularly relevant during the transition between the near- and long-term time periods. In the remainder of this section, a brief overview of the drivers of global and regional sea level rise is provided. Next, updates to Sweet et al. (2017) are discussed, and the motivation and scientific justification for these changes are given. Finally, the updated information for the two time periods, along with the transition between these periods, is provided.

2.1. Overview of Regional and Global Sea Level Rise

Over long, multidecadal to centennial timescales, the primary drivers of changes in GMSL are thermal expansion due to the heating of the ocean and the addition of water mass associated with ice-mass loss from the ice sheets and glaciers. Other changes in the movement of water between ocean and land, including from groundwater depletion and water impoundment, have a secondary impact on GMSL, although they can increase in importance for certain time periods (see Frederikse et al., 2020). During the 20th century, GMSL estimated from tide-gauge records has been explained by the individual processes contributing to it (see Figure 1.2a; Frederikse et al., 2020). More recently, observed GMSL from satellite altimetry over the past 15 years has been explained using the in situ measurements of the Argo profiling floats and the observations of water-mass change from the GRACE and GRACE-FO satellites (WCRP, 2018). On shorter timescales, considerable interannual and decadal variability in GMSL is linked primarily to variations in terrestrial water storage and driven heavily by the El Niño–Southern Oscillation (ENSO; Boening et al. 2012; Fasullo et al., 2013; Piecuch and Quinn, 2016; Hamlington et al., 2020a, 2020b].

At the regional level, rates of sea level rise can deviate significantly from the globally averaged rate. Sea level rise is not uniform across the globe; rather, it manifests as relative sea level (RSL) rise that also responds to several key factors important at regional and local scales (Kopp et al., 2014; Sweet et al., 2017; Hamlington et al., 2020a; Fox-Kemper et al., 2021). On short timescales and in short records, natural variations on interannual to decadal timescales can impact estimates of rates and accelerations. On long timescales, however, there are three primary causes of regional variations in estimated rates and accelerations: 1) sterodynamic sea level change; 2) gravitational, rotational, and deformational (GRD) changes due to contemporary ice-mass loss and the movement of water between land and ocean; and 3) vertical land movement (VLM; subsidence or uplift) due to glacial isostatic adjustment (GIA), tectonics, sediment compaction, groundwater and fossil fuel withdrawals, and other non-climatic factors. These three causes are discussed briefly below.

Sterodynamic sea level changes are those that arise from changes in the ocean's circulation (currents) and its density (temperature and salinity). Sea level rise associated with sterodynamic sea level change is the combination of global mean thermosteric rise associated with global ocean warming and local deviations from the global mean due to ocean dynamic processes. It is these changes in ocean dynamics that lead to regional differences. Focusing on possible causes of long-term sterodynamic sea level changes for the U.S. coastlines, future changes in the Atlantic meridional overturning circulation (AMOC) are particularly relevant. The IPCC AR6 (IPCC, 2021a) determined that it is *very likely* that the AMOC will decline in the future, although there is still disagreement as to the extent of this decline. A weakening AMOC will lead to an increase in sea level along the coastal Northeast and Southeast regions (Yin et al., 2009; Krasting et al., 2016; see Figure A1.1 for region definitions). For the Northwest and Southwest coastal regions, ENSO plays a substantial role in interannual sea level change, although there is no clear evidence for a sustained shift in ENSO that will result in a long-term increase or decrease in sea level. Some models project future sea level changes associated with ocean dynamics to be large in magnitude in some locations, but these projections remain uncertain (Fox-Kemper et al., 2021).

The ice-mass loss from ice sheets and glaciers to the ocean has a strong influence on regional sea level. Changes in Earth's GRD responses dictate the spatial distribution of water across the global ocean (Farrell and Clark, 1976; Milne and Mitrovica, 1998; Mitrovica et al., 2001). These so-called sea level fingerprints are important to determining regional sea level rise. Mass loss causes a sea level fall in the near-field, a reduced sea level rise at intermediate distances, and a greater-than-global-average sea level rise at larger distances. For U.S. coastlines, particularly in the Northeast, this means that a similar amount of ice-mass loss in Antarctica will have a larger impact than ice-mass loss in Greenland. Similarly, ice-mass loss in Greenland leads to bigger increases in sea level along the Northwest and Southwest coastal regions than along the Northeast coastal region. At any time horizon, the regional sea level rise associated with GRD will be driven both by the amount of ice that is being lost and the source of that ice. These regional fingerprints are tied to projected trajectories of mass loss from the associated source. Changes in terrestrial water storage (groundwater withdrawal and dam building) also have an associated fingerprint, but the regional contribution is generally smaller than that from the ice sheets and glaciers.

Lastly, the VLM considered in this report refers to either subsidence or uplift that occurs in coastal regions and can lead to the change in the height of sea level relative to land. VLM is not a singular phenomenon but instead results from various processes that display different patterns in space and time. These patterns have different impacts from place to place, especially in coastal settings where many of them operate at the same time. For much of the coastal United States, subsidence is driven on local scales by groundwater and fossil fuel withdrawal and on larger scales by GIA. However, in some regions such as southern Alaska, GIA leads to high rates of uplift in coastal regions. GIA is the ongoing response of the solid earth due to ice-mass changes in the past, particularly the deglaciation after the last glacial maximum. GIA induces VLM, in particular subsidence along the U.S. East Coast, as well as changes in the gravity field, which cause local sea level changes. Accurate future projections of VLM require an understanding of the underlying processes and the time and space scales on which they vary. Currently, and in this report, VLM projections are based in part on analysis of past observations. If activities change in a particular location (e.g., reduction in groundwater pumping), an associated change in the rate of VLM will not necessarily be captured. Modeling of future VLM under a range of possible scenarios is not currently available over large scales. (See the vertical land motion use case in Section 4.4 for more information.)

Beyond these processes that impact long-term changes in sea level, there is also considerable natural (or "unforced") climate variability that can lead to significant, albeit temporary, changes to sea level on the order of years or even decades. In many of the available observational records, it can be a challenge to distinguish between these natural signals and those processes discussed above. As an example, in Figure 2.1, the regional rates of sea level rise along U.S. coastlines are shown for the first half (a, 1993–2006), second half (b, 2007–2020), and full (c, 1993–2020) satellite altimeter record (which do not measure VLM effects), along with overlaid tide-gauge rates (which measure VLM effects) measured over the same time period. A significant shift occurs from the first half of the record to the second half, with high sea level rise rates found along all coastlines of CONUS from 2007 to 2020. For the Northwest and Southwest coastal regions, in particular, the rate was near 0 for the first half of the record before shifting to almost 10 mm/year over the second half, driven by decadal variability linked to the Pacific Decadal Oscillation (PDO; e.g., Bromirski et al., 2011; Hamlington et al., 2021). For the full record, there is considerably less spatial variability, with most regions approaching the globally averaged rate of 3.1 mm/year.

In this section of the report, the contribution of natural variability is not assessed directly, but its importance and contribution should be considered when looking at observed rates and assessing possible sea level at a specific time in the future. In other words, there is an "envelope" of naturally occurring sea level variability on top of the sea level rise discussed here that needs to be included to estimate sea level at a particular location at a specific time in the future. A depiction of the relationship between sea level rise and this envelope is provided in Figure 1.3. The median of the distribution increases over time as a result of the rising sea levels, while other sea level variability on a range of timescales contributes to the spread around this central value.

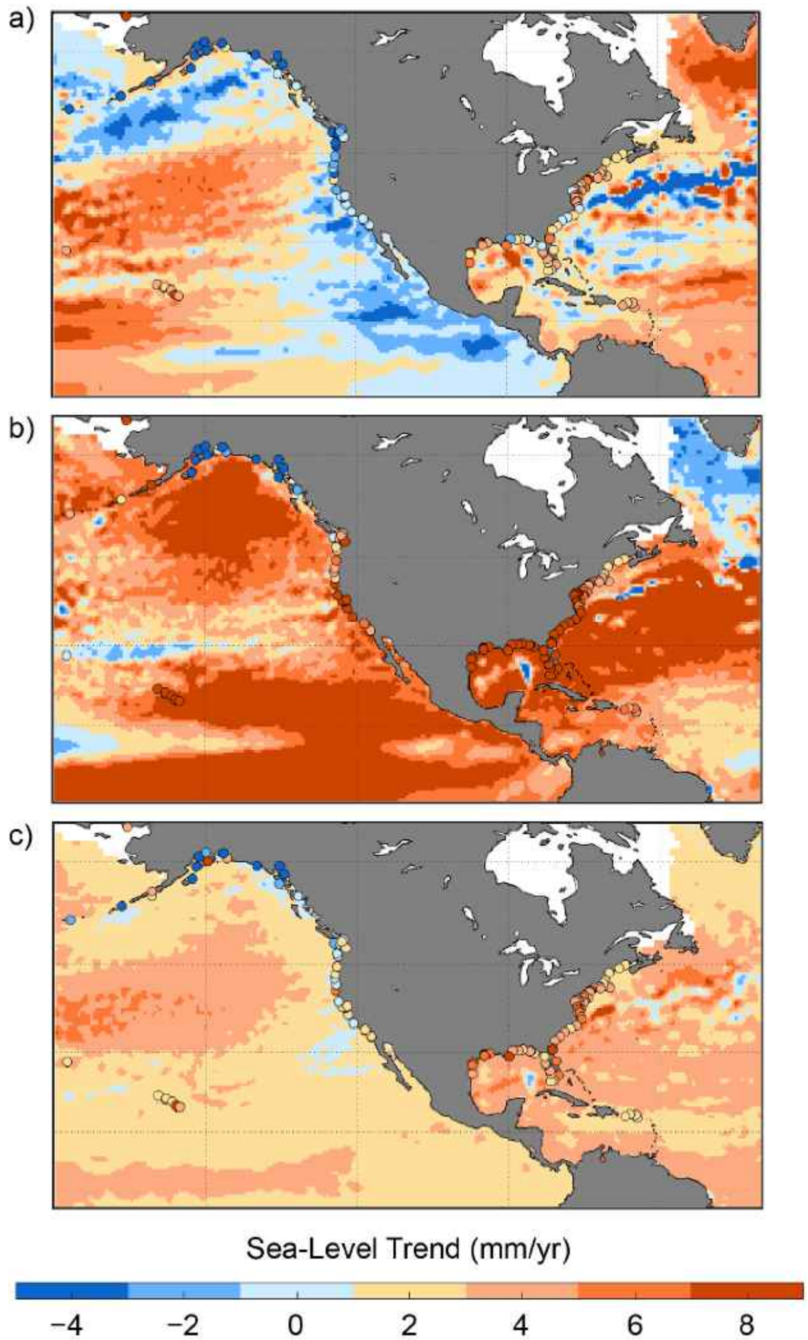


Figure 2.1: Regional sea level linear rates of rise (mm/year) from satellite altimetry over three different time periods: (a) 1993–2006, (b) 2007–2020, and (c) 1993–2020. Linear rates of change of relative sea level (ocean and land height changes) from tide gauges over the same time period are also shown (circles).

2.2. Updates from Sweet et al. (2017)

One of the main structural changes from the Sweet et al. (2017) report to this one is a specific emphasis on the near-term time period, 2020–2050. There is also a detailed discussion of GMSL scenario divergence and tracking that becomes particularly important in the transition from the near term to the long term. The motivation for the focus on these two topics is given below. Following this explanation, the primary advances in the sea level scenarios and assessments of future sea level are discussed in two subsections. The first provides an overview of the science and framework advancements that have led to an update of the scenarios first presented in Sweet et al. (2017). The second covers the inclusion of observation-based assessments of near-term sea level change for the first time.

2.2.1. Inclusion of Near-Term Time Period (2020–2050)

The dedicated focus on the near-term time period represents a new element in this report. Motivation for this change is provided briefly here. With increasing record lengths, the impact of natural sea level variability on estimated rates and accelerations diminishes, revealing more of the underlying climate change signal (see Figure 2.1c, for example). Tide gauges surrounding the U.S. coastlines provide records exceeding 100 years in some locations, and the satellite altimeter record is nearing three decades in length. Recent studies have assessed the degree to which rates and accelerations estimated from these records are reflective of the long-term increase in sea level (via satellite altimetry; e.g., Fasullo and Nerem, 2018; Richter et al., 2020) and RSL (via tide gauges; e.g., Wang et al., 2021). These studies suggest that with appropriate consideration of uncertainty, observation-based extrapolations can be informative in the near term. In this report, an assessment based solely on extrapolation of the observed rates and acceleration out to 2050 is used for trajectory tracking and a comparison to the GMSL and regional scenarios. These trajectories serve as an additional line of evidence for near-term sea level rise and provide a mostly independent (observational VLM information is shared in both) comparison to the model-based scenario. To maintain a distinction between estimates arising from observations and those coming from model-derived GMSL scenarios, the observation-based assessments are referred to in this report as "extrapolations" or "trajectories" and not as "projections." These terms are also preceded by "observation-based" whenever used.

Beyond this renewed observational focus, the inclusion of this near-term time period is motivated by the fact that for certain decision types, short time horizons and nearer-term assessments are most relevant. For the typical lifetime of buildings and infrastructure in coastal areas, for example, a 30-year planning horizon has particular relevance (e.g., Fu, 2020; Hinkel et al., 2018). Additionally, flexible adaptation pathways and solutions typically require significant lead times on upgrades or replacements of coastal structures that necessitate assessments across a range of timescales. (Haasnoot et al., 2013, 2019; Bloeman et al., 2018; Werners et al., 2021; Hall et al., 2019). Knowing whether adaptation actions are required within the next 30 years or afterwards informs decisions about initial designs, the adaptations required, and the metrics that would trigger adaptation.

2.2.2. GMSL Scenario Divergence and Tracking

After 2050, the assessments and comparisons made using the observation-based extrapolations of future sea level rise become less informative and should be made with caution. This is because uncertainty in the current estimates of rates and accelerations leads to large projected ranges and because current estimates may not be reflective of shifts or process changes that may occur in the future with additional emissions and global warming, resulting in increasing divergence between the future GMSL scenarios after 2050. During the transition from near- to long-term assessments, an understanding of when the GMSL scenarios will diverge and what drives this divergence becomes increasingly important. Two types of uncertainty are important to consider in this context: uncertainty in physical processes and uncertainty in future emissions and ensuing warming. Although there are possible alternative definitions and framings, as used in this report, *process uncertainty* (Box 2.1) is associated with how well we currently understand why sea level has changed in the past and how it will change in the future. Stated another way, how well do we understand and model the processes that will combine to impact sea level at a specific time and location in the future? This uncertainty is also reflected in the likely range of future sea level rise for a given GMSL scenario. The spread between the five GMSL rise scenarios is intended to reflect the range of potential future emissions pathways and associated warming levels that depends highly on global socioeconomic factors that have yet to unfold. This unknown future pathway leads to what is referred to here as *emissions uncertainty* (Box 2.1).

At some point in the future, the separation between GMSL rise scenarios will overtake the process uncertainty associated with individual GMSL rise scenarios. In other words, scenario dependence will emerge, and it will be possible to distinguish between the observation-based trajectories associated with two neighboring GMSL rise scenarios. In general, these time periods are important for connecting the near-term similarities between scenarios to the time period where scenarios diverge rapidly. An effort is made here to understand when divergence of the GMSL rise scenarios might occur and to link them to possible future warming and emissions pathways. This analysis then serves as the foundation for process-based monitoring that could be useful in determining the trajectory of ongoing sea level rise and, by extension, the possible future sea level rise out to 2150.

Box 2.1: Uncertainties

When assessing future changes in sea level, this report considers two main sources of uncertainty.

Process Uncertainty

An increase in emissions will cause ice-mass loss, ocean thermal expansion, and local ocean dynamic changes, but the sensitivity of these processes to these forcing changes comes with uncertainty. For example, the sensitivity of the Antarctic ice sheet is not yet fully understood, leading to a substantial uncertainty in how sea level reacts to forcing changes. Additionally, the future contributions from processes, such as changes in ocean circulation and VLM, that impact RSL change more locally have an associated uncertainty. This uncertainty in the contribution of these various processes to future RSL change is referred to in this report as *process uncertainty*.

Emissions Uncertainty

Increasing the amount of greenhouse gases (GHGs) in the atmosphere will trap more heat in the earth system. The amount of GHGs in the atmosphere determines the “forcing” of climate change and its effects, such as changes in temperature and sea level rise. Various forcing scenarios describe possible GHG emissions pathways, which range from quick emissions reduction to unmitigated future emissions. In the IPCC AR6 (IPCC, 2021a), these possible future pathways are referred to as Shared Socioeconomic Pathways (SSPs). The uncertainty in the future pathway is referred to as *emissions uncertainty*.

Uncertainties in this Report

In this report, emissions uncertainty and process uncertainty are combined to generate five sea level scenarios with GMSL target values in 2100: Low (0.3 m), Intermediate-Low (0.5 m), Intermediate (1 m), Intermediate-High (1.5 m), and High (2 m). These sea level scenarios are related to but distinct from the emissions pathway scenarios in the IPCC AR6.

Natural Variability

Next to sea level changes caused by changes in GHG forcing, many physical processes cause natural variations (e.g., ENSO). The scenarios and uncertainty ranges for each scenario and for the observation-based trajectories in this report do *not* include variations due to natural variability (the decadal scenario values are 19-year averages that remove most variability effects). Natural variability is not directly considered a source of uncertainty in the context of this report but does contribute to the uncertainty range in the observation-based extrapolations, as it can influence the estimated rates and accelerations in observational records. Natural, or non-forced, variations can also make significant contributions to sea level on a wide range of timescales. For example, along the U.S. West coast, sea levels are higher during El Niño years. When assessing sea level at a specific location and time in the future, the sea level contribution from natural variability must be combined with the scenarios and trajectories provided here.

2.2.3 Updates to the 2017 Sea Level Scenarios

In order to support decision-making efforts related to future sea level risks, past interagency efforts (Parris et al., 2012; Hall et al., 2016; Sweet et al., 2017) have defined a set of GMSL rise scenarios spanning a range from a Low scenario, consistent with no additional GMSL acceleration, to a worst-case, or high-end, Extreme scenario, judged to be at the physically plausible limits based on the scientific literature. In Sweet et al. (2017), these scenarios were developed to span a range of 21st-century GMSL rise from 0.3 m to 2.5 m. Sweet et al. (2017) built these scenarios upon the probabilistic emissions scenario–driven projections of Kopp et al. (2014). Kopp et al. (2014) combined a variety of different lines of evidence—global climate model (GCM) projections, the IPCC AR5 assessment of ice-sheet changes, and structured expert-judgment ice-sheet projections, among other sources of information—to generate distributions of future global and associated regional sea level changes consistent with low, medium, and high emissions scenarios. Sweet et al. (2017) filtered the ensemble of different future projections generated by Kopp et al. (2014) to identify those subsets consistent with 0.3 m, 0.5 m, 1.0 m, 1.5 m, 2.0 m, and 2.5 m of 21st-century GMSL rise. These subsets constituted the six Sweet et al. (2017) GMSL scenarios. For most purposes, Sweet et al. (2017) focused on the median of each subset, although 17th and 83rd percentile levels were also reported.

This report retains the Sweet et al. (2017) scenarios (except the Extreme 2.5 m scenario, discussed below), with the principal difference being updated temporal trajectories and exceedance probabilities now based on global warming levels rather than emissions scenarios. Linking to global warming levels provides a straightforward physical link for the GMSL scenarios and establishes a connection to global temperature monitoring efforts. The updates made in this report reflect the underlying ensemble of future projections based on methods used in the IPCC AR6 (Fox-Kemper et al., 2021; Garner et al., 2021) and listed in Table A1.1. As in Sweet et al. (2017), these projections are filtered based on 21st-century GMSL rise. In other words, projected pathways that intersect the GMSL scenario target values in 2100 are retained and then used to generate the GMSL scenarios from Low to High described here.

In addition to being updated based on the latest generation of GCMs and the IPCC AR6, this set of projections incorporates multiple methods of projecting future ice-sheet changes, which are the major sources of future sea level rise and pose the biggest source of uncertainty in projecting the timing and magnitude of future possible rise amounts. For Antarctica, this includes emulators derived from two different ice-sheet model intercomparison exercises (Edwards et al., 2021; Levermann et al., 2020), as well as from a single-model study focused on the potentially high-impact but uncertain-likelihood marine ice cliff instability (MICI) mechanism (DeConto et al. 2021) and a structured expert-judgment study (Bamber et al, 2019). For Greenland, this includes a single intercomparison-derived emulator (Edwards et al., 2021) and a structured expert-judgment study (Bamber et al., 2019). There is now a broader range of both Antarctic and Greenland potential contributions, compared to Sweet et al. (2017). Whereas the high-end scenarios of Sweet et al. (2017) were all dominated by Antarctic contributions, the potential for high Greenland contributions now also adds to these high-end scenarios, and due to its proximity, also drives larger differences along U.S. coastlines.

The use of multiple methods, including methods that consider mechanisms that could substantially increase ice-sheet sensitivity under high emissions scenarios, means that the time path of the higher GMSL scenarios is more realistic than in Sweet et al. (2017), which assumed (based on the underlying Kopp et al. [2014] projections) that ice-sheet loss would accelerate at a constant rate over the remainder of the century. A result is that there is less acceleration in the higher scenarios until about 2050 and greater acceleration toward the end of this century. This has two primary implications. First, despite maintaining the same target values and having the same range between scenarios in 2100, the range covered by the scenarios is smaller in the near term than in Sweet et al. (2017). Second, the likely (17th–83rd percentile) ranges of projections consistent with each scenario before and after the 2100 time point used to define the scenarios tend to be broader than in Sweet et al. (2017).

An important change from the Sweet et al. (2017) report is the exclusion of the Extreme (2.5 m) scenario in this report. Based on the most recent scientific understanding and as discussed in the IPCC AR6, the uncertain physical processes such as ice-sheet loss that could lead to much higher increases in sea level are now viewed as less plausible in the coming decades before potentially becoming a factor toward the end of the 21st century and beyond. A GMSL increase of 2.5 m by 2100 is thus viewed as less plausible, and the associated scenario has been removed from this report. Nevertheless, the increased acceleration in the late 21st century and beyond means that the other high-end scenarios provide pathways that potentially reach this threshold in the decades immediately following 2100 (and continue rising).

2.2.4. Observation-Based Extrapolations

As discussed above, the pathways of the updated GMSL scenarios differ from those presented in Sweet et al. (2017), and the range between the scenarios in the near term is now reduced. This report, for the first time, includes observation-based extrapolations to serve as a near-term (2020–2050) comparison for the scenarios. They can also be viewed as "trajectories" of current sea level rise. When interpreting these extrapolations, they should be considered as an additional line of evidence for near-term sea level rise alongside the model-based GMSL scenarios. They are not intended to replace the GMSL scenarios. Additionally, such observation-based extrapolations, or trajectories, can be potentially misleading if not appropriately constrained. This report makes no detailed assessment of whether the long-term rate and acceleration have emerged from the influence of natural variability in the observational record, although recent studies suggest this could be the case in some regions (Lyu et al., 2014; Richter et al., 2020; Fasullo and Nerem, 2018; Wang et al., 2021). Instead, the observation-based extrapolations are presented as computed and without interpretation after several methodological choices were made to generate extrapolations that can be compared to the scenarios and identify those scenarios that "bound" the 2050 extrapolations. These methodological choices are described briefly below.

First, the rates and accelerations are estimated from the tide-gauge records starting in 1970. Recent studies have shown a consistent acceleration in GMSL since 1970 (Dangendorf et al., 2019; Frederikse et al., 2020), and this is a primary motivator for the time period chosen. The impact of varying this start date on the regional scales relied on here was assessed and found to be negligible within a few years of 1970 (more below). This is not true, as a general statement, when using individual tide-gauge records. Second, the observation-based extrapolations are made only to 2050. Beyond that date, it is assumed that processes not fully represented in the observations could become dominant. Third, the uncertainty in the rate and acceleration associated with the influence of natural variability is accounted for as fully as possible and included in the extrapolation. Finally, the extrapolations are made for GMSL, the coastlines of CONUS, and 10 separate coastal regions around the United States and outlying islands (see Figure A1.1 for region definitions). By grouping tide gauges regionally, the influence of localized variability is reduced, and challenges associated with individual tide gauges with incomplete or short records are overcome, thus yielding more useful and narrower extrapolated ranges. These regional comparisons also fulfill the intent of providing an additional line of evidence and comparison point to the GMSL scenarios.

For each individual region, the observation-based extrapolation is performed as follows:

1. The tide gauges in the region are grouped and combined following the virtual station method (see Frederikse et al., 2020) to generate a monthly time series of RSL from 1920 to present.
2. Natural variability is partially removed through regression analysis using climate indices representing the El Niño–Southern Oscillation, Pacific Decadal Oscillation, and North Atlantic Oscillation (see Calafat et al., 2012; Hamlington et al., 2021).
3. The rate and acceleration from 1970 to present is computed, and the uncertainty on each term is assessed, accounting for the influence of remaining natural variability (see Hamlington et al., 2021) and serially correlated variability in the tide-gauge record (Bos et al., 2013, 2014).

4. The rates, accelerations, and uncertainties are used to generate an ensemble of 5,000 extrapolations with a baseline year of 2000 and extending to 2050. Median projections and a likely (17th–83rd) range are computed from this ensemble.

Following this procedure, observation-based extrapolations are obtained for GMSL, CONUS, and 8 coastal regions (Figure A1.1)—the Northeast (Maine to Virginia), the Southeast (North Carolina to the east coast of Florida), the Eastern Gulf (west coast of Florida to Mississippi), the Western Gulf (Louisiana to Texas), the Southwest (California), the Northwest (Oregon to Washington), the Hawaiian Islands, and the Caribbean. Elsewhere in the report, projections are discussed for the Pacific Islands, but due to the availability of tide-gauge data and the geographic range covered by the region, the extrapolations are conducted using only those gauges on the Hawaiian Islands. Observation-based extrapolations are also made for the southern and northern coasts of Alaska and mentioned in the text but not included in the tables below. Differential VLM heavily impacts the tide-gauge records along the southern coastline of Alaska and makes the creation of a regionally representative time series challenging. The observation-based extrapolations for Alaska are thus caveated with increased uncertainty in the underlying regional processes that heavily limit their utility as a comparison to the GMSL scenarios.

2.3. Near-Term Sea Level Change (2020–2050)

In Sweet et al. (2017), the range between the median values of the Low and High GMSL scenarios in 2020, 2030, 2040, and 2050 was 0.05 m, 0.12 m, 0.23 m, and 0.38 m, respectively. As a result of improved science and the updated framework and procedure for generating the GMSL scenarios, the time path of the scenarios—particularly the higher scenarios—is now more realistic and consistent with current process-based understanding. In this report, the range between the Low and High scenarios in 2020, 2030, 2040, and 2050 is now 0.02 m, 0.06 m, 0.15 m, and 0.28 m, respectively (Table 2.1). In other words, there is less divergence between the GMSL scenarios in this near-term time period, which reduces uncertainty in the projected amount of GMSL rise up to the year 2050. The Low scenario remains largely the same between this report and Sweet et al. (2017); this range reduction reflects a downward shift in the higher scenarios in 2050 and times prior, as discussed above. As an example, the projected value in 2050 for the High scenario in this report (~0.4 m) is the same as that for the Intermediate-High projected value in 2050 in Sweet et al. (2017). In short, while the scenarios continue to be defined by projected values of GMSL increase in 2100, it is important to note that the paths to get to these target values have changed in this report compared to the previous one.

Following the procedure outlined in Section 2.2.4, an observation-based extrapolation of GMSL is computed using the global tide-gauge reconstruction from Frederikse et al. (2020; Figure 2.2a; also see top row of Table 2.1). The extrapolated value of GMSL increase in 2050 relative to a baseline of 2000 is 0.24 m, with a likely (17th–83rd percentile) range between 0.19 m and 0.29 m. A similar extrapolation was made using GMSL data measured by satellite altimeters over 1993–2021, resulting in an estimate of 0.23 m of rise from 2000 to 2050 and in agreement with the results of the tide-gauge extrapolation. Based on the updated GMSL scenarios, the median of the 2050 observation-based extrapolation is bounded by (i.e., it falls between) the Intermediate-Low and Intermediate scenarios. The likely ranges for the Low and High scenarios do not overlap with the likely range of observation-based extrapolation in 2050, although the very likely ranges (5th–95th percentiles) do overlap. The likely range of the Intermediate-High scenario does overlap with the likely range of the observation-based extrapolation. A similar observation-based extrapolation is completed using only the tide gauges located around CONUS (Figure 2.2b), resulting in a projected increase of 0.38 m in 2050, with a likely range of 0.32 m to 0.45 m. This range for CONUS is again narrower than in Sweet et al. (2017). Similar to GMSL, this observation-based assessment is bounded by the Intermediate-Low and Intermediate scenarios in 2050.

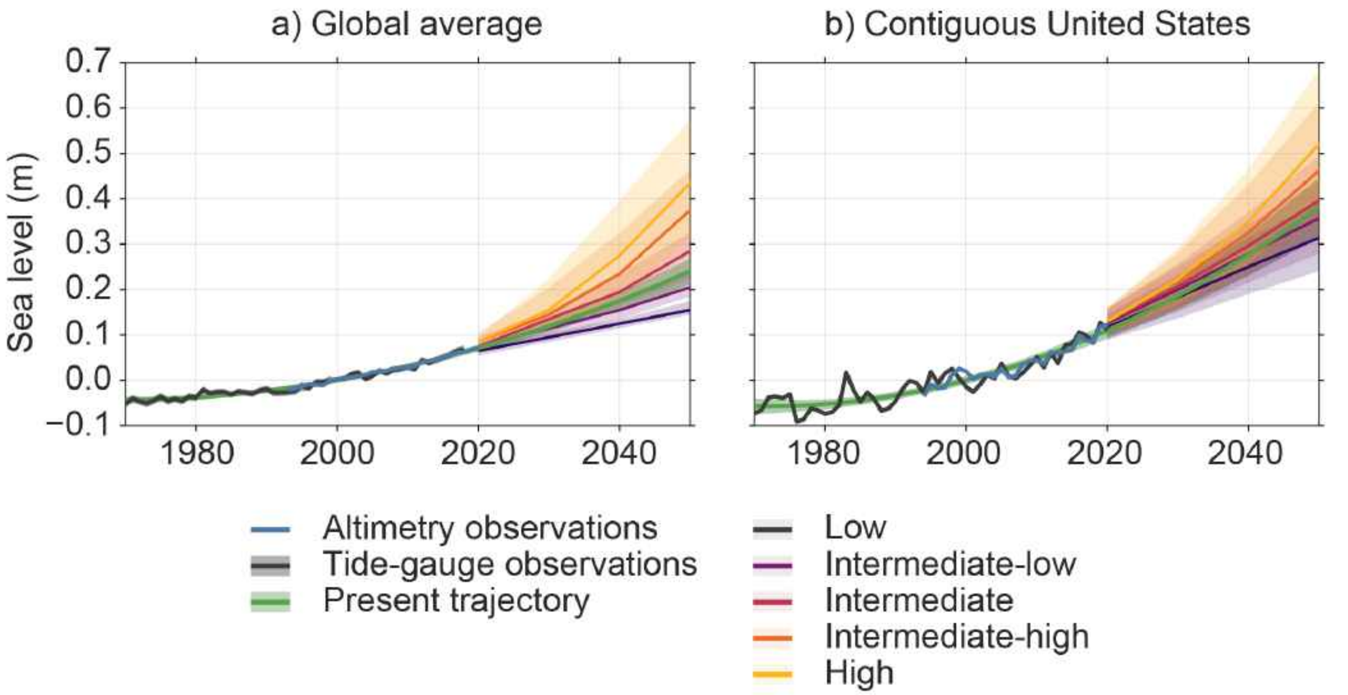


Figure 2.2: Observation-based extrapolations using tide-gauge data and five Scenarios, in meters, for a) global mean sea level and b) relative sea levels for the contiguous United States from 2020 to 2050 relative to a baseline of 2000. Median values are shown by the solid lines, while the shaded regions represent the likely ranges for the observation-based extrapolations and each scenario. Altimetry data (1993–2020) and tide-gauge data (1970–2020) are overlaid for reference.

As a result of the smaller region used and the increased influence of natural variability and VLM, the likely ranges in 2050 for CONUS in both the scenario projections and observation-based extrapolations are larger than those associated with the GMSL scenarios themselves. The likely range from the observation-based extrapolation does overlap with the likely ranges from both the Low and High scenarios. This is both a reflection of the larger range in the extrapolation for CONUS and the narrower range between the High and Low scenarios in this report. A key takeaway from this assessment is that on global and national scales, two lines of evidence (observations and GMSL scenarios) are consistent out to 2050 and support a narrower range in possible near-term sea level change than provided in Sweet et al. (2017). As discussed previously, this is consistent with and a result of the improved process-based understanding and projection approach that has been incorporated in this report.

The observation-based extrapolations are also computed for 10 coastal regions of the United States. Only 8 of these regions are shown in the tables and figures below, with the coastlines of Alaska covered separately in the text. As in the global and national cases, the observation-based extrapolations are extended out to 2050. Following the procedure outlined in section 2.2.4, tide gauges within each of these regions are combined into a single time series prior to extrapolating estimated rates and accelerations. Building on the discussion in section 2.2.4, the motivation for doing these assessments regionally as opposed to at each individual tide gauge location is two-fold. First, the observation-based extrapolations are intended to serve as a comparison to the model-based GMSL scenarios. Outside the possibility of very localized VLM, the processes included in the regionalized GMSL scenarios are generally spatially coherent over the regions considered. Indeed, the selection of specific regions is driven by process-based similarities mostly associated with ocean dynamics and large-scale VLM. Grouping the tide gauges and generating regional comparisons yields a closer analog to the information contained in the scenarios. The regional averages also reduce the influence of local signals—including VLM and other natural ocean variability—that can influence extrapolations and associated ranges. Second, some of the individual tide gauges around the U.S. coastlines have records that either do not span the full time period from 1970 to 2020 or contain data gaps. Generating

Table 2.1: Observation-based extrapolations and five scenarios, in meters, for global mean sea level and relative sea level for the contiguous United States from 2020 to 2050 relative to a baseline of 2000. Median [likely ranges] are shown.

Global Mean Sea Level				
	2020	2030	2040	2050
Obs. Extrapolation	0.07 [0.06, 0.08]	0.12 [0.11, 0.13]	0.18 [0.16, 0.19]	0.24 [0.19, 0.29]
Low	0.06 [0.05, 0.07]	0.09 [0.08, 0.10]	0.12 [0.11, 0.13]	0.15 [0.14, 0.17]
Intermediate-Low	0.07 [0.06, 0.07]	0.11 [0.09, 0.12]	0.15 [0.13, 0.17]	0.20 [0.18, 0.23]
Intermediate	0.07 [0.07, 0.09]	0.13 [0.11, 0.15]	0.19 [0.16, 0.23]	0.28 [0.22, 0.32]
Intermediate-High	0.08 [0.07, 0.10]	0.14 [0.11, 0.20]	0.23 [0.18, 0.32]	0.37 [0.27, 0.46]
High	0.08 [0.07, 0.10]	0.15 [0.11, 0.22]	0.27 [0.18, 0.39]	0.43 [0.31, 0.57]
Contiguous United States				
	2020	2030	2040	2050
Obs. Extrapolation	0.11 [0.09, 0.13]	0.19 [0.16, 0.21]	0.28 [0.23, 0.32]	0.38 [0.32, 0.45]
Low	0.12 [0.09, 0.15]	0.18 [0.14, 0.23]	0.25 [0.19, 0.31]	0.31 [0.24, 0.39]
Intermediate-Low	0.13 [0.10, 0.16]	0.20 [0.15, 0.25]	0.28 [0.22, 0.34]	0.36 [0.28, 0.44]
Intermediate	0.13 [0.10, 0.16]	0.21 [0.16, 0.26]	0.30 [0.23, 0.37]	0.40 [0.31, 0.49]
Intermediate-High	0.13 [0.10, 0.16]	0.22 [0.16, 0.28]	0.33 [0.24, 0.43]	0.46 [0.35, 0.61]
High	0.13 [0.10, 0.16]	0.22 [0.17, 0.29]	0.35 [0.26, 0.47]	0.52 [0.39, 0.68]

regional time series alleviates these challenges and allows us to provide generalized comparisons and assessments about the match between observations and model-based scenarios along the U.S. coastlines. These regional comparisons then provide an additional line of evidence for the possible overall trajectory of sea level in the near term. The result is shown in Figure 2.3, with corresponding values in Table 2.2 for each of the eight regions and compared to the scenarios in each region.

The regional differences in the observation-based extrapolations and scenarios in Figure 2.3 are consistent with the current process-based understanding of sea level rise. Processes such as ocean dynamics, the GRD response to contemporary ice-mass loss (i.e., fingerprints), and coastal VLM lead to differences between the eight regions. Additionally, uncertainty ranges on the extrapolations can be bigger or smaller depending on the number of tide gauges in a particular region and the influence of natural variability on the rate and acceleration estimates. To demonstrate this regionalization, Figure 2.4 shows these regional variations of sea level in 2050 for the Intermediate-Low and Intermediate-High scenarios. In 2050, the regional variation in future sea levels does not change significantly between scenarios. Although the values increase from the Intermediate-Low scenario to the Intermediate-High scenario, the east–west difference in sea level rise is similar. Higher values for both scenarios are found along the entire East and Gulf Coasts. Subsidence leads to the highest rates along the Gulf Coast, driven by regional and local factors, such as river sediment compaction and withdrawal of subsurface fluids (Dokka, 2011; NGS, 2001; Rydlund and Densmore, 2012). Along the East Coast, subsidence is generally associated with the large-scale process of GIA, with fluid extraction being an issue in some areas (Frederikse et al., 2017; Karegar et al., 2016). Beyond VLM, many of the regional differences are driven by differences in the ocean dynamic variability. For example, the sterodynamic contribution from 2000 to 2050 in the Northeast is more than double the sterodynamic contribution in the Southwest. This regional difference is similarly reflected in the observation-based extrapolations in 2050. It should be noted that this difference arises from higher-than-global-average projections for the Northeast as opposed to lower-than-global-average projections for the Southwest, which tracks very closely to the GMSL values shown in Table 2.1.

For the observation-based extrapolations, the largest estimates of sea level rise in 2050 are found along the entire Gulf Coast (Table 2.2). The Western Gulf has the highest extrapolated values in 2050, driven by high rates of coastal subsidence in the region and consistent with the scenarios discussed above. The Northwest and Southwest coastal regions have the lowest observation-based extrapolations to 2050. For the purposes of offering a comparison to the scenarios, the scenarios that either bound or track the median of the observation-based extrapolations are provided (denoted by red text or markers in Table 2.2). Two regions track the Intermediate-Low scenario (Northeast and Hawaiian Islands), and two regions track the Intermediate scenario (Southwest and Caribbean). The Intermediate-Low to Intermediate scenarios bound the Northwest, and the Intermediate to Intermediate-High scenarios bound the Southeast and Western Gulf regions. Finally, the Intermediate-High to High scenarios bound the Eastern Gulf region. With only the exceptions of the low-end scenarios in the Southwest and Eastern Gulf, the likely ranges from the observation-based extrapolations have at least some overlap with the likely ranges of all the scenarios within a given region. This is due to a combination of the larger uncertainty on the observation-based assessments at these regional levels for an individual scenario and the narrower ranges between the median values of each GMSL scenario found in this report compared to Sweet et al. (2017). While not shown in Table 2.2, the observation-based extrapolation for the northern coast of Alaska in 2050 (median value of 0.27 cm) is bracketed by the Intermediate and Intermediate-High scenarios. The extrapolation of the southern coast of Alaska leads to a large RSL decrease in 2050 and is inconsistent with the scenario median values. As mentioned above, this is a result of challenges in generating a representative tide-gauge time series to use in the extrapolation.

As a note on the interpretation of the results provided in this near-term section, the regional comparisons between the observation-based extrapolations and scenarios need to be considered in the context of the global comparison in Figure 2.2. The regional scenarios are intrinsically linked to their associated GMSL target values in 2100. In an ideal framework that perfectly represented the regionalization of these GMSL scenarios and the relevant regional processes, separate comparisons on a regional level would be unnecessary. In other words, all regions and locations would track the same GMSL scenario. Since this is not the case, if a particular region deviates from the others, it would be an indication that either the observation-based extrapolation for that region is biased high or low or that the framework used to generate the regionalization of the GMSL scenarios is not adequately representing the contribution of a regional process. Since the observed GMSL trajectory is near the Intermediate-Low scenario, as shown here, based on the current understanding of the processes driving regional RSL, it is not expected that a particular region would track a much higher scenario. These regional comparisons during the near-term time period then serve two potential purposes: 1) they provide an additional line of evidence along with the GMSL and CONUS comparisons for the near-term trajectory of sea level rise, and 2) they can serve to identify cases when the contributions of regional processes may be tracking differently than represented by the regionalization of the GMSL scenarios.

As a general assessment of these two purposes, the likely ranges of all but one of the regions are either bounded on one side by the Intermediate scenario or tracks a scenario neighboring the Intermediate scenario, showing some level of consistency with the GMSL and CONUS comparisons. This provides additional confidence in the narrower range (when compared to Sweet et al., 2017) of sea level rise at the regional level out to 2050 presented in this report. The Eastern Gulf is the only region bounded by the High scenario. The high observation-based extrapolation for the Eastern Gulf should be interpreted with caution, as it does not necessarily mean a higher scenario is applicable compared to other regions. As a possible explanation, unresolved natural ocean variability in the observational record could lead to an observation-based extrapolation that is biased high. Such variability would need to be low-frequency—or long period—to significantly impact a rate and acceleration estimated in a 50-year record. For all regions considered here, it is likely that natural variability still contributes to the median observation-based extrapolation, and as seen in Figure 2.1, this variability has a substantial impact on the coastlines of the United States. This influence of natural variability on rates and accelerations is captured to the extent possible in the likely ranges of the observation-based extrapolations, and these likely ranges should be considered in tandem with the median values when assessing near-term trajectories. Beyond the possible influence of natural variability, there may also be a mismatch in the process representation between the observations and regionalized, model-based GMSL scenarios that leads to a projection that is too low in the latter. One possibility is non-linear or unresolved VLM in the region. The regionalized GMSL scenarios consider only long-term linear rates of VLM, while the observation-based extrapolations could represent a shift in the rate of VLM in the estimated acceleration.

An explanation of regional differences between observation-based extrapolations and model-based scenarios requires additional investigation, likely on a tide gauge-by-tide gauge basis. As a first step in this direction, the range between Low and High scenarios at each individual tide gauge (considering only the tide gauges with at least 30 years of data—102 of the full set of 121) is provided in Figure A1.2a, and the departure between the observation-based extrapolation and Intermediate scenario at each individual tide gauge is shown in Figure A1.2b. These figures show that the range between Low and High scenarios is generally lower than 20 cm in 2050 at the local level and that most observation-based extrapolations are within 15 cm of the Intermediate scenario in 2050. Of the 102 tide gauges used in this report, 65 have observation-based extrapolations that fall within the narrower Low to High ranges in 2050, and 80 of these 102 are within 15 cm of the Intermediate scenario. The majority of those falling below the Low scenario are found in the Northwest and southern Alaska regions, and the majority of those exceeding the High scenario are found in the two Gulf regions. This supports the regional comparisons shown in Figure 2.3 and Table 2.2 while also conveying that there is general agreement and consistency between the ranges of the observation-based extrapolations and regionalized GMSL scenarios even on a local, tide gauge-by-tide gauge level. A more definitive assessment of why some regions track higher (e.g., Eastern Gulf) or lower relative to others requires further analysis that should be done with consideration of the associated uncertainty and ranges.

As a general concluding statement on this near-term section, the link between the regional and global scenarios needs to be considered when drawing conclusions at the regional level based on the observation-based extrapolations. In practice, regionally identifying the scenario that upper-bounds the observation-based extrapolation at year 2050 (Table 2.2) may help compensate for potential interannual variability when projecting sea level for a particular location. The associated uncertainties in the approaches adopted here do emphasize the importance of ongoing monitoring using the observations and the need to update trajectories. As records continue to lengthen, likely ranges on near-term assessments will narrow. Additionally, satellite altimeter records are reaching sufficient length to be important in such monitoring. As a final note, the same framework used for extrapolating the observations forward can also be used to assess the increases—or offsets—observed over different recent time periods. These offsets are useful for adjusting baselines of the scenarios and are provided for each region in Table A1.2.

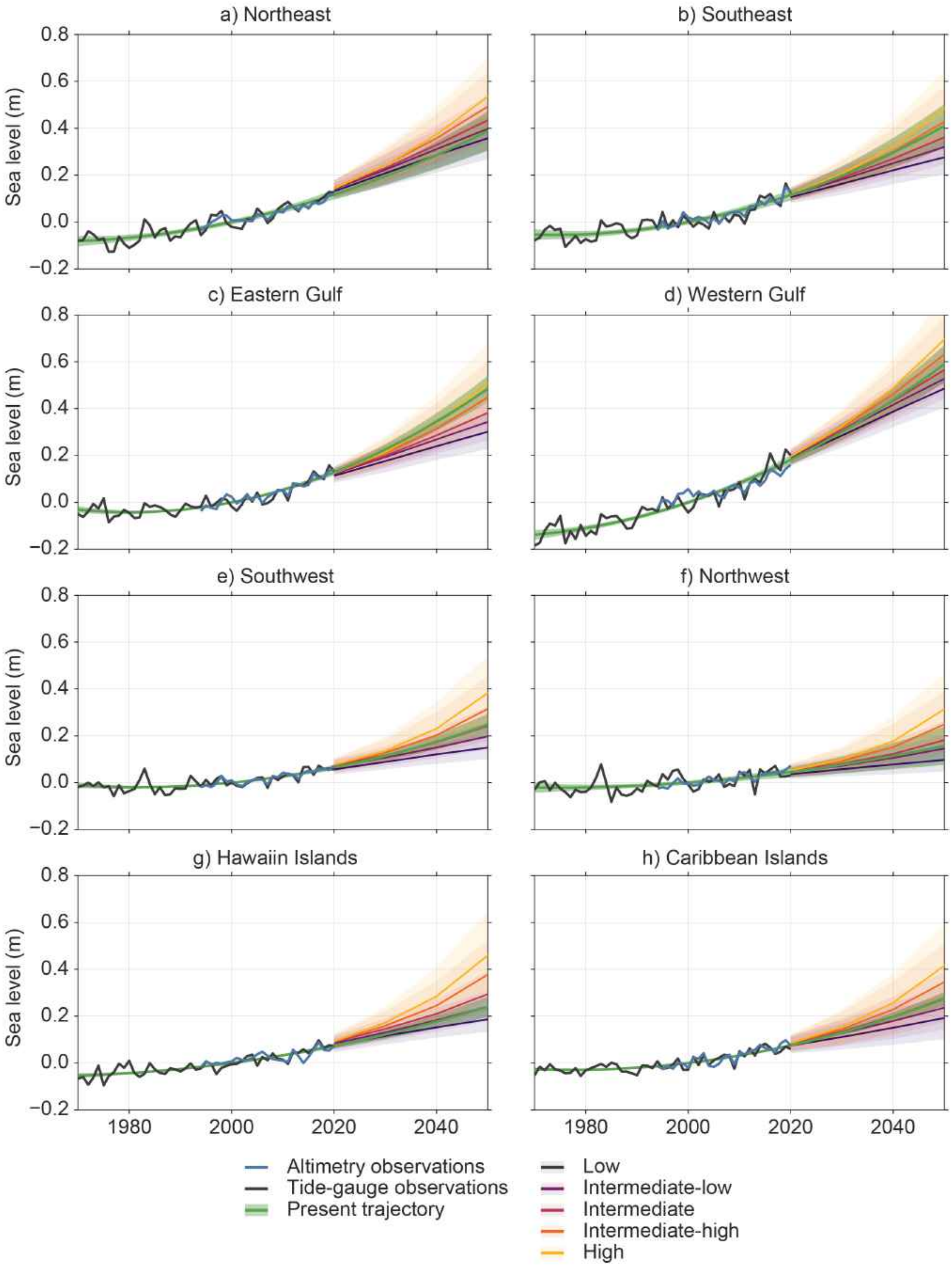


Figure 2.3: Observation-based extrapolations and five regionalized global mean sea level scenario projections, in meters, of relative sea levels for eight coastal regions around the United States from 2020 to 2050 relative to a baseline of 2000. Median values are shown by the solid lines, while the shaded regions represent the likely ranges for the observation-based extrapolations and each scenario. Tide-gauge data (1970 to 2020) are overlaid for reference, along with satellite altimetry observations, which do not include contributions from vertical land motion.

Table 2.2: Observation-based extrapolation and regionalized global mean sea level scenario–based estimates, in meters, of relative sea level in 2050 relative to a baseline of 2000 for eight coastal regions of the United States. Median [likely ranges] are shown. The two scenarios that bound the median observation-based extrapolation are also provided for each region and indicated by red dividing lines. In regions where the observation-based extrapolation is the same as a particular scenario, the scenario is indicated in red text and the bounding scenarios can be assumed to be the next higher or lower scenario (e.g., the Intermediate bounds the Northeast's observation-based extrapolation).

Observation Extrapolations	Low	Intermediate-Low	Intermediate	Intermediate-High	High	Median Bounding Scenarios
Northeast						
0.40 [0.30, 0.47]	0.36 [0.27, 0.45]	0.40 [0.31, 0.49]	0.43 [0.34, 0.54]	0.49 [0.38, 0.64]	0.54 [0.40, 0.69]	Int-Low
Southeast						
0.41 [0.32, 0.50]	0.28 [0.20, 0.35]	0.32 [0.25, 0.40]	0.36 [0.28, 0.46]	0.43 [0.32, 0.58]	0.49 [0.35, 0.64]	Int–Int-High
Eastern Gulf						
0.48 [0.43, 0.54]	0.30 [0.22, 0.38]	0.34 [0.26, 0.42]	0.38 [0.30, 0.48]	0.45 [0.34, 0.60]	0.51 [0.38, 0.68]	Int-High–High
Western Gulf						
0.59 [0.51,0.67]	0.49 [0.41, 0.57]	0.53 [0.44, 0.62]	0.57 [0.47, 0.67]	0.63 [0.51, 0.79]	0.69 [0.56, 0.87]	Int–Int-High
Southwest						
0.24 [0.20,0.29]	0.15 [0.10, 0.20]	0.20 [0.14, 0.26]	0.24 [0.18, 0.32]	0.31 [0.22, 0.45]	0.38 [0.26, 0.54]	Intermediate
Northwest						
0.16 [0.08, 0.24]	0.10 [0.05, 0.15]	0.15 [0.09, 0.20]	0.18 [0.12, 0.26]	0.25 [0.15, 0.39]	0.31 [0.19, 0.47]	Int-Low–Int
Hawaiian Islands						
0.24 [0.20, 0.28]	0.19 [0.13, 0.24]	0.24 [0.18, 0.31]	0.29 [0.22, 0.39]	0.38 [0.27, 0.53]	0.46 [0.31, 0.64]	Int-Low
Caribbean						
0.28 [0.24, 0.31]	0.19 [0.10, 0.29]	0.24 [0.14, 0.33]	0.28 [0.18, 0.39]	0.35 [0.22, 0.51]	0.42 [0.27, 0.59]	Intermediate

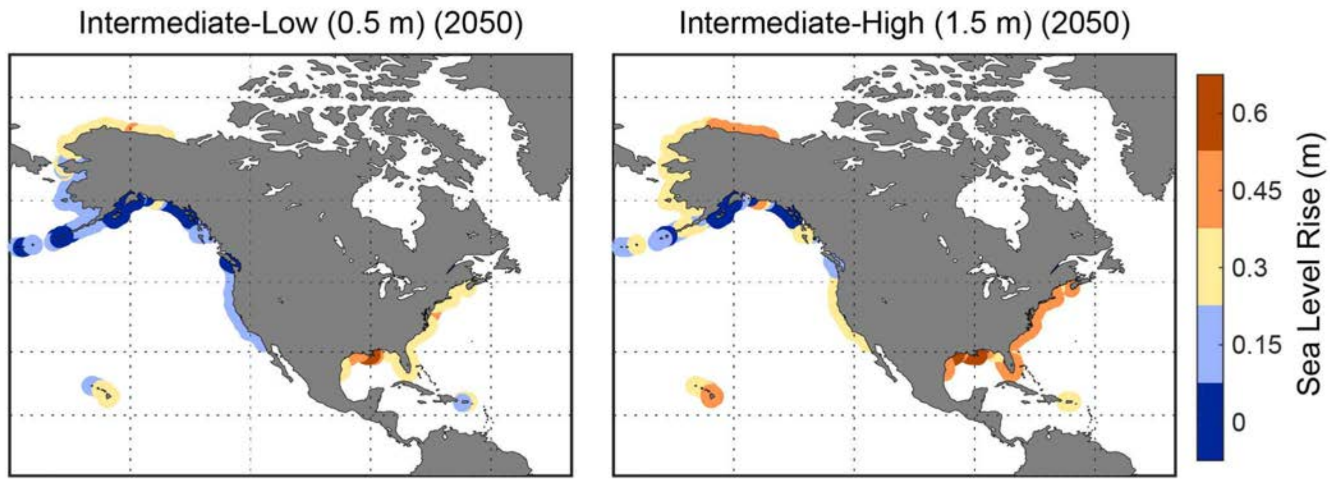


Figure 2.4: Relative sea level rise, in meters, in 2050 for the a) Intermediate-Low and b) Intermediate-High scenarios relative to the year 2000.

2.4. Long-Term Sea Level Change (2050–2150)

The updated GMSL values in 2050, 2100, and 2150 relative to a 2000 baseline are shown for each of the five scenarios in Table 2.3. Note that the current National Tidal Datum Epoch (NTDE) has a baseline of 1992 (midpoint of the 1983–2001 epoch). Comparisons between the projections here and calculations tied to the NTDE will require an adjustment between 1992 and 2000 (see Table A1.2 for offsets). Beyond the middle of this century, the differences between sea level scenarios become increasingly large, and the differences between sea level scenarios become more closely associated with differences in potential future GHG emissions pathways and associated global warming. Although the GMSL scenarios (names and their values) are the same at 2100 for this report and for Sweet et al. (2017), there is a narrowing in the range covered by the scenarios in both 2050 and 2150, driven primarily by a reduction in the values at those two target dates associated with the Intermediate-High and High scenarios in this report. As previously discussed, in 2050, the updated median value for the High scenario is similar to the median value for the Intermediate-High scenario from Sweet et al. (2017). This is not the case in 2150, however, where the separation between the scenarios remains similar to Sweet et al. (2017). Because of this, and because the scenarios are defined by the 2100 values, the same scenario naming is used in this report as in Sweet et al. (2017), with the notable exception of the omission of the Extreme (2.5 m) scenario.

In the very long term (over millennia), the magnitude of global mean sea level rise closely relates to the magnitude of global warming; however, over the timescales of decades and centuries, the magnitude of global warming more closely relates to the *rate* of GMSL rise. It is thus not possible to tie specific levels of warming in general to amounts of sea level rise, but it is possible to relate specific levels of warming *at specific points in time* (e.g., at the end of the century) to different levels of sea level rise. Thus, based on the IPCC AR6 (§9.6.3.4 in Fox-Kemper et al., 2021), it is possible to connect the GMSL rise scenarios to different levels

Table 2.3: Global mean sea level and contiguous United States scenarios, in meters, relative to a 2000 baseline.

Global Mean Sea Level				Contiguous United States			
	2050	2100	2150		2050	2100	2150
Low	0.15	0.3	0.4	Low	0.31	0.6	0.8
Intermediate-Low	0.20	0.5	0.8	Intermediate-Low	0.36	0.7	1.2
Intermediate	0.28	1.0	1.9	Intermediate	0.40	1.2	2.2
Intermediate-High	0.37	1.5	2.7	Intermediate-High	0.46	1.7	2.8
High	0.43	2.0	3.7	High	0.52	2.2	3.9

of future global mean surface air temperature occurring at the end of the century. The median GMSL projection for 2100 for a world with global mean surface air temperature in 2081–2100 averaging 2.0°C above 1850–1900 levels is about 0.5 m (*likely* range of 0.4–0.7 m; Table 2.4), consistent with the Intermediate-Low scenario. The median GMSL projection for a world with global mean surface air temperature in 2081–2100 averaging 4.0°C higher is about 0.7 m (*likely* range of 0.6–0.9 m), between the Intermediate-Low and Intermediate scenarios, with the upper end of the *likely* range approaching the Intermediate scenario. These two scenarios are also consistent with the current observed acceleration, which, if extrapolated, would yield about 0.24 m of GMSL rise by 2050 and 0.69 m by 2100.

However, these projections include only physical processes in which there is at least *medium confidence* in the current scientific understanding. As described in the IPCC AR6 (Box 9.4 in Fox-Kemper et al., 2021), the largest potential contributions to long-term GMSL rise come from ice-sheet processes in which there is currently *low confidence*. Projections that include the magnitudes, rates, and thresholds associated with these ice-sheet processes, particularly under higher emissions futures, could give rise to GMSL rise values well above the *likely* range. Pathways to such unknown-likelihood, high-impact outcomes—"potential surprises" in the words of NCA4 (Kopp et al., 2017)—include

- earlier-than-projected ice-shelf disintegration in Antarctica,
- abrupt, widespread onset of marine ice-sheet instability and/or marine ice-cliff instability in Antarctica, and
- faster-than-projected changes in surface-mass balance on Greenland, potentially associated with changes in atmospheric circulation, cloud processes, or albedo changes.

These outcomes are represented in the IPCC projections (§9.6.3 in Fox-Kemper et al., 2021) through the inclusion of an illustrative very high emissions (SSP5-8.5), *low-confidence* projection range, the 83rd percentile of which for 2100 extends to 1.6 m (modestly above the Intermediate-High scenario) and the 95th percentile of which extends to 2.3 m (above the High scenario). In 2150, the 83rd and 95th percentiles of this *low-confidence* scenario are 4.8 and 5.4 m, respectively. Because these outcomes are based on processes poorly represented in climate and ice-sheet models, the IPCC assessment of these processes incorporates information from a structured expert-judgement study (Bamber et al., 2019) and a single Antarctic ice-sheet modeling study that explicitly incorporates ice-shelf hydrofracturing and ice-cliff collapse mechanisms (DeConto et al., 2021). (See §9.6.3.2, §9.6.3.3, and Box 9.4 of Fox-Kemper et al., 2021, for further discussion.)

To connect this to the scenarios provided here, the Intermediate-High and High scenarios represent potential futures in which these deeply uncertain ice-sheet processes play important roles in the late 21st century and beyond. After 2100, these processes may also play important roles in the Intermediate scenario. These trajectories are highly emissions-dependent. For example, in an illustrative low emissions (SSP1-2.6) future, in which the world achieves net-zero carbon dioxide emissions by the 2070s and net-negative emissions thereafter, the corresponding AR6 l*ow-confidence* ranges in 2100 extend to 0.8 m at the 83rd percentile (between the Intermediate-Low and Intermediate scenarios) and 1.1 m at the 95th percentile (modestly above the Intermediate scenario), reaching 1.3 m (between the Intermediate-Low and Intermediate scenarios) and 1.9 m (consistent with the Intermediate scenario), respectively, in 2150. Thus, in a low emissions future, there is little evidence to support the plausibility of GMSL projections substantially higher than the median Intermediate scenario.

These warming levels are further compared to the five scenarios in this report by assessing the probability that the given GMSL value in 2100 will be exceeded for a particular warming level (Table 2.4). At all warming levels, there is at least a 92% chance of *exceeding* the Low scenario in 2100. The probability for exceeding the Intermediate-Low (0.5 m) scenario drops for all warming levels when compared to the probability for exceeding the Low scenario. For the Intermediate, Intermediate-High, and High scenarios, the probability drops off at each warming level. Consistent with the framing of the five scenarios in this report, greater warming and higher emissions are generally needed to arrive at the Intermediate through High scenarios in 2100.

Table 2.4: IPCC warming level–based global mean sea level projections. Global mean surface air temperature anomalies are projected for years 2081–2100 relative to the 1850–1900 climatology. Sea level anomalies are relative to a 2005 baseline (adapted from Fox-Kemper et al., 2021). The probabilities are *imprecise probabilities*, representing a consensus among all projection methods applied. For imprecise probabilities >50%, all methods agree that the probability of the outcome stated is at least that value; for imprecise probabilities <50%, all methods agree that the probability of the outcome stated is *less than or equal to* the value stated.

Global Mean Surface Air Temperature 2081–2100	1.5°C	2.0°C	3.0°C	4.0°C	5.0°C	Unknown Likelihood, High Impact – Low Emissions	Unknown Likelihood, High Impact – Very High Emissions
Closest Emissions Scenario–Based GMSL Projection	Low (SSP1-2.6)	Low (SSP1-2.6) to Intermediate (SSP2-4.5)	Intermediate (SSP2-4.5) to High (SSP3-7.0)	High (SSP3-7.0)	Very High (SSP5-8.5)	Low (SSP1-2.6), *Low Confidence* processes	Very High (SSP5-8.5), *Low Confidence* processes
Total (2050)	0.18 (0.16–0.24)	0.20 (0.17–0.26)	0.21 (0.18–0.27)	0.22 (0.19–0.28)	0.25 (0.22–0.31)	0.20 (0.16–0.31)	0.24 (0.20–0.40)
Total (2100)	0.44 (0.34–0.59)	0.51 (0.40–0.69)	0.61 (0.50–0.81)	0.70 (0.58–0.92)	0.81 (0.69–1.05)	0.45 (0.32–0.79)	0.88 (0.63–1.60)
Bounding Median Scenarios in 2100	Low to Intermediate-Low	Intermediate-Low to Intermediate	Intermediate-Low to Intermediate	Intermediate-Low to Intermediate	Intermediate-Low to Intermediate	Low to Intermediate-Low	Intermediate-Low to Intermediate
Probability > Low (0.3 m) in 2100	92%	98%	>99%	>99%	>99%	89%	>99%
Probability > Int.-Low (0.5 m) in 2100	37%	50%	82%	97%	>99%	49%	96%
Probability > Int. (1.0 m) in 2100	<1%	2%	5%	10%	23%	7%	49%
Probability > Int.-High (1.5 m) in 2100	<1%	<1%	<1%	1%	2%	1%	20%
Probability > High (2.0 m) in 2100	<1%	<1%	<1%	<1%	< %	<1%	8%

The median regional scenario values in 2100 and 2150 for the eight coastal regions discussed in Section 2.3 are provided in Table 2.5. The values in 2100 for each region differ from the GMSL value used to define a given scenario due to the combination of regionally relevant factors that are discussed in Section 2.1. Similar to the near term, the highest values across all scenarios are found in the Western Gulf region, followed by the Eastern Gulf. These high values are heavily driven by the high rates of subsidence in the region. For all but two regions (Southwest and Northwest), the projected values exceed the GMSL values associated with a particular scenario. The values for each scenario in the Southwest region correspond closely to the GMSL values, which is consistent with the agreement seen between the observation-based extrapolations in 2050 for the global and regional case discussed in Section 2.3. To further understand the regional variability for a given scenario, Figure 2.5 shows the regional departure from the GMSL value for each scenario in 2100. In other words, the provided maps display the amount that needs to be added to the global value to get the associated regional value for a given scenario. The regional pattern is similar in each case. The Eastern Gulf and Western Gulf regions are consistently much higher than the global value, and the southern coast of Alaska is much lower across all scenarios. In the highest scenarios, the Northeast, Southeast, Northwest, and Southwest regions are near the global values, although there is a larger east–west separation in the lower scenarios. In these lower scenarios, the higher projections for the Northeast, when compared to the Southwest, are a result of both VLM and ocean circulation changes along the U.S. East Coast. In the higher scenarios, the contributions from the ice sheets dominate and lead to less separation between the U.S. East and West Coasts.

Table 2.5: Scenarios of relative sea level, in meters, for eight coastal regions of the United States in 2100 and 2150 relative to a baseline of 2000. Median values are shown.

Region	Low	Intermediate-Low	Intermediate	Intermediate-High	High
Northeast					
2100	0.6	0.8	1.3	1.6	2.1
2150	0.9	1.3	2.3	2.7	3.7
Southeast					
2100	0.5	0.7	1.1	1.6	2.1
2150	0.7	1.1	2.1	2.7	3.7
Eastern Gulf					
2100	0.6	0.8	1.2	1.7	2.2
2150	0.8	1.2	2.2	2.8	3.9
Western Gulf					
2100	0.9	1.1	1.6	2.1	2.6
2150	1.3	1.7	2.8	3.4	4.5
Southwest					
2100	0.3	0.5	1.0	1.5	2.0
2150	0.4	0.8	1.9	2.6	3.7
Northwest					
2100	0.2	0.4	0.8	1.3	1.8
2150	0.3	0.7	1.6	2.3	3.3
Pacific Islands					
2100	0.4	0.6	1.1	1.7	2.3
2150	0.6	1.0	2.2	2.9	4.2
Caribbean					
2100	0.4	0.6	1.0	1.5	2.1
2150	0.5	0.9	2.0	2.6	3.7

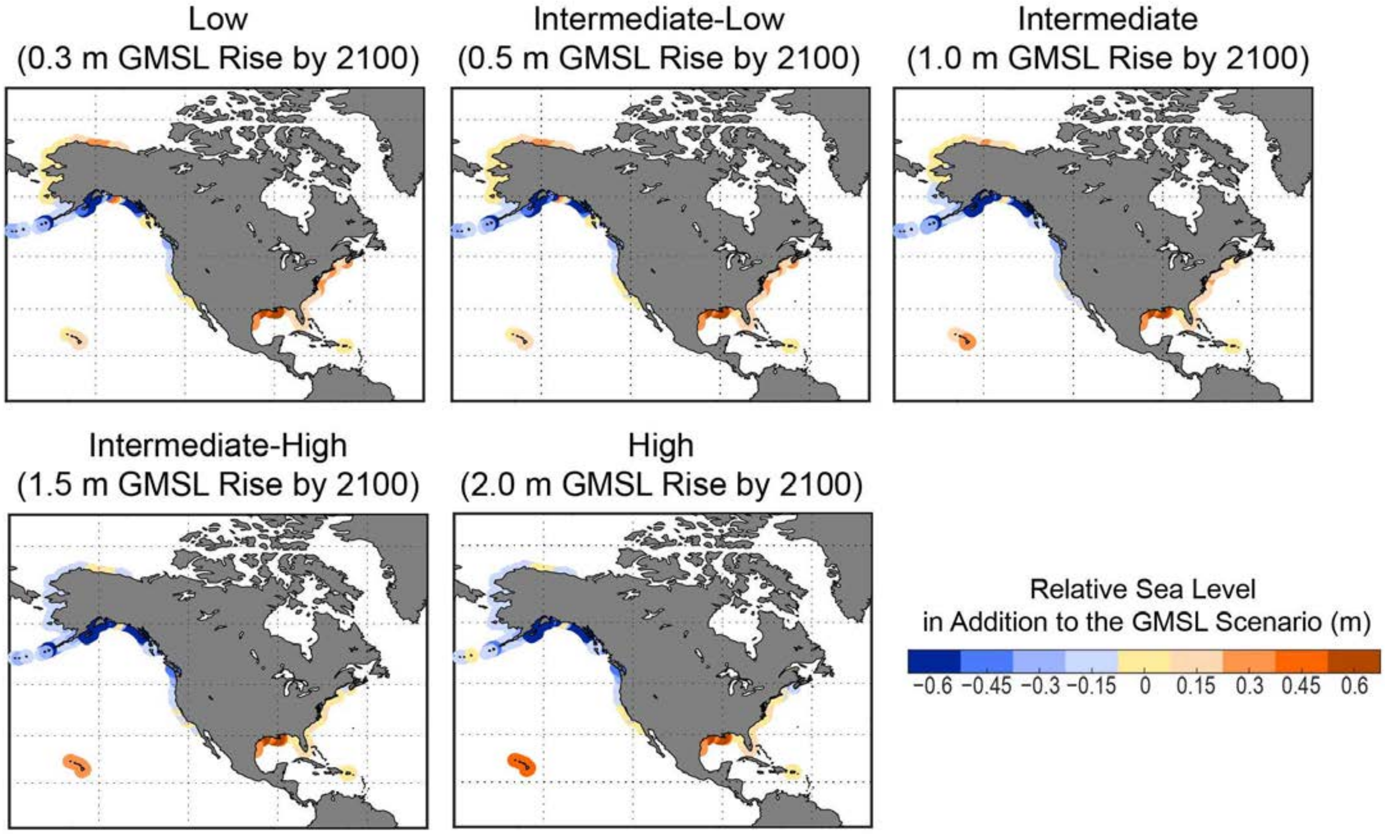


Figure 2.5: Regional deviations of relative sea level from the global mean sea level (GMSL; in meters) value for each scenario in 2100. To obtain the regional projection in 2100 for each scenario, the mapped values must be added to the GMSL value for the associated scenario.

2.5. Scenario Divergence and Tracking

In this report, for the first time, a specific focus is given to the near-term time period (2020–2050). During this window, observations can provide useful information on the trajectory of sea level rise on global and regional scales and serve as a comparison to the model-based GMSL scenarios. Prior to 2050, there is relatively small process uncertainty and little sensitivity to different emissions trajectories, and there is reduced spread between the scenarios in this report compared to Sweet et al. (2017). Connected to this reduced spread, the likely ranges of the revised GMSL scenarios presented here remain overlapping after 2050, whereas the Sweet et al. (2017) scenarios do not overlap after about 2040. In other words, in this report, the process uncertainty continues to exceed the GMSL scenario divergence past the near-term time period. Until the divergence exceeds the range for a given scenario, it will not be possible to determine when higher-end GMSL scenarios will unambiguously emerge from the potential range of the lower-end GMSL scenarios for decades to come. In this report, the time periods (or "gates") when the scenarios become separable are estimated. Different considerations for determining these gates must be made before and after the near-term time period, when the observations are most useful. It should be noted that the gates presented here are based solely on the GMSL differences between scenarios. Regionally, the timing of these gates may be different due to uncertainty in the contributing regional processes. Additionally, other lines of evidence including monitoring of individual processes or emissions trajectories could allow for distinguishing between the scenarios earlier than the gates provided here.

In Figure 2.6, the time pathways of the five GMSL scenarios from 2020 to 2100 are shown, and the gates at which the likely ranges diverge from a particular trajectory or scenario are determined. In Figure 2.6a, the divergence relative to the observation-based GMSL extrapolation is assessed. Note: the GMSL observation-based extrapolation is extended only to 2100 here for the purposes of this divergence assessment. For the Low and High scenarios, the likely ranges separate prior to 2060, with the Intermediate-High scenario separating after 2060. On the other hand, the Intermediate-Low and Intermediate scenarios do not diverge from the extrapolated observation-based trajectory until after 2080. Consistent with the discussion in Section 2.3, if the processes driving sea level rise are assumed to remain similar for the next three decades, the Intermediate-Low and Intermediate scenarios provide useful bounds on GMSL rise for the near-term time period.

In the decades beyond 2050, however, the more uncertain processes described in Section 2.4 could become a factor and the observation-based trajectory becomes less informative. Instead of assessing the divergence relative to this trajectory, the separation gates relative to the Intermediate scenario are shown in Figure 2.6b. In this case, the Intermediate-High and High scenarios will not diverge from the Intermediate scenario until after 2070 and 2060, respectively. Only the Low scenario diverges from the Intermediate scenario prior to 2050. Although not depicted in Figure 2.6, the higher scenarios also start to overlap again after 2100; for example, GMSL rise consistent with the Intermediate scenario in 2100 (1.0 m) does not rule out GMSL rise consistent with the Intermediate-High scenario by 2150. In tying the two different gate assessments together, even though the Intermediate scenario tracks near the current observation-based trajectory, it will not be possible to statistically distinguish between the Intermediate scenario and the two higher scenarios for decades to come. This also provides important context and caution if attempting to use the observations directly to infer future sea level rise beyond the near-term time period.

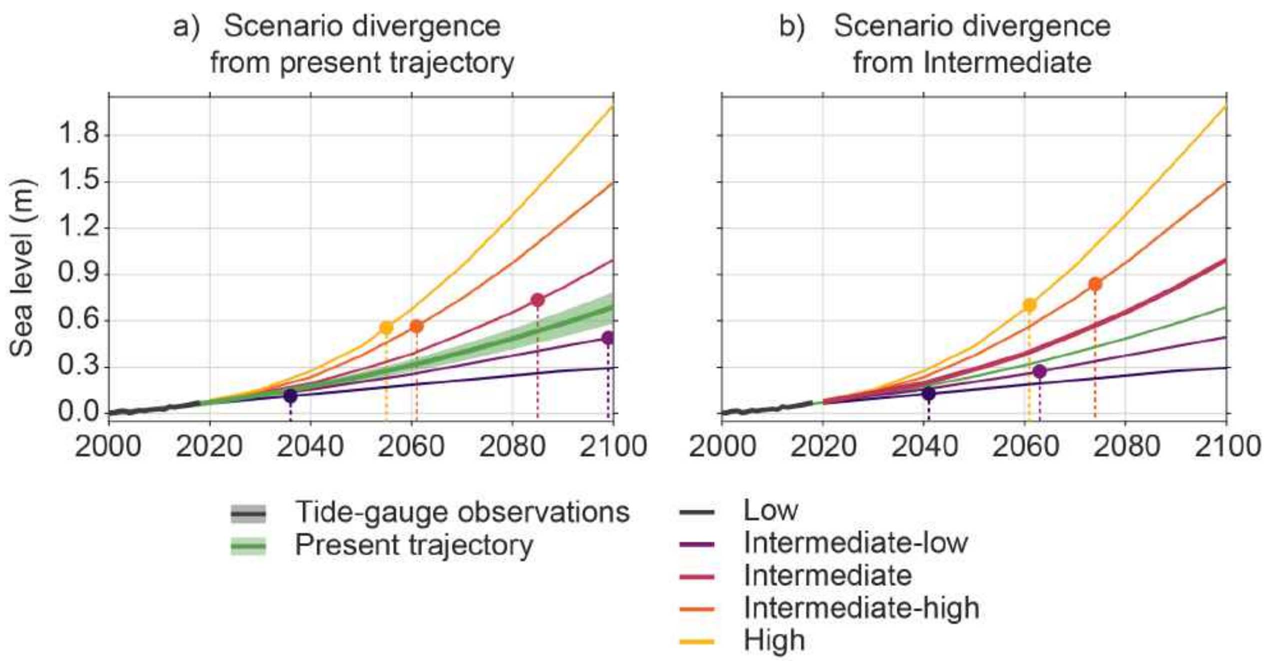


Figure 2.6: Divergence of global mean sea level (GMSL) trajectory and scenarios. The time series shows the observation-based GMSL trajectory and the five GMSL scenarios from 2000 to 2100. The dots denote where each scenario significantly (2 sigma) deviates from the a) observation-based trajectory and from the b) Intermediate scenario.

To explore this further, the proportions of the IPCC AR6 sea level projections contributing to each GMSL rise scenario are shown in Figure 2.7, with contributing emissions pathways specified. As an example interpretation of this figure, the Low scenario generally requires a low emissions pathway, while the Intermediate-Low scenario arises from low, intermediate, and high emissions pathways. Pathways consistent with the Intermediate scenario include low emissions trajectories but are mostly related to high emissions scenarios. In fact, the Intermediate, Intermediate-High, and High scenarios are all heavily driven by high emissions scenarios, and differences between these scenarios are associated predominantly with the possible role and contributions of the low-confidence ice-sheet processes described in section 2.4. The other processes that cause future sea level change have similar contributions across these scenarios. In other words, sterodynamic sea level change is similar for the Intermediate, Intermediate-High, and High scenarios.

These estimates provide a link between the emissions trajectories in the near term and the possible scenario for GMSL rise in the long term. When coupled with the gating assessment in Figure 2.6, these estimates hold particular relevance for assessing the pathway of sea level rise and determining which long-term scenarios are then possible or even likely. As a way of connecting the elements of the report, the time period where the GMSL scenarios begin to diverge can be put in the context of the analysis done in both the near-term and long-term sections. The likely ranges of the Low and Intermediate-Low versus Intermediate scenarios separate at about 2040 and 2065, respectively. The observation-based extrapolations of global GMSL rise have a relatively narrow range out to this time horizon and can therefore play a role in determining whether a particular low-end trajectory or scenario is more or less likely to be exceeded in the coming decades. As shown in Figure 2.7, the Low scenario depends very heavily on a low emissions pathway on any time horizon. Monitoring using observations of both sea level and emissions can be useful for evaluating the likelihood of the Low scenario, both in the near term and long term.

On the other hand, the separations of the likely ranges for the Intermediate to Intermediate-High and Intermediate to High scenarios do not occur until after 2060 and 2070, respectively. The values at the end of the 21st century and beyond for these scenarios can arise under a variety of different emissions pathways, although higher scenarios are predominantly linked to higher emissions, as expected. To state it another way, the near-term trajectories discussed in Section 2.3 do not currently inform the likelihood of a given scenario occurring in 2100 or 2150. However, the observations can provide useful monitoring as the windows of separation (gates) for a different scenario approach in the future. On these global scales, process-based monitoring of the ice sheets, for example, can play an important role, as the higher scenarios (Intermediate to High) are closely linked to the potential for ice-sheet changes. Additionally, a link between the scenarios in 2100–2150, emissions pathways, and warming levels has been established here. Ongoing and continuous monitoring of both global temperatures[9] and emissions[10] will aid in determining the possible trajectory of future GMSL rise. It should be noted that while the windows provided in Figure 2.6 would be different on the national or regional level, the scenarios for a given location are still closely linked to emissions and warming, and the monitoring discussion above is still relevant.

Finally, regardless of future emissions pathways, GMSL rise will continue past 2150. The amount of “committed” rise can be assessed based on historical comparisons, modeling, and the current process-based understanding of GMSL rise. This committed rise is the amount of total sea level rise that will likely occur for a given warming level. For higher warming levels, the ranges of committed sea level are wide, but the possible values are large in magnitude. Even for a relatively low warming level of 1.5°C, the committed sea level over the next 2000 years still ranges between about 2 m and 3 m. For 2°C, the upper range increases to 6 m (IPCC, 2021a). Although the focus of this report is on the time period between 2020 and 2150, it does reinforce the “when, not if” framing provided in Section 1.

[9] https://climate.nasa.gov/vital-signs/global-temperature/

[10] https://gml.noaa.gov/ccgg/trends/

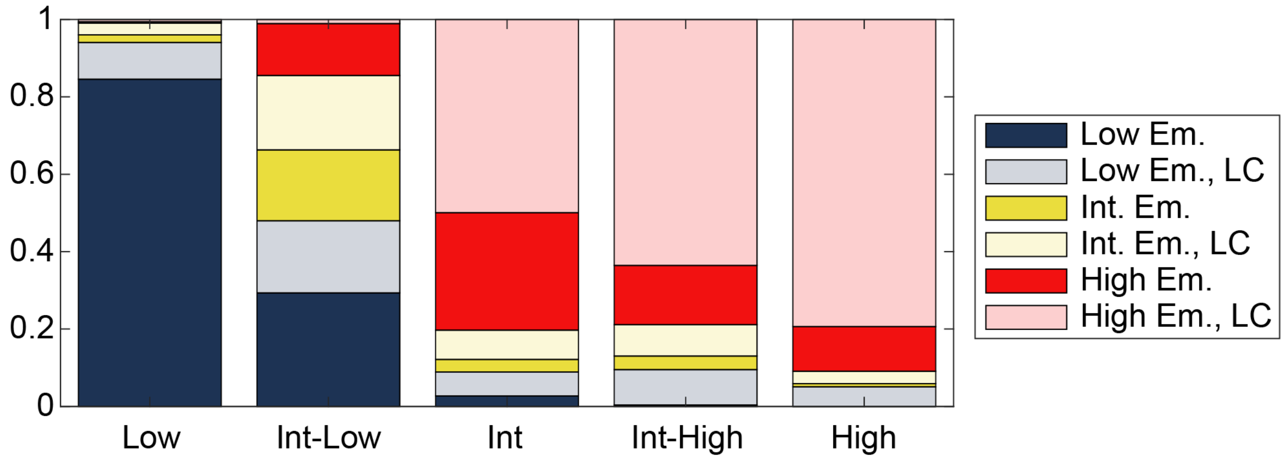


Figure 2.7: Proportions of the contributions from different IPCC AR6 sea level trajectories to each of the five global mean sea level (GMSL) rise scenarios used in this report: Low, Intermediate-Low, Intermediate, Intermediate-High, and High. The IPCC AR6 trajectories are Low Emissions; Low Emissions, LC (where LC indicates inclusion of low-confidence ice-sheet processes); Intermediate Emissions; Intermediate Emissions, LC; High Emissions; and High Emissions LC. The emissions pathways associated with the IPCC AR6 trajectories are as follows: Low Emissions = Shared Socioeconomic Pathway (SSP) 1-1.9 or SSP1-2.6; Intermediate Emissions = SSP 2-4.5; High Emissions = SSP3-7.0 or SSP5-8.5. Shifts between different GMSL rise scenarios approximately reflect the relative odds of being close to a given scenario under different emissions pathways; e.g., the Low scenario is much more plausible under a low emissions pathway, while Intermediate and higher scenarios are much more likely to be associated with high emissions pathways, as well as with low-confidence ice-sheet processes.

Section 3: Extreme Water Levels and Changing Coastal Flood Exposure

Since Sweet et al. (2017), some objectives of the Task Force have been to define and develop for the U.S. coastline 1) a set of coastal-climate flood-resilience standards and 2) a gridded set of extreme water level (EWL) probabilities that span flood frequencies with associated impacts to assess these standards. Together, these sets of information are used to describe how flood exposure within coastal floodplains are slated to change from rising sea levels (i.e., without mitigative action). Specifically for 1), we use a nationally calibrated set of the coastal water-level-impact-severity thresholds from the NOAA National Weather Service (Sweet et al., 2018), which are used in public communications. For 2), a regional frequency analysis (RFA) of tide-gauge observations is developed by adapting methods for exposure assessments within the Pacific Basin (Sweet et al., 2020b) and for the U.S. Department of Defense coastal installations worldwide[11] (Hall et al., 2016). Regional frequency analysis can provide many types of geospatial information based on limited sets of local observations, such as rainfall characteristics published by NOAA[12] (Perica et al., 2018), which are widely used in stormwater design and management within the United States. Both the RFA-based extremes and NOAA flood-threshold information are discussed below.

There are a few important notes about terminology for this section (and the report as a whole). First, "average event frequency" terminology is used throughout (except in Section 4.2 to build off of relevant papers/concepts) to describe extreme water level probabilities instead of the more traditional "return period" terminology. This is done primarily to address best practices (or avoid bad practices), which have been reviewed by the United States Corps of Engineers (USACE; USACE, 1994). Although "frequency" and "period" are related (they are reciprocals), the use of "periods" can be misconstrued; e.g., the so-called 100-year event can be easily confused or communicated (e.g., IPCC, 2021b) as an event that "occurs once per century." Such an interpretation could be assumed to imply a static and permanent water level that happens, on average, 100 years from the last event. In reality, such coastal water levels have and will continue to change with sea level rise, among other potential factors, and can occur (albeit with low probability) several times over the span of a few years. Second, although annual exceedance probability terminology is often used to describe average event frequencies (e.g., 0.1 events/year frequency expressed as the 10% annual chance event), we again stick to events/year frequency terminology, partly due to underlying method but also because events occurring more often than once a year are also being quantified and communicated (a 5 events/year frequency is poorly conveyed as a 500% annual chance event). Finally, the use of the word "occurrence" in this section means "has the probability of equaling or exceeding," as it applies to a particular water level or flood height.

3.1. Overview of Extreme Water Levels and Coastal Flooding

As sea levels continue to rise, coastal water levels—from the mean to the extreme—are growing deeper and reaching farther inland along most U.S. coastlines. Where local relative sea level (RSL) is rising, the wet–dry land delineation (i.e., mean higher high water [MHHW] tidal datum; NOAA, 2003) is encroaching landward, causing more permanent inundation and land loss (e.g., in Louisiana); affecting groundwater levels (Befus et al., 2020), stormwater systems' effectiveness (Habel et al., 2020), and water quality (McKenzie et al., 2021); and altering the intertidal zone and its ecosystems (Kirwan and Gedan, 2019). Where local RSL is falling relative to the land surface, other problems can occur, such as changes in coastal erosion processes, incision of tributaries, decreased draft for waterborne transport, decreased sedimentation in saltwater marshes, and alterations in intertidal zones and estuaries (Larsen et al., 2004; Sweeny and Becker, 2020). Especially problematic for society's coastal footprint is that the entire spectrum of flood exposure is also growing where RSL is rising, from minor high tide flooding (HTF) to more severe major flooding during storms (Sweet and Park, 2014; Fox-Kemper et al., 2021). For example, the national rate of minor HTF is accelerating and is now (circa 2020) more than double what it was in 2000 due to RSL rise (Figure 3.1), with projections suggesting

[11] https://drsl.serdp-estcp.org/

[12] https://www.weather.gov/owp/hdsc

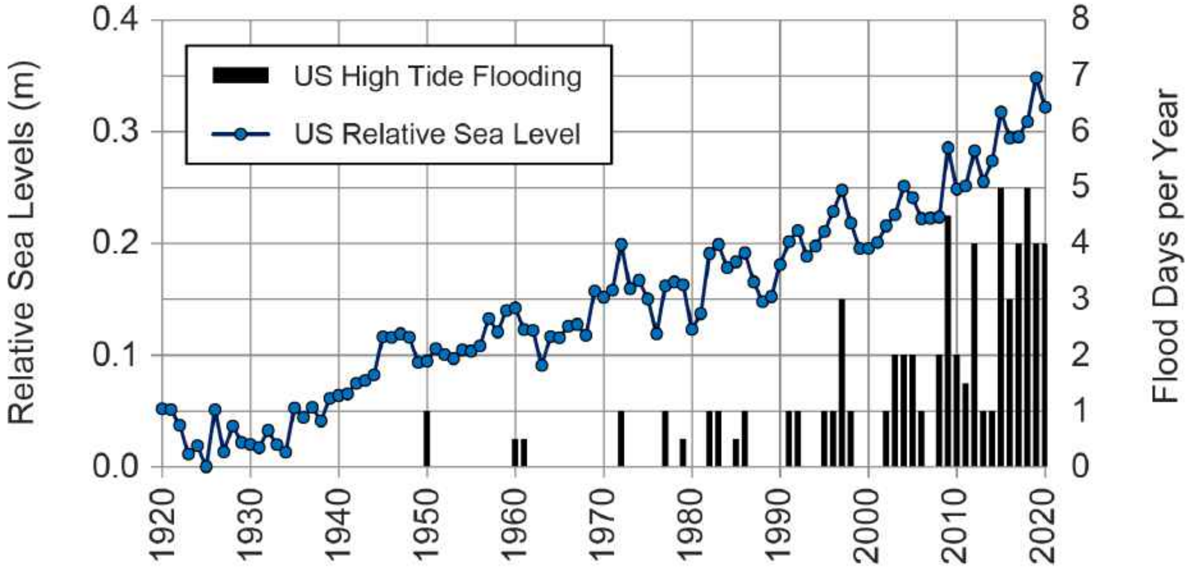


Figure 3.1: National median rate of minor high tide flooding and relative sea level, in meters, from 98 NOAA tide gauges along U.S. coastlines outside of Alaska used to monitor and track flood-frequency changes (from Sweet et al., 2021). Relative sea levels reference the lowest annual (1925) level.

a doubling of its current rate by 2030 (Sweet et al., 2018, 2021; The State of High Tide Flooding and Annual Outlook[13]; Thompson et al., 2021; Flooding Days Projection Tool[14]).

Assessments of current and future changes in minor to major HTF using RSL projections require probabilistic information about local water level variability. Specifically, they require the envelope of variability encapsulating EWLs that define the magnitude and frequency of events capable of causing a range of known or assumed impacts (Tebaldi et al., 2012; Church et al., 2013; Hall et al., 2016; USGCRP, 2017; Oppenheimer et al., 2019; Fox-Kemper et al., 2021). The basis for quantifying EWLs along U.S. coastlines originates with NOAA's tide-gauge network, which measures water level responses from multiple processes operating over a range of frequencies (Table 3.1). However, due to their general placement (e.g., in harbors), protective housings that dampen wave effects, and their multi-minute sampling rates, tide gauges typically do not measure or report values that include higher-frequency wave effects (Sweet et al., 2015; see Box 3.1). Other sources of useful tide level information for the U.S. and globally include USACE inventories (e.g., USACE MRG&P, 2017), the University of Hawaii Sea Level Center,[15] and the Global Extreme Sea Level Analysis database.[16]

Extreme water levels are often used as a proxy for impacts, such as the 0.01 events/year frequency level, better known as the "once per century" event (Oppenheimer et al., 2019), with connotations of the "flood of the century." However, such a probabilistically defined event can be both misleading about its true frequency (USACE, 1994) or might go mostly unnoticed in some locations (Sweet et al., 2020b). High tide flood heights, on the other hand, are absolute heights that are calibrated to the depth-severity impact thresholds of the NOAA National Weather Service and local emergency managers to trigger public notification of impending flood risks (NOAA, 2020). NOAA minor, moderate, and major HTF is defined as a water level reaching or exceeding about (national median values) 0.55 m, 0.85 m, and 1.20 m above current MHHW, respectively (Sweet et al., 2018). Put another way, an EWL is only a "flood" if it actually impacts the public in some manner and is not necessarily a description of a meteorological event.

[13] https://tidesandcurrents.noaa.gov/HighTideFlooding_AnnualOutlook.html

[14] https://sealevel.nasa.gov/data_tools/15

[15] https://uhslc.soest.hawaii.edu/

[16] https://www.gesla.org/

But the NOAA tide-gauge network is relatively sparse compared to the density of coastal communities, and the tide gauges have varying record lengths. From the perspective of a particular coastal community, this may result in either 1) a lack of local data (often data that are simply extrapolated from the closest NOAA tide gauge) or 2) a data record that is biased by lack of or overexposure to regionally significant rare events such as storm surges from landfalling tropical cyclones. Probabilistic assessments using atmospheric/ocean circulation models can increase spatial coverage (Vousdoukas et al., 2018), but they often perform poorly in areas with high tropical storm activity or with complex bathymetries (Muis et al., 2016). Targeted deployments of in situ sensors by communities to monitor changes in sea level, tide heights, and flood exposure (McCallum et al., 2013) can be informative but still lack the necessary longer-term regional perspective.

Table 3.1: Physical processes affecting U.S. coastal water levels and their temporal and spatial scale properties (modification of Sweet et al., 2017). Extreme water levels, which, as measured by tide gauges, generally exclude high-frequency wave effects, include processes between tsunami and ocean-basin variability and, to a lesser extent, low-frequency changes or trends associated with land ice melt/discharge, thermal expansion, and vertical land motion.

Physical Process	Spatial Scale			Temporal Scale	Potential Magnitude (yearly)
	Global	Regional	Local		
Wind Waves Effects	—	—	X	seconds to minutes	<10 m
Tsunami	—	X	X	minutes to hours	<10's of m's
Storm Surge (e.g., tropical and extra-tropical storms)	—	X	X	minutes to days	<10 m
Tides	—	X	X	hours to years	<15 m
Ocean/Atmospheric Variability (e.g., ENSO response)	—	X	X	days to years	<0.5 m
Ocean Gyre and Over-turning Variability	—	X	X	years to decades	<0.5 m
Land Ice Melt/Discharge	X	X	X	years to centuries	mm's to cm's
Thermal Expansion	X	X	X	years to centuries	mm's to cm's
Vertical Land Motion	—	X	X	minutes to centuries	mm's to m's

For the U.S., there are two primary sources of federally provided EWL probabilities. The first comes from the Federal Emergency Management Agency (FEMA, 2016b), which provides sets of regional solutions using a combination of NOAA storm-tide observations, historical high-water marks,[17] synthetic storm simulations (e.g., Nadal-Caraballo et al., 2020; ERDC Coastal Hazards System[18]), and wave effects to estimate the regulatory floodplain and its exposure to the rarest of events (e.g., 1% and 0.2% annual chance events). FEMA provides this information for national flood insurance purposes[19] but does not consider future sea levels. Another set of EWL probabilities is from NOAA's Center for Operational Oceanographic Products and Services (Zervas, 2013), which currently uses a generalized extreme value (GEV) distribution fit to annual highest water levels for tide-gauge records of >30 years).[20] The U.S. Army Corps of Engineers and their Sea Level Change Calculator[21] provide the NOAA EWL probabilities (Zervas, 2013) with several projections of future RSL to help in project planning but only for specific long-term tide-gauge locations.

A primary goal of the following subsections is to introduce a new set of EWL probabilities to support sea level rise and flood-exposure assessments and planning. The EWL set is applicable for most of the U.S. coastline and further resolves (both in physical and probability space) the EWL information currently available from

[17] https://stn.wim.usgs.gov/FEV/
[18] https://chs.erdc.dren.mil/
[19] https://www.fema.gov/flood-maps/national-flood-hazard-layer
[20] https://tidesandcurrents.noaa.gov/est/
[21] https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html

FEMA and NOAA; although again, the EWL data here, which are derived from tide-gauge data, generally do not include wave effects (see Table 3.1 and Figure 1.1). Section 3.2 briefly describes the RFA of NOAA tide-gauge data with pointers to the Appendix for a fuller description. In Section 3.3, data for all NOAA tide gauges with >10 years of record are used to compute EWL probabilities, and these results are compared to NOAA and FEMA datasets. Section 3.4 discusses methods on how local EWL probabilities can be 1) computed using other records, such as those of shorter duration (<10 years) from NOAA or other (user supplied) sources, and 2) estimated approximately every 500 m along the U.S. coastline based on local tide range information from NOAA models (e.g., VDatum[22]). Lastly, Section 3.5 assesses current and future flood exposure within the coastal floodplain using NOAA's height-severity categories of minor, moderate, and major HTF (Sweet et al., 2018), which broadly define water levels where U.S. infrastructure becomes impacted and are used in weather forecasting to trigger emergency responses (NOAA, 2020). Estimates of how flood exposure is projected to change by 2050 (assuming no additional adaptation or risk-deduction measures) are provided using the upper-bounding scenarios of the regional observation-based extrapolations along U.S. coastlines (see Table 2.2).

3.2. Regional Frequency Analysis of Tide-Gauge Data

Extreme water level probabilities and their 95% confidence intervals are provided at a 1-degree spacing along nearly the entire U.S. coastline (Figure 3.2). The EWL information is based on an RFA (Hosking and Wallis, 1997) of NOAA tide gauges within a 400-km radius of the center of each individual 1-degree grid and fit with a Generalized Pareto Distribution (GPD) of threshold exceedances (Coles, 2001). The RFA process not only better assesses EWL exceedance probabilities from a regional perspective as compared to a single-gauge assessment but also can supply information where no tide gauges exist. Furthermore, a GPD fit to exceedances above a high threshold as compared to a GEV fit to annual maxima uses more of the data record (e.g., two or more significant events within a particular year), not just those maxima within a certain (e.g., annual) time block. This approach, using RFA-based GPD fits, better resolves both the low- and high-frequency spectrum with output in this report ranging from 0.01 events/year to 10 events/year frequencies. Combining an RFA with GPD fits to obtain EWL probabilities is unique for U.S. coastlines, although there are other statistical methods such as the joint probability method (Baranes et al., 2020) and Bayesian hierarchical modeling (Calafat and Marcos, 2020), which may also prove useful in assessing rare event probabilities or providing information where no tide gauges exist.

[22] https://vdatum.noaa.gov/

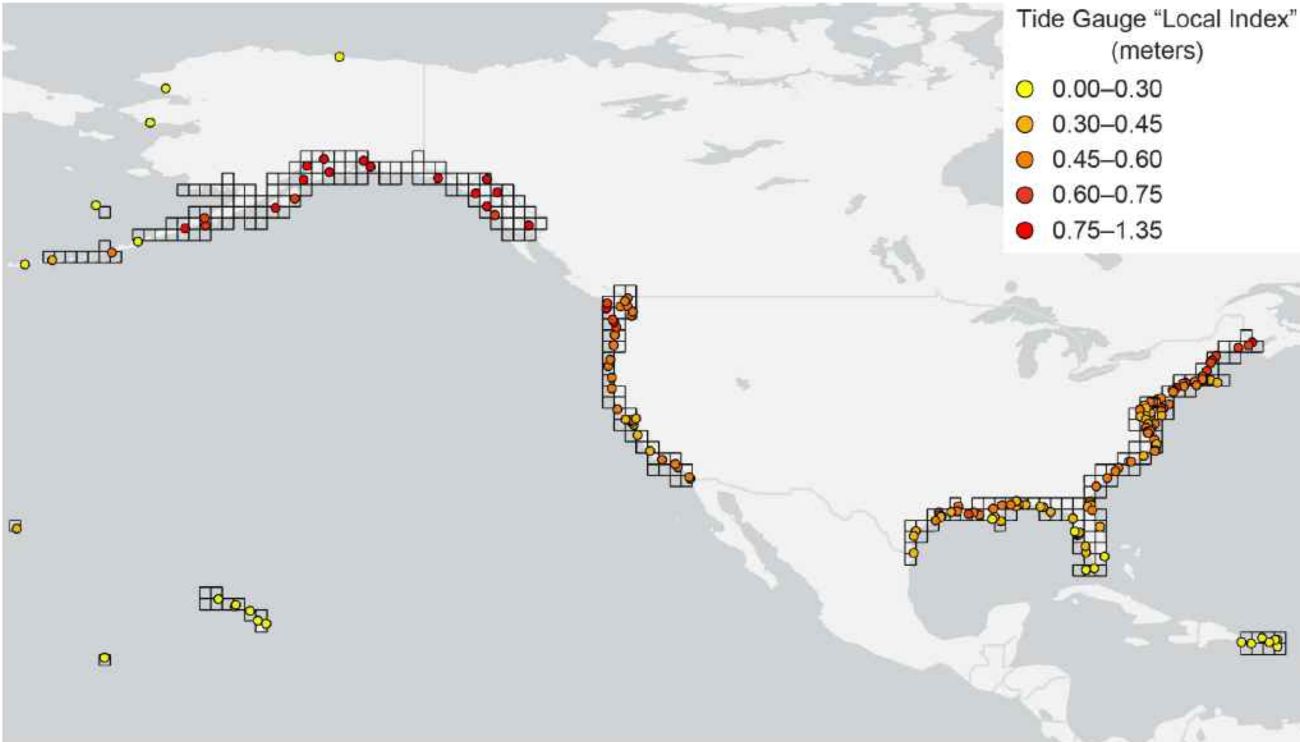


Figure 3.2: Regional Frequency Analysis 1-degree grids and local index values (u) relative to local mean higher high water tidal datum at the NOAA tide gauges used in this study.

To be useful for local decision-making, the gridded EWLs ($EWL_{gridded}$) derived by RFA need to be further localized (EWL_{local}), which is achieved via a "local index" (u) estimated at a particular tide gauge (u values are shown in Figure 3.2) or for a particular location and converted to the vertical control datum on the land surface, normally the North American Vertical Datum of 1988 (NAVD88). The following equation is used to estimate EWL_{local} probabilities (median and 95% confidence intervals):

$$EWL_{local} = EWL_{gridded} * u_{local} + u_{local} \quad (1)$$

where $EWL_{gridded}$ is the gridded EWL composed on normalized (unitless) sets of tide-gauge data, and u_{local}, referred to simply as "u," are the same value and represent the height of the 98th percentile of daily highest water levels with a 4-day filter applied and are relative to the 1983–2001 (or 5-year modified epoch; Gill et al., 2014) MHHW tidal datum. For statistical independence when quantifying the EWL probabilities, the filtering process is needed to isolate and only include the peak water level value from a particular storm or "event," rather than including multiple consecutive daily peak levels resulting from the same event (e.g., a multiday storm surge). See Section A2 for more details.

3.3. Average Event Frequencies of Extreme Water Levels

The focus of this analysis is on EWL events and their probabilities that span the frequency space associated with coastal flooding under current sea levels (Sweet et al., 2018). An example for the NOAA tide gauge at The Battery in New York City (NYC) in Figure 3.3a shows the NOAA HTF heights and probability distributions for hourly water levels and also for their daily maxima.[23] Also shown is the local index (u = 0.55 m above MHHW) computed for this tide gauge, which is used to estimate EWL_{local} from the $EWL_{gridded}$ probabilities for this location (Figure 3.3b). See Figure A2.2f for the gridded probabilities applicable for NYC. At higher frequencies, such as those associated with the height of the minor HTF level (0.56 m above MHHW), the EWL_{local} probabilities for "events" (about 4–5 events/year) are close but slightly underestimate flood frequency estimates for "days" (about 11 days/year; not shown), which are based on a multidecadal distribution

[23] https://tidesandcurrents.noaa.gov/stationhome.html?id=8518750

of daily highest water levels (shown in Figure 3.3a) used by NOAA when making projections of minor HTF (Sweet et al., 2018). This difference reflects the 4-day event filter in estimates of the EWL_{local} probabilities discussed above. A similar ratio (about 2 days per event) exists in NOAA's HTF Outlook (about 11 days/year for 2020 at NYC, which is based on an extrapolation of quadratic or linear fits to annual counts of minor HTF days (Sweet et al., 2020a). The ratio of minor HTF "events" to "days" estimated at NOAA tide gauges as a whole is further discussed later in this section. The main point is that, typically, the duration of a minor HTF "event," as in NYC and along U.S. coastlines, spans about 2 days and multiple tide cycles on average.

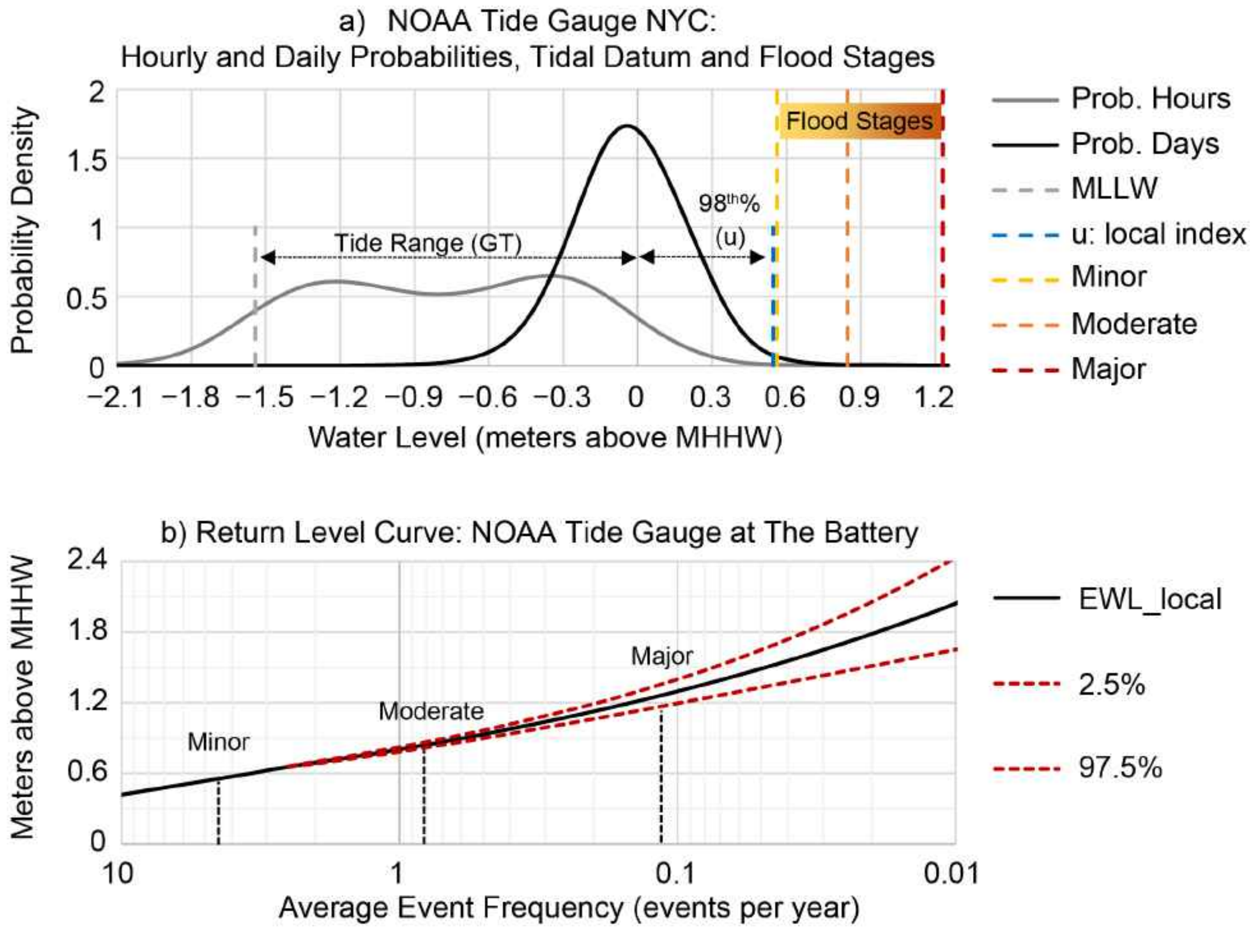


Figure 3.3: a) Empirical probability densities of hourly water levels and their daily maxima measured by the NOAA tide gauge at The Battery (New York City), as well as the tidal datums of mean lower low water (MLLW), great diurnal tide range (GT), local high tide flood (HTF) heights, and the local index (u) used to localize the RFA-gridded EWL for this location (see Figure A2.2f). All values are referenced to the mean higher high water (MHHW) tidal datum and shown in b) as a return interval curve with the 95% confidence interval (2.5% and 97.5% levels) normalized to year 2020 RSLs.

Some general patterns emerge in regional $EWLs_{local}$ with 1 event/year (Figure 3.4a) and 0.01 events/year frequencies (Figure 3.4b). Locations with higher 0.01 events/year EWL_{local} are found adjacent to wide, shallow continental coasts that are exposed to frequent tropical or extratropical storm surges, such as occur along the Eastern and Western Gulf coastal regions at 2.5 ± 1.1 m and 2.8 ± 0.8 m (median ± 1 standard deviation), respectively. In contrast, the U.S. Pacific/Hawaiian Islands and Southwest Pacific coastal regions have lower 0.01 events/year $EWLs_{local}$ due to deep, narrow continental shelves and generally calmer conditions (0.8 ± 0.1 m and 1.0 ± 0.1 m, respectively), although wave effects not inherent to the EWL probabilities are often the primary factor causing flooding, overwash, and erosion along natural landscapes in these locations (Barnard et al., 2019; see Box 3.1). In terms of the 1 event/year heights, tide ranges become influential (correlation of ~0.7 between great diurnal tide range [GT] and u across all locations), as is the case in the Northwest Pacific coastal region and the southern Alaska coasts, where the highest 1-year EWLs occur (0.8 ± 0.1 m and 1.0 ± 0.3 m, respectively) and larger tide ranges are found.

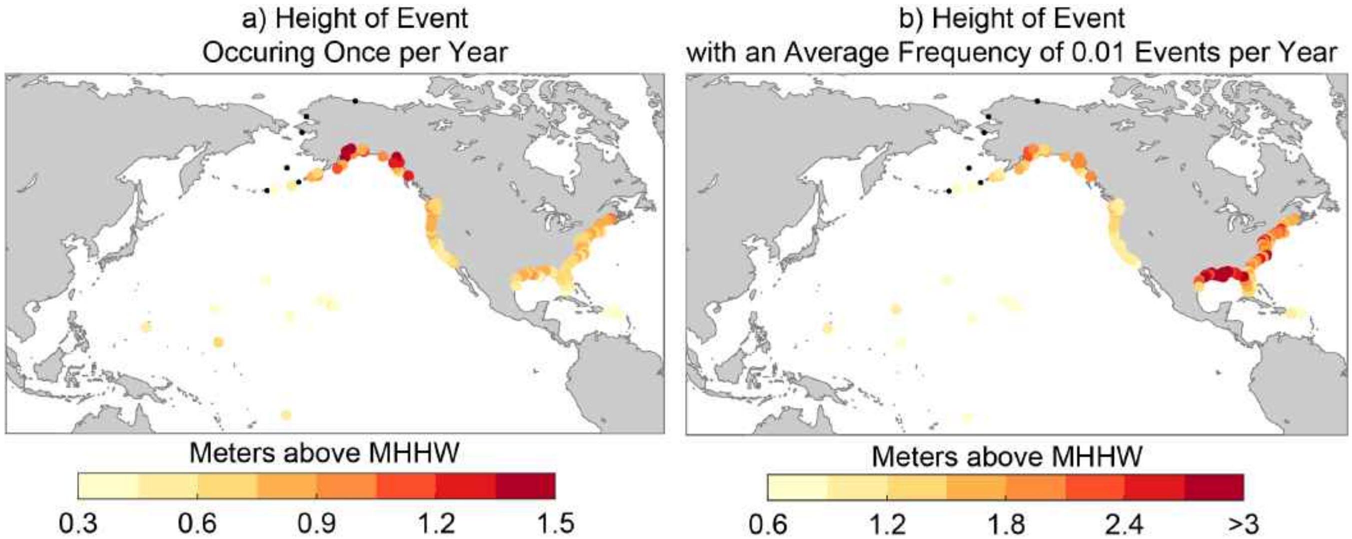


Figure 3.4: Current (circa 2020 relative sea levels) EWL_{local} that a) occur annually on average and b) have a 0.01-year average event frequency. Note: the scales in the two figures are not the same, and to be useful for decision-making, a conversion to land-based heights (e.g., NAVD88) should be made.

There are differences when comparing the RFA-based $EWLs_{local}$ from this study to current FEMA and NOAA governmental datasets. Comparisons to NOAA EWLs (Zervas, 2013) in Figure 3.5a–c show that the RFA-based 0.01, 0.1, and 0.5 events/year levels are about 6%, 9%, and 13% higher across the board based on linear regression, respectively. The bias between datasets is not unexpected, as an RFA typically results in higher EWL probabilities with narrowed confidence intervals due to the regionalization process as compared to a single-gauge analysis (Sweet et al., 2020b). Overall, there is strong correlation between datasets, although less so at the 0.01 events/year EWL_{local} (R^2 = 0.49) due in part to the large differences occurring along the Gulf coastlines of Alabama, Mississippi, and Louisiana, where the RFA-based 0.01 events/year EWL_{local} (~4 m above MHHW) values are substantially higher (>1 m) than the NOAA GEV estimates in a few locations.

The RFA-based EWL_{local} probabilities are also compared to the tide-gauge-equivalent “stillwater” component (tides, storm surge, and limited wave set-up, but not wave swash; see Figure 1.1) generated by FEMA and used within their regional Flood Insurance Studies[24] (Figure 3.5d–f). The FEMA EWLs vary in their construction by region, using a combination of singular and RFA tide-gauge analyses, storm-surge modeling, and synthetic tropical storm modeling (for the Northeast, Southeast, and Eastern and Western Gulf coastal regions) via a joint probability method–optimal sampling (JPM–OS) procedure (FEMA, 2016a, 2016b). The 0.01 and 0.1 events/year EWL_{local} are slightly lower (7% and 4%, respectively), with differences again noted along the Eastern and Western Gulf and Caribbean coastal regions. At the 0.5 events/year levels, both sets of EWLs are nearly the same based on linear regression. The goodness-of-fit (R^2) values are about the same as with the NOAA (2013) GEV results, although a little less at the 0.01 events/year levels—likely due to the inclusion of synthetic storm-surge modeling in the FEMA estimates, compared to the NOAA (2013) values, which are based on tide-gauge observations. Thus, it is concluded that the RFA-based EWL provides higher estimates than a single-gauge analysis (Zervas, 2013) but less than those of FEMA stillwater values at lower probabilities, since FEMA’s data also include storm-surge modeling, synthetic storms, and high-water marks in addition to tide-gauge data.

[24] https://www.fema.gov/glossary/flood-insurance-study-fis

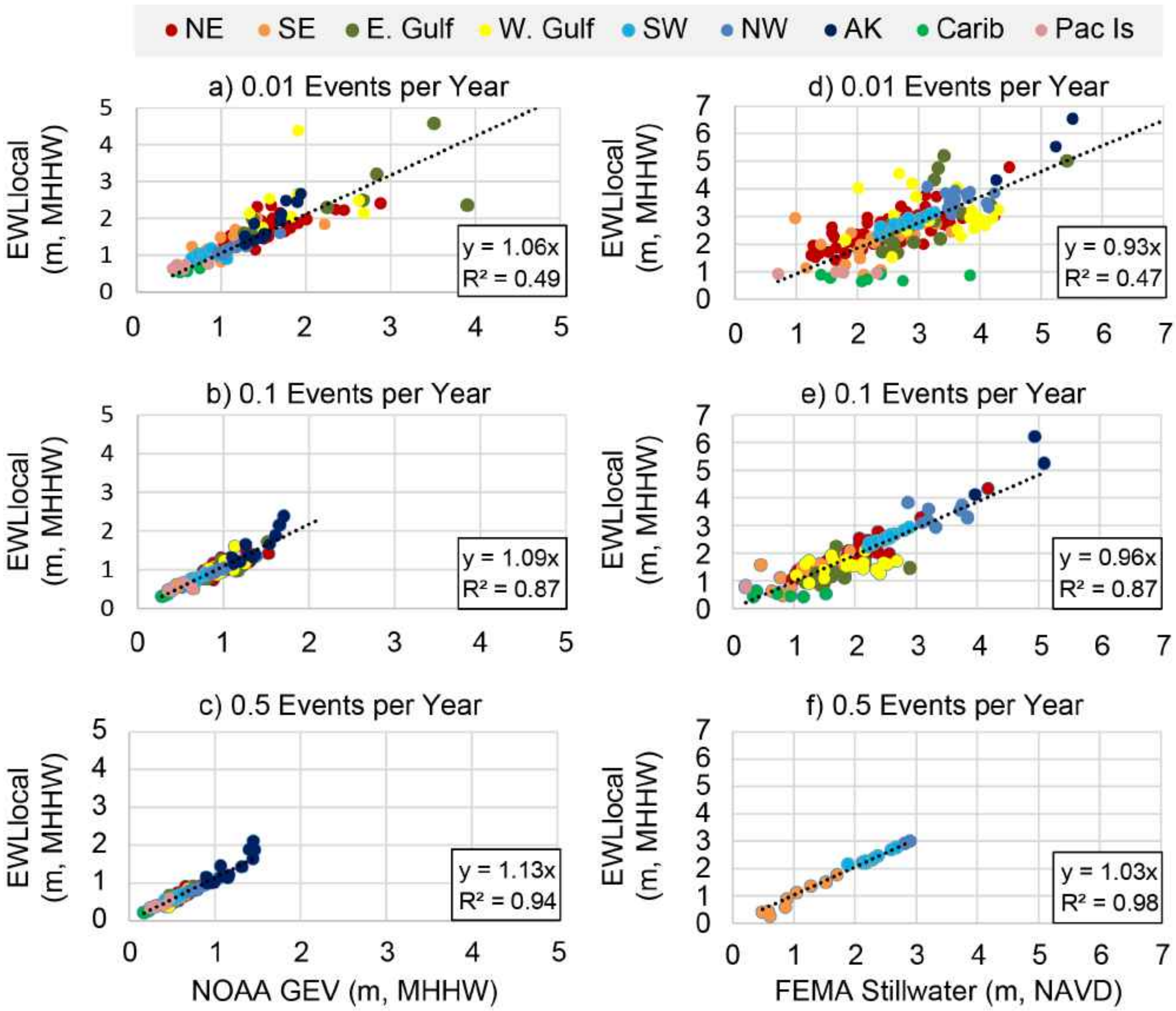


Figure 3.5: Comparison between (a–c) this study's EWL_{local} to those of NOAA (Zervas, 2013) based on a GEV fit of annual highest water levels and to (d–f) the stillwater (storm surge, tides, and wave set-up) components of FEMA used in their Flood Insurance Study at the 0.01-year, 0.1-year, and 0.5-year average event frequency levels.

3.4. Methods to Localize the Gridded Extreme Water Level Event Probabilities

There are several ways to obtain EWL_{local} from the $EWL_{gridded}$. All require a local index (u), which can be obtained from 1) a NOAA tide gauge used in this study (Figure 3.2; Table A1.3); 2) alternative sources of water level/tide-gauge data not used in this study (e.g., see Figure A2.3); or 3) tide range knowledge from measurements or models. When using short-term water level measurements (Figure A2.4), additional uncertainty, dependent on record length, is factored into the 95% confidence interval of the EWL_{local} estimate (see Equation 4 in the Appendix). This additional uncertainty relates to the fact that the local index (u) will vary from year to year akin to how RSL varies through time.[25] On a national scale (and for most regions as well; see Figure A2.4), the root mean square error (RMSE) in local index estimates is about 6–7 cm after 5 years and falls to less than 3 cm at 10 years, which is close to the standard error in tidal datum calculations themselves (see datum errors in Bodnar, 1981).

Where local water level measurements are not available, another option is to estimate a local index (u) and EWL_{local} probabilities based on an underlying relationship between local index values and tide range along U.S. coastlines. Additional uncertainty using this method will need to be factored into the results as well.

[25] https://tidesandcurrents.noaa.gov/sltrends/sltrends.html

This relationship (Figure A2.5) builds off of the findings of Sweet et al. (2020b) within the Pacific Ocean and of Merrifield et al. (2013) globally, who found a strong global correlation between the range of water level variability and average annual highest water level across the globe. Nationally, there exists a strong positive relationship (R^2 = 0.72 in Figure A2.5), although with fairly large uncertainty (RMSE of 0.11 m). But when tide range and local index values are regressed regionally, all the fits' RMSEs are less (see Figure A2.5). Across all U.S. regions, it takes about 6 years of data for the RMSE (see Figure A2.4) in local index (u) estimates to match the RMSE values based on measured tide range (see Figure A2.5). Tide range information can be obtained from NOAA Vertical Datum Transformation (VDatum).[26] Comparison of RMSEs based on multiple years of record versus tide range estimates of a local index (u) will vary by region (see Figures A2.4 and A2.5), and the lesser of the two is considered the better option in estimating an EWL_{local} for any specific location not associated with a tide-gauge location used in the study.

Here we provide an example of how to obtain EWL_{local} probabilities for a location not used in this study. The location for this example is the NOAA National Estuarine Research Reserve in Grand Bay, Mississippi (Figure 3.6a), which has a NOAA tide gauge, but the hourly record is only about 4 years long.[27]

1. The first step is to identify the specific EWL grid where the location resides, which in this case is grid number 42811 (Figure 3.6a), and obtain the $EWL_{gridded}$ probabilities.
2. Next, a local index needs to be estimated for an EWL_{local} to be computed, either by the tide-range-based method (Figure 3.6b) or using the existing short data record (Figure 3.6c) for the specific region, depending on the smaller RMSE of the two methods. The RMSE based on the tide range regression is 0.078 m (Figure 3.6b) and is less than the 0.099 m RMSE based on a 4-year water level record for this region (solving the equation shown in Figure 3.6c).
3. Using the published NOAA tide range value at this location (0.49 m) leads to an estimated local index value of 0.47 m through the regional regression (solving the equation shown in Figure 3.6b).
4. An EWL_{local} return level curve (Figure 3.6d) relative to the 1983–2001 tidal epoch is generated by substituting a local index value of 0.47 m and an RMSE of 0.078 m (with a variance of 0.078^2) into Appendix Equations 1 and 4 (see Section A2), respectively.
5. Finally, to update the curve to current conditions (circa 2020) from the midpoint of the 1983–2001 epoch (1992), 0.12 m is added to the return level curve values. The 0.12 m value represents the regional-median trend in u of 4.3 mm/year multiplied by 28 years (see Table A1.3 and Section A2.3.4 for more information). Alternatively, 0.15 m could be added instead by applying the RSL offsets from the regional observation-based extrapolations for this region (Table A1.2).

The resultant EWL_{local} probabilities estimated for Grand Bay are similar to others at nearby tide gauges that share the same 1-degree $EWL_{gridded}$ (see Figure 3.4). Less noticeable is that the 95th confidence intervals are more inflated (i.e., 0.5 m vs. 0.1 m at the 1 event/year EWL) because of the additional uncertainty from using the tide-range-based method to obtain a local index. Nationally, the spread of the 95% confidence interval at the 1 event/year EWL_{local} using a local index (u) estimated by tide range (Figure 3.6b and Figure A2.5) is 0.32 m as compared to 0.03 m when assessed across all NOAA tide gauges.

[26] https://vdatum.noaa.gov/

[27] https://tidesandcurrents.noaa.gov/stationhome.html?id=8740166

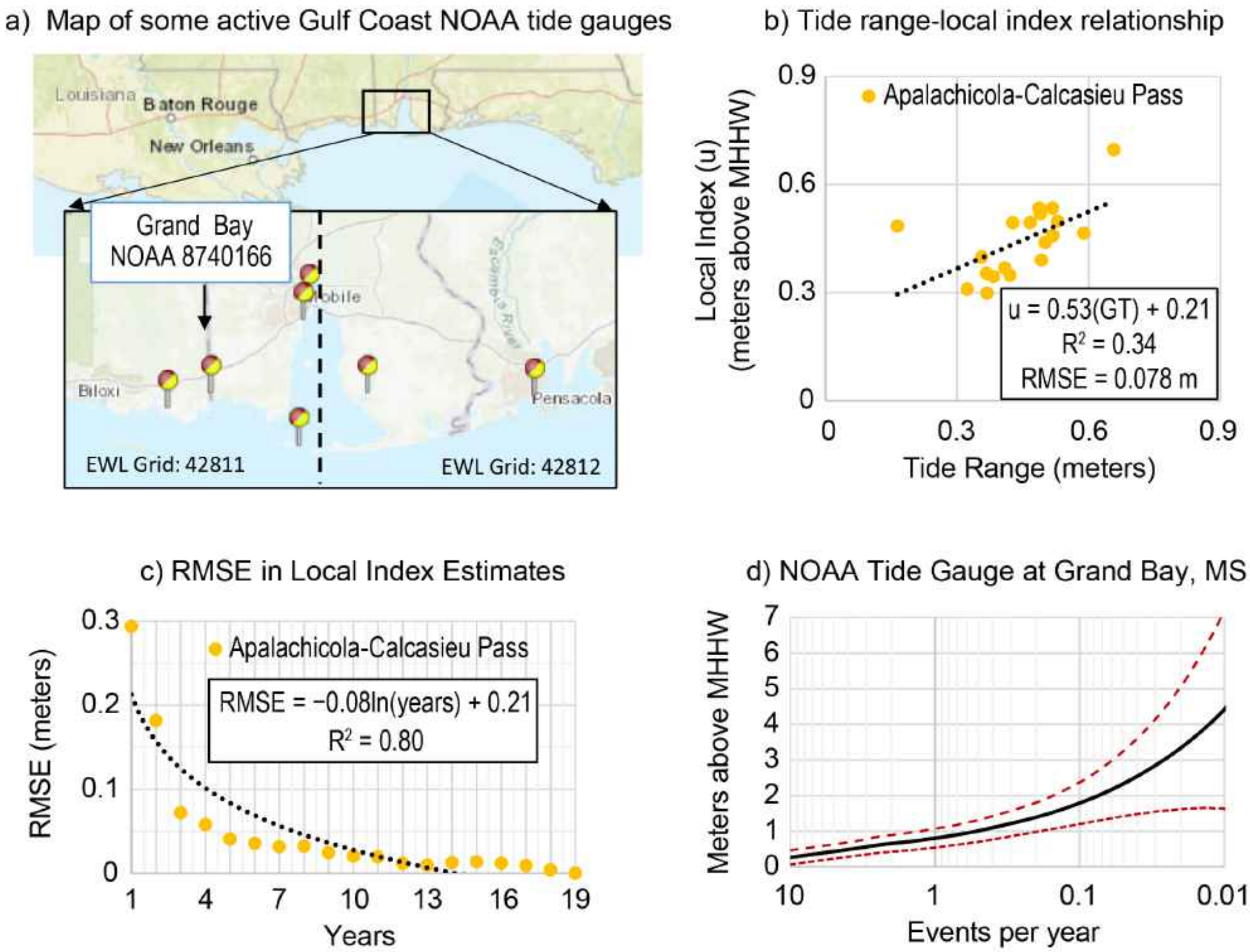


Figure 3.6: a) Map showing active NOAA tide gauges indicating Grand Bay, Mississippi, which has about 4–5 years of hourly data, b) tide range to local index (u) regression relative to the 1983–2001 tidal datum epoch with fit equation, goodness of fit (R^2), and associated root mean square error (RMSE) for the surrounding region, c) RMSE for estimates of u based on 1–19 years of consecutive data over the 2001–2019 period based on the regional tide gauges for the surrounding region; and d) a 2020 EWL_{local} return level curve for Grand Bay using a local index (u) from tide range regression. Note: to be useful for decision-making, a conversion to land-based heights (e.g., NAVD88) should be made.

3.5. The Changing Nature of Coastal Flood Exposure

To assess U.S. coastal flood exposure using the EWL_{local} probabilities, we use the nationally calibrated coastal HTF heights of NOAA (Sweet et al., 2018) and a modification of Sweet et al. (2020b) for Alaska coastlines (see Section A2.4). The NOAA HTF heights include three categories: minor, moderate, and major (national median) starting at about 0.55 m, 0.85 m, and 1.20 m, respectively (Figure A2.6), whose impacts are disruptive, typically damaging, and often destructive, respectively, under current flood defenses. NOAA provides data (e.g., Flood Frequency [MapServer][28]) and maps (Figure 3.7) in its SLR Viewer of exposure to HTF to help communities recognize potential flood exposure associated with weather–water level forecasts and for vulnerability assessments associated with sea level rise.

Currently (with EWL_{local} relative to year 2020 trend levels), minor HTF events occur (median value) about 3 times per year along U.S. coastlines and are most frequent along the Northeast, Western Gulf, and Northwest coastlines (about 4 events/year) and along the Southeast and Eastern Gulf coastlines (about 2 events/year; Figure 3.8a). A similar pattern emerges when comparing the 2020 NOAA minor HTF outlook (Sweet et al., 2020a) for the number of flood "days" at about 100 of the tide gauges (Figure 3.8b). The NOAA outlook for

[28] https://coast.noaa.gov/arcgis/rest/services/dc_slr/Flood_Frequency/MapServer

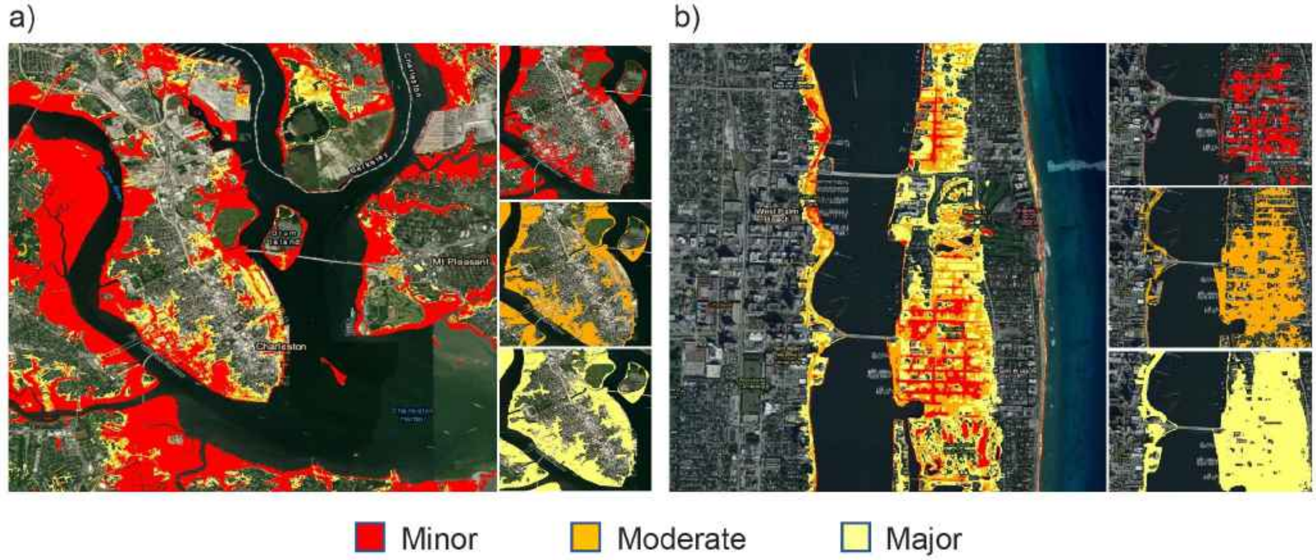


Figure 3.7: NOAA minor (red layer: land between mean higher high water [MHHW] and minor high tide flood [HTF] height above MHHW), moderate (orange layer), and major (yellow layer) HTF maps showing a regional layered map with individual layer panes to the right for a) Charleston, South Carolina, and b) West Palm Beach, Florida. MHHW for 1983–2001 is the shoreline edge. Note: to be useful for decision-making, a conversion to land-based heights (e.g., NAVD88) should be made.

minor HTF days uses extrapolations of linear and/or quadratic fits to days per year with a water level at or above the flood height. As a whole, there are about twice the number of days of minor HTF than the number of discrete events (Figure 3.8b inset), which is largely reflective of typical synoptic-scale (temporal) variability and the 4-day event filtering used in the RFA process and GPD fitting. The national (median) outlook for minor HTF in 2020 was 4–5 days, with about 8–9 days each along the Northeast and Western Gulf coastlines and 3–5 days each along the Southeast and Eastern Gulf coastlines (Sweet et al., 2020a).

Currently, moderate HTF in 2020 (Figure 3.8c) has about a 0.3 events/year frequency (median value) nationally and a similar 0.2–0.4 events/year frequency along the Southeast, Eastern Gulf, and Northwest coastlines. Moderate HTF is most likely along the Western Gulf coastlines (0.6–0.7 events/year). Major HTF (Figure 3.8d) nationally and along the Southeast coastline has about a 0.04 events/year frequency. Major HTF is most likely along the Western Gulf coastline (0.15 events/year) and along the Northeast and Eastern Gulf coastlines (0.08–0.09 events/year). For a more local perspective (see Figure 3.7), 2020 annual frequencies of minor, moderate, and major HTF in Charleston, South Carolina, and West Palm Beach, Florida, were about 2–3 events/year, 0.15–0.25 events/year, and about 0.02–0.04 events/year, respectively, based on the nearest tide gauge (see Table A1.2).

Changes in flood exposure are projected to 2050 considering no additional flood risk reduction or adaptation (e.g., via improved stormwater system functionalities) at NOAA tide gauges (Figure 3.9). The EWL_{local} probabilities are brought to 2050 levels by adding the local RSL projections initiating in year 2005 associated with the upper-bounding sea level scenario identified by the regional observation-based extrapolations (Table 2.2). Other scenarios could be used, but we opted for this particular set because it uses observational evidence—extrapolation of fits over the last 50-years (i.e., 1970–2020) to provide some level of prediction for the next 30 years. For instances where the extrapolations are the same as a particular scenario (e.g., Northeast), the adjacent (higher) scenario is used (e.g., the Intermediate is considered the upper-bounding scenario for the Northeast), which also serves to partially compensate for natural variability that is not reflected in the extrapolations.

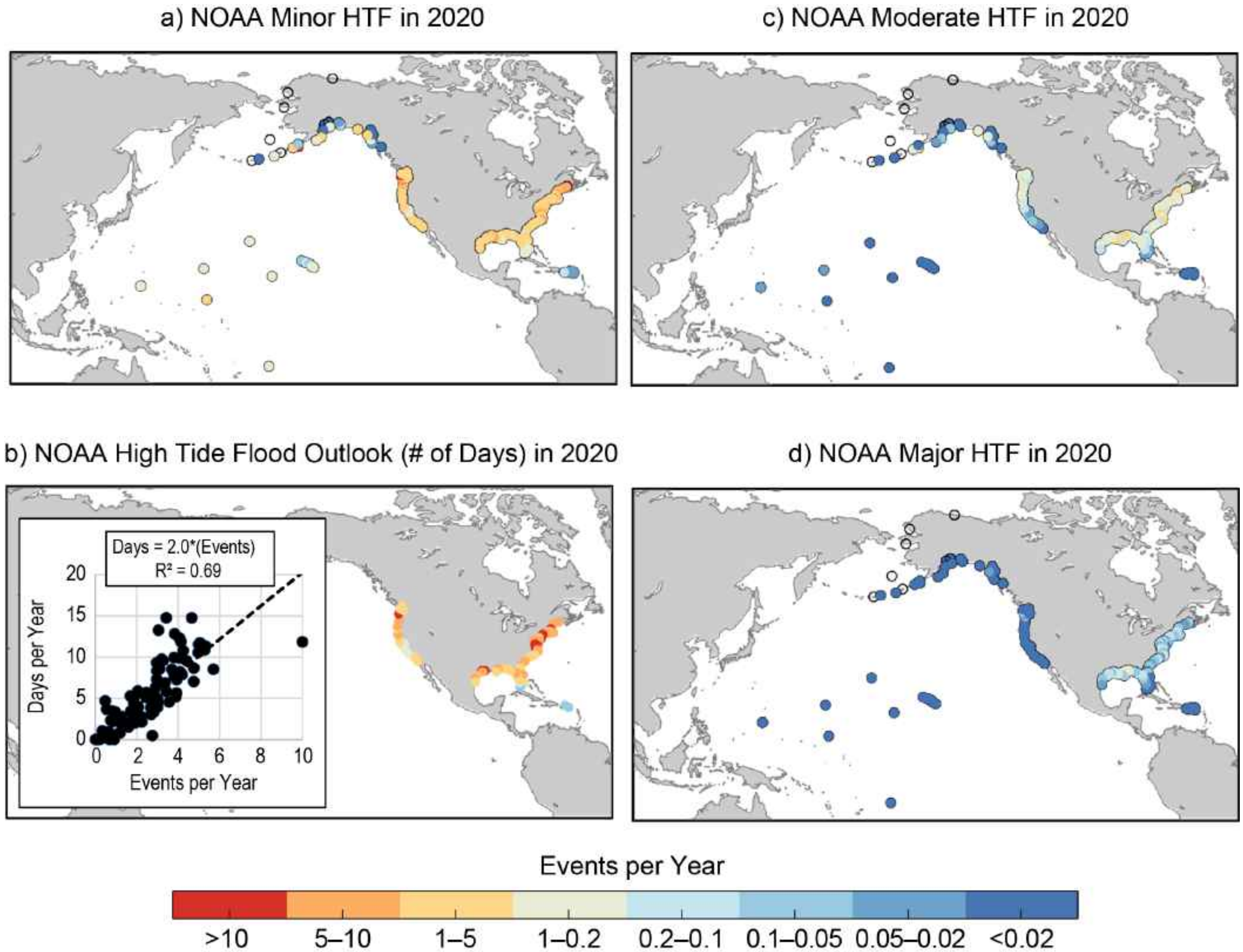


Figure 3.8: Average event frequencies in 2020 of a) minor high tide flooding (HTF); b) number of "days" (as compared to "events") of HTF estimated in NOAA's annual outlook (Sweet et al., 2021) and regression between events and days; c) average event frequencies in 2020 of moderate HTF; and d) average event frequencies in 2020 of major HTF. Flood height-severity definitions are from NOAA (Sweet et al., 2018) and, specifically for Alaska locations, from Sweet et al. (2020b).

Nationally and along all regions except the Hawaiian/Pacific Islands (about 9 events/year), the Caribbean (about 6 events/year), and Alaska (0.7 events/year) coastlines, the median event frequency in minor HTF is projected to increase to >10 events/year (Figure 3.9a). Moderate HTF (median) frequencies (Figure 3.9b) are projected by 2050 to increase nationally to about 4 events/year; >10 events/year along the Western Gulf coastline; 3–6 events/year along the Northeast, Southeast, and Eastern Gulf coastlines; about 1 event/year along the Northwest coastline; and 0.7 events/year along the Southwest coastline. Major HTF frequencies (Figure 3.9c) are projected to increase to about 0.2 events/year nationwide (median), with 1 event/year along the Western Gulf coastline, 0.5 events/year along the Northeast coastline, and 0.2–0.3 events/year along the Southeast Atlantic and Eastern Gulf coastlines. For a local perspective, the 2050 projections of annual frequencies of minor HTF in Charleston and West Palm Beach are >10 events/year, with 4–5 of those events reaching or exceeding moderate HTF and the possibility (0.1–0.2 events/year) of major HTF.

For perspective and a summary assessment by region, Table 3.2 quantifies how minor, moderate, and major HTF frequencies have changed and are projected to change considering the local RSL scenarios associated with the upper-bounding scenario of the regional observation-based extrapolations (Table 2.2) using 1990, 2020, and 2050 time slices. Nationally, minor HTF frequencies nearly tripled between 1990 and 2020, growing from about 1 to 3 events/year. They are projected to more than triple by 2050 to

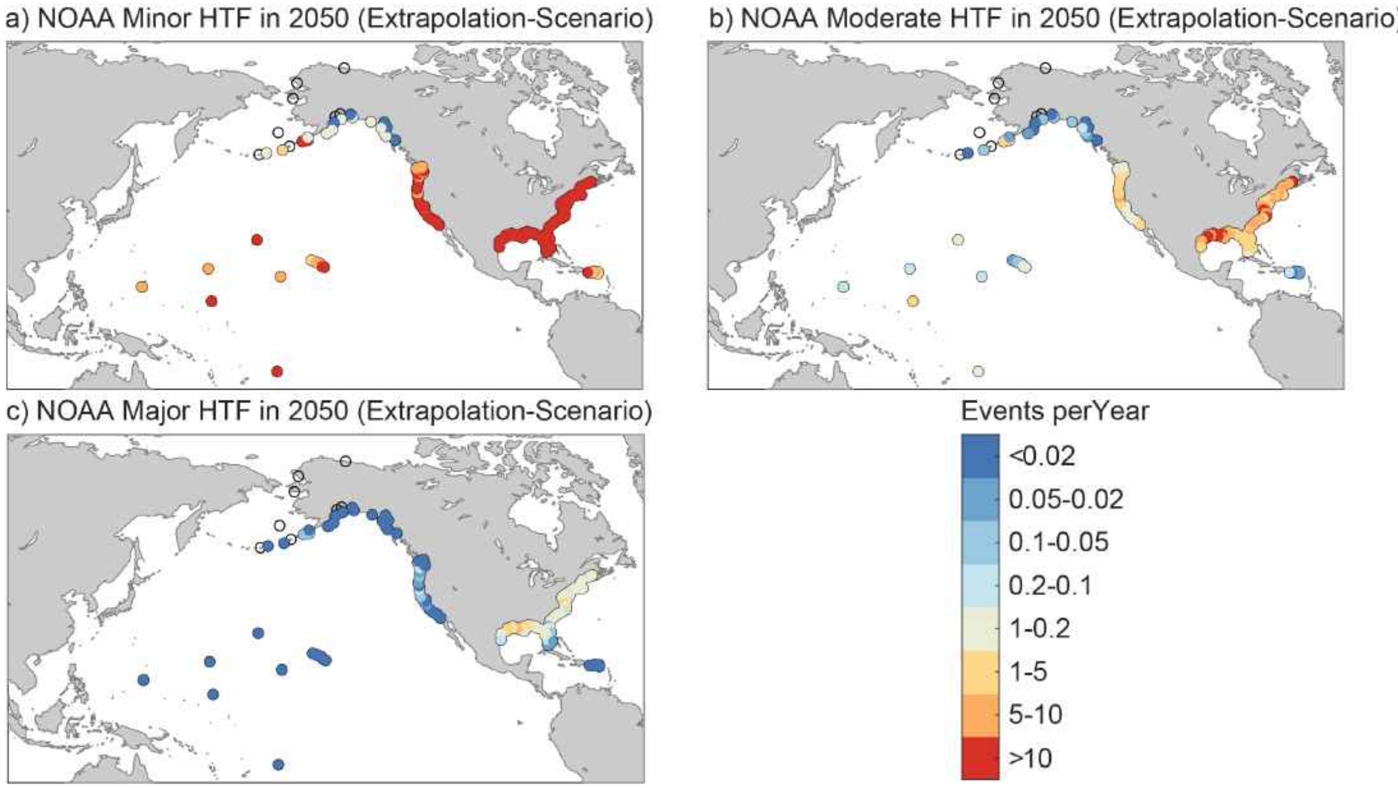


Figure 3.9: Coastal high tide flooding (HTF) frequencies projected at 2050 applying the sea level scenario that upper-bounds the regional observation-based extrapolations for NOAA a) minor, b) moderate, and c) major HTFs.

>10 events/year. Moderate HTF frequencies nationally experienced about a 50% increase (0.2 events/year growing to 0.3 events/year) from 1990 to 2020, which is slightly higher than the frequency increase in major HTF frequencies. By 2050, moderate HTF frequencies nationally are projected to increase by more than a factor of 10, with about a factor of 5 increase in major HTF frequencies. In short, assuming continuation of current trends and summarized at the national level, a flood regime shift is projected by 2050, with moderate HTF occurring a bit more frequently than minor HTF events occur today and major HTF events occurring about as frequently as moderate HTF frequencies occur today.

Table 3.2: Annual average event frequencies for NOAA-defined minor, moderate, and major HTF heights by region that were typical (median values) in 1990, under current (circa 2020) sea levels and projected to occur considering the upper-bounding scenario of the observations-based extrapolations in 2050 (see Table 2.2).

U.S. Region	1990			2020			2050		
	Minor Flood	Moderate Flood	Major Flood	Minor Flood	Moderate Flood	Major Flood	Minor Flood	Moderate Flood	Major Flood
National	1	0.2	0.03	3	0.3	0.04	>10	4	0.2
*Hawaii/Pac Is	0.06	<0.02	<0.02	0.2	<0.02	<0.02	9	0.1	<0.02
NE Atlantic	2	0.3	0.06	4	0.6	0.09	>10	6	0.4
SE Atlantic	0.9	0.1	0.03	2	0.2	0.04	>10	4	0.2
E Gulf	0.7	0.2	0.06	2	0.3	0.08	>10	3	0.3
W Gulf	1	0.3	0.1	4	0.7	0.2	>10	>10	1
SW Pacific	0.8	0.02	<0.02	1	0.04	<0.02	>10	0.7	<0.02
NW Pacific	3	0.3	<0.02	4	0.4	<0.02	>10	1	0.03
**Alaska	0.7	<0.02	<0.02	0.2	<0.02	<0.02	0.7	0.03	<0.02
US Carib	0.02	<0.02	<0.02	0.04	<0.02	<0.02	6	0.04	<0.02

*The Pacific Island locations use the same scenario assigned to the Hawaiian Islands (see Table 2.2); **Alaska locations, which as a whole could not be regionalized due to large differences in VLM, use the lower-bounding scenario per CONUS, which is the Intermediate-Low scenario (see Table 2.1). The lower-bounding scenario for Alaska is used to reflect the significant deviations below the Intermediate scenario (Figure A1.2b).

Box 3.1: Wave Contributions to Extreme Water Levels

Water level heights are a common proxy for coastal flooding (e.g., Sweet et al., 2018) and consist of a variety of components (see Figure 1.1). This report focuses primarily on projections of relative sea level (RSL) rise together with tides and storm surge contributions to extreme water levels (EWLs). However, along exposed coasts, wave-driven water levels can play a significant role in EWLs during storm events and during lesser storm conditions as exacerbated by sea level rise. Here we illustrate the relative influence of wave-driven water levels, broken down into the components of set-up and swash during extreme events across the United States, compared to tide and surge contributions.

Wave set-up is the quasi-static rise in water level at the shoreline due to breaking waves (Longuet-Higgins and Stewart, 1963). Swash is the time-varying elevation of the leading edge of wave uprush, which varies in frequency from seconds (due to incident waves) to minutes (e.g., surf beat; Guza and Thornton, 1982). Wave set-up and swash components, collectively known as wave run-up, are dependent on wave height, period, and beach slope (Stockdon et al., 2006) and are therefore controlled by local beach morphology and transient ocean conditions. To perform regional assessments of present-day or future wave-driven water level contributions, wave conditions are typically determined via global wave models forced by wind-reanalysis studies (e.g., Reguero et al., 2012) or historical/future wind fields produced by global climate models (e.g., Hemer et al., 2013).

Leveraging the global total water level assessment of Vitousek et al. (2017), which combines reanalysis models for waves, surge, and tides ("total water level" implying that all relevant components in Table 3.1 are included), we demonstrate the relative influence of waves on coastal water levels during extreme events (Figure Box 3.1). Even though the coarse resolution of this study (1° x 1° grid cells) cannot fully resolve tropical cyclones, which play a significant role in EWL events for the Southeast, Eastern and Western Gulf, Caribbean, and Hawaiian/Pacific Islands regions, this analysis demonstrates the relevance of waves in contributing to EWLs. Across the United States and its territories, using the 0.1 events/year EWL event as an example, this study estimates that wave set-up ranges from about 20–75 cm (Figure Box 3.1a) and swash from 35–125 cm (Figure Box 3.1b), together accounting for 25%–90% of EWLs (Figure Box 3.1c and based on Vistousek et al., 2017—not this study's RFA-based EWLs) for open-coast beaches (i.e., not for embayments protected from ocean waves). Wave-driven water levels (i.e., wave run-up) represent ~50% or more of the EWL contributions (again, not from this study) in areas with narrow continental shelves (reduces surge potential) and/or small tidal ranges, in particular the Hawaiian and Pacific Islands, the Caribbean, the Outer Banks (North Carolina), most of Florida, the entire U.S. West Coast, and portions of Louisiana, Texas, and Alaska. But swash oscillations only amplify coastal EWLs over short periods (i.e., seconds to minutes), whereas wave set-up represents a relatively sustained

Box 3.1 (cont.): Wave Contributions to Extreme Water Levels

contribution during storm events with about a 10% to 80% contribution to EWLs, with the highest values in the tropics (Figure Box 3.1d). As these examples indicate, when omitting wave-driven processes, coastal flood risk can be significantly underestimated for open-coast beaches, especially along U.S. island coastlines. Including wave-driven processes will be a focus of subsequent Task Force attention leading up to the Sixth National Climate Assessment (NCA6).

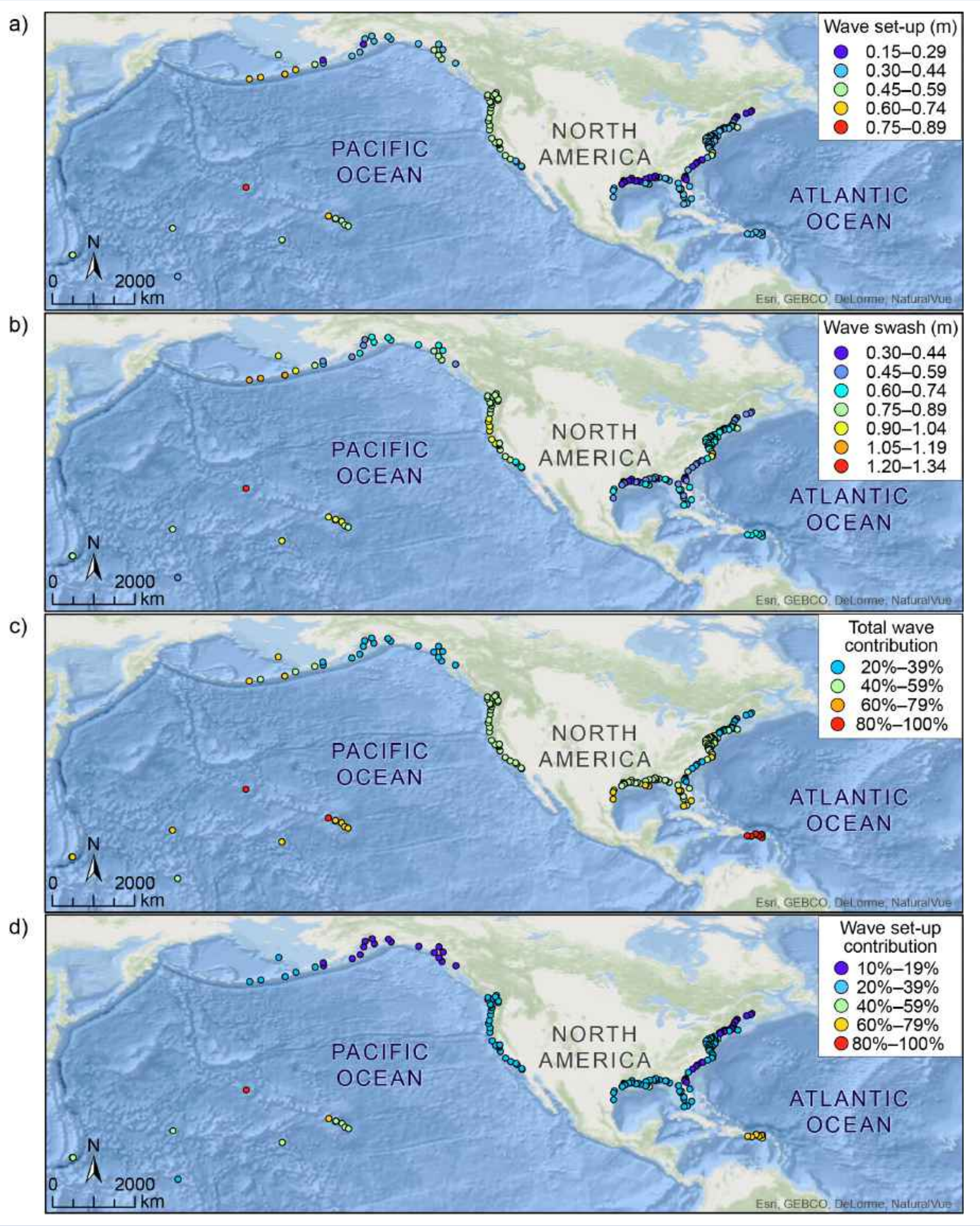


Figure Box 3.1. Water level contribution due to a) wave set-up and b) wave swash; c) percent contribution of wave-driven water levels (i.e., wave run up = wave set-up and swash) relative to all components: tide, storm surge, and waves; and d) percent contribution of wave set-up relative to the sum of tide, storm surge, and wave set-up based on model reanalysis of Vitousek et al. (2017).

Section 4: Use Cases

Below are four use cases, which use

- the (regional frequency analysis) RFA-based extreme water levels (EWLs) to map (at city scales) the annual probabilities/frequencies for the NOAA minor (disruptive), moderate (typically damaging), and major (often destructive) high tide flooding (HTF) layer classifications that are nationally calibrated to those used in weather-warning forecasting by NOAA;
- the relative sea level (RSL) projections and the RFA-based EWLs to incorporate trends (e.g., sea level rise projections) into design engineering criteria for risk management and adaptive planning;
- the RSL projections and RFA-based EWL probabilities with maps of NOAA minor, moderate, and major HTF layers to assess current and future vulnerabilities to combined storm and wastewater systems; and
- vertical land motion (VLM) rates inherent to the RSL projections are compared to rates from new satellite technologies at very high spatial resolution to showcase possibilities to monitor current rates from space and further localize the RSL projections.

The goal is to contextualize how the emerging science and this report's datasets can assist in developing products suitable for approaching (mapping, designing, or bounding) important problems in coastal risk assessment and management.

4.1. Mapping of NOAA High Tide Flood Thresholds and Flood Frequencies

High tide flooding[29] is increasingly common due to years of RSL rise. NOAA has been 1) documenting changes in minor HTF patterns since 2015, with about 100 NOAA tide gauges along the U.S. coastlines, and 2) providing a yearly coastal HTF outlook for these locations for the coming year,[30] as well as projections for the next several decades based on RSL projections from NCA4/Sweet et al., 2017. NOAA has also mapped the three HTF depth-severity (minor, moderate, and major) categories based on the relationship with tide range (Sweet et al., 2018) to show the spatial extent of associated impacts (see Figure 3.7). The minor HTF maps are provided in the NOAA SLR Viewer,[31] and all three map layers are accessible through NOAA map services.[32]

In an effort to provide better flood exposure information, NOAA is developing a product with input from partners (e.g., the Federal Emergency Management Agency [FEMA]) to assign exceedance probabilities using the RFA-based EWLs to the minor, moderate, and major HTF categories as shown for Charleston, South Carolina, and West Palm Beach, Florida (Figure 4.1). The annual event frequency shown for each NOAA HTF "zone" is assigned to the particular flood height. For example, the moderate HTF zone in Charleston is shown as the orange-brown layer in Figure 4.1a, which includes all land elevations between the minor HTF height threshold (0.570 m above mean higher high water [MHHW]; see Table A1.2) and the moderate HTF threshold (0.853 m above MHHW). This moderate HTF zone is expected to be completely (up to 0.853 m above MHHW) at risk of flooding, with an average event frequency between about 1 event/year and 0.2 events/year. A frequency range is provided to partially address the 95% confidence intervals in both the EWL statistics and the mapping data. In the case of local maps, like Charleston and West Palm Beach, the average event frequency for each NOAA HTF layer is a constant across the area shown.

These types of products can help inform the probability of higher-frequency, lower-impact events. As agencies (e.g., FEMA) start to develop products that provide more comprehensive hazard and risk information

[29] https://oceanservice.noaa.gov/facts/high-tide-flooding.html

[30] https://tidesandcurrents.noaa.gov/HighTideFlooding_AnnualOutlook.html

[31] https://coast.noaa.gov/slr/

[32] https://coast.noaa.gov/arcgis/rest/services/dc_slr/Flood_Frequency/MapServer

(e.g., graduated flood risk; see The Future of Flood Risk Data[33]), there is a need to better define and resolve the probabilities of these more frequent flood conditions. In addition, considering today's height-severity flood thresholds in the face of sea level rise (see Figure 1.3), understanding the event probabilities in this more frequent space is critical. Such information would help graduate the flood probabilities more comprehensively than FEMA's binary 1% annual chance floodplain definition and allow for a more comprehensive picture of structure-level risk.

How Can This Be Done?

The process to spatially assign probabilities again relies on a relationship to tide range (see Figure A2.5), with tide range values obtained by subtracting VDatum's MHHW and mean lower low water [MLLW] modeled tidal surfaces.[34] Using VDatum's tide range and the regional regression equations (Figure A2.5) to obtain a local index (u), the EWL return level (or rather, average event frequency) curves for the associated grid are downscaled to individual VDatum grid cells (~100 m) using Equation 1 in Section 3.2. With these downscaled curves, the HTF levels at each VDatum cell—also based on VDatum's tide range (i.e., great diurnal tide range [GT] tide datum) relationships (Sweet et al., 2018)—are intersected with the localized frequency curve (expected values) for the cell in order to determine event frequencies on a cell-by-cell basis. The average event frequencies are then associated with their respective mapped inundation footprints (3–5 m horizontal resolution). To refine the data, they were clipped to the coastal HUC (hydrologic unit code) 12 watersheds[35] that overlapped VDatum model data. This was done in order to provide a probability in watersheds that contained source VDatum data only.

The value of these data is that we can now provide not only the mapped inundation extent of each of the three HTF levels (see Figure 3.7) but also the probability, or event frequencies, for each level on high-resolution inundation data (Figure 4.1). By leveraging the relationship between the local indices (u) to GT on a regional basis, the EWL statistics can provide event frequencies for 1) most water levels or flood heights of interest and 2) most locations, even if there is not a local tide gauge nearby to assist coastal managers when planning for potential impacts to their communities. In terms of the mapped product and inherent uncertainties, it should be recognized that the VDatum model's standard error is on the order of 15 cm,[36] which is similar to that of the LIDAR elevation data.[37] The associated 95% confidence intervals from both VDatum and the LIDAR used in the mapping is then (standard error x 1.96) about 30 cm and similar to that of the EWL at the 1 event/year frequency (0.3 m median) using tide range to spatially derive EWL_{local} (Figure A2.5), although it increases to about 0.9 m at the 0.01 events/year frequency. Thus, it is recommended that these maps be used cautiously in any type of application.

Both NOAA and FEMA are currently exploring methods to further localize the $EWL_{gridded}$ probabilities, such as using NOAA short-term gauges (e.g., Section 3.4) and multidecadal hindcast modeling to develop a higher resolution set of local indices (u). FEMA is working to merge the higher-frequency portion of the EWL distributions (e.g., > 0.05 events/year) with the FEMA EWL stillwater datasets (some of which are shown in Figure 3.5). These efforts will serve, in general, to refine coastal exposure by today's standards and, specifically, minor to major HTF probabilities to better understand and communicate the Nation's coastal flood risk through products such as FEMA's National Risk Index.[38]

---

33 https://www.fema.gov/fact-sheet/future-flood-risk-data-ffrd

34 https://vdatum.noaa.gov/

35 https://www.usgs.gov/core-science-systems/ngp/national-hydrography/watershed-boundary-dataset?qt-science_support_page_related_con=4 - qt-science_support_page_related_con

36 https://vdatum.noaa.gov/docs/est_uncertainties.html

37 https://www.usgs.gov/ngp-standards-and-specifications/lidar-base-specification-online

38 https://hazards.fema.gov/nri/

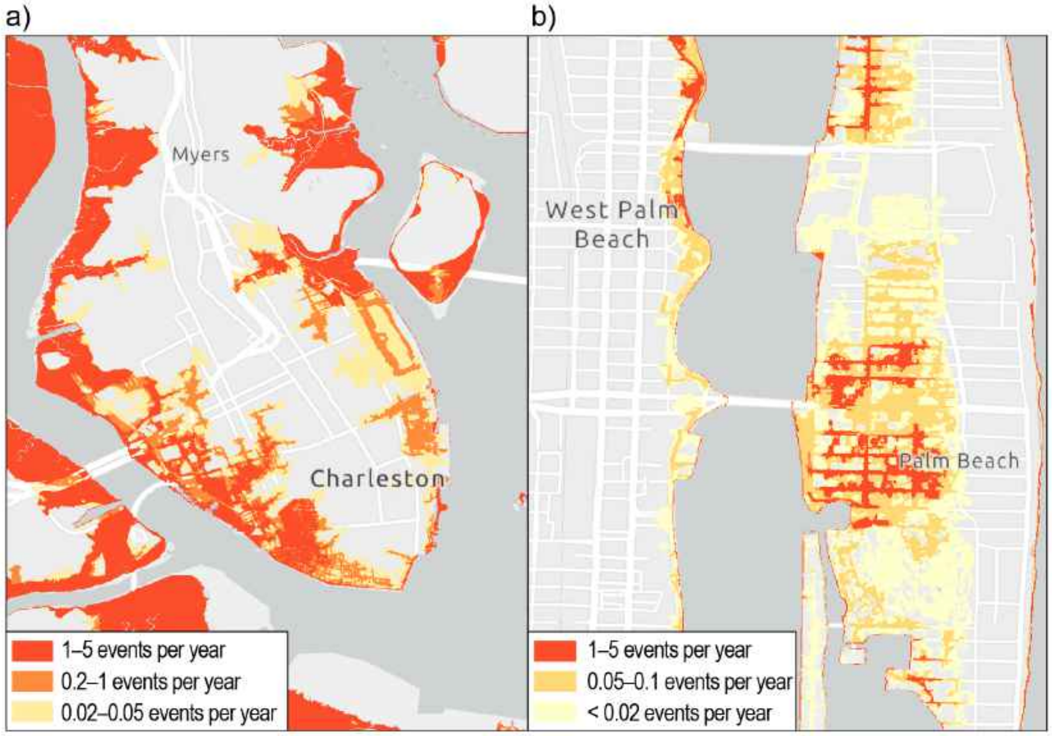


Figure 4.1: Maps of the NOAA minor, moderate, and major high tide flooding layers for a) Charleston, South Carolina, and b) West Palm Beach, Florida (as in Figure 3.7 but providing average event frequencies for each layer). Note: the shoreline on these maps is mean higher high water, but to be useful for decision-making, a conversion to land-based heights (e.g., NAVD88) should be made.

4.2. Application of Scenarios, Observation-Based Extrapolations, and Extreme Water Levels

Because future sea level rise amounts are inherently uncertain, planners and engineers who engage in addressing adaptation to future sea level rise in coastal communities often adopt a scenario approach. Based on several national and regional sea level projections (Hall et al., 2019; Parris et al., 2012; USACE, 2014; Hall et al., 2016; Sweet et al., 2017), many communities have developed their own specific scenario sets and guidelines for how to use them. In this section, the application of the regional sea level scenarios (see Section 2) that leverage the newly developed observation-based extrapolations (see Section 2.3) and the EWL probabilities produced using the RFA (see Section 3) are illustrated for representative locations around the United States.

This use case is not meant to provide standardized planning guidance for using information on sea level rise projections; rather, it is provided as an example of applying concepts of time-varying extreme value probabilities due to sea level rise, risk reduction, and adaptive planning that may be used in practice (Salas and Obeysekera, 2014; Salas et al., 2018). One of the primary tasks in coastal infrastructure projects is to determine the design elevation (also known as the return level) of a particular structure (e.g., seawall or building) for a desired level of risk or probability. Such design problems typically require the knowledge of advanced statistical methods associated with extreme values such as those illustrated in the commonly referenced textbook by Coles (2001).

The use case is illustrated for 10 tide gauges around the United States (Figure 4.2). For reference, the upper-bounding scenarios of the observation-based extrapolations for 2050 (see Table 2.2) and the RFA-based EWL distribution parameters (Section 3) are provided in Table 4.1. The EWL probability parameters are necessary to replicate this use case, and they are specifically from a Generalized Pareto Distribution (GPD) peaks-over-threshold approach (Coles 2001): a) the local Index, u; b) rate of exceedances above the local index, λ; c) scale, σ_{RFA}; and d) shape, ξ (see Section A2 for more details). In the examples below, the upper-bounding scenario is used (Figure 4.3a) with the corresponding return level curves for the selected tide-gauge locations (Figure 4.3b).

Figure 4.2: Tide gauges selected for the application of sea level scenarios and extreme water level methods.

Table 4.1: Tide-gauge locations, scenarios bounding the observation-based extrapolations, and the extreme value distribution Generalized Pareto Distribution (GPD) model parameters estimated using the regional frequency analysis (RFA).

Tide-gauge location details			Upper-bounding scenarios circa 2050 of the observation-based extrapolations	RFA-based GPD parameters			
NOAA ID	Location	Region	Upper Bound	Local Index u	λ	σ_{RFA}	ξ
1612340	Honolulu, HI	Haw.	Int	0.248	3.19	0.218	0.066
8518750	The Battery, NY	NE	Int	0.546	2.98	0.261	0.179
8638610	Sewells Point, VA	NE	Int	0.502	2.95	0.332	0.067
8723214	Virginia Key, FL	SE	Int-High	0.284	3.00	0.152	0.251
8726520	St. Petersburg, FL	E. Gulf	High	0.337	2.99	0.266	0.354
8729840	Pensacola, FL	E. Gulf	High	0.345	2.85	0.212	0.456
8771450	Galveston Pier 21, TX	W. Gulf	Int-High	0.366	2.75	0.289	0.340
9410660	Los Angeles, CA	SW	Int-High	0.472	3.21	0.150	−0.063
9414290	San Francisco, CA	SW	Int-High	0.375	3.15	0.211	0.038
9447130	Seattle, WA	NW	Int	0.541	3.07	0.233	−0.110

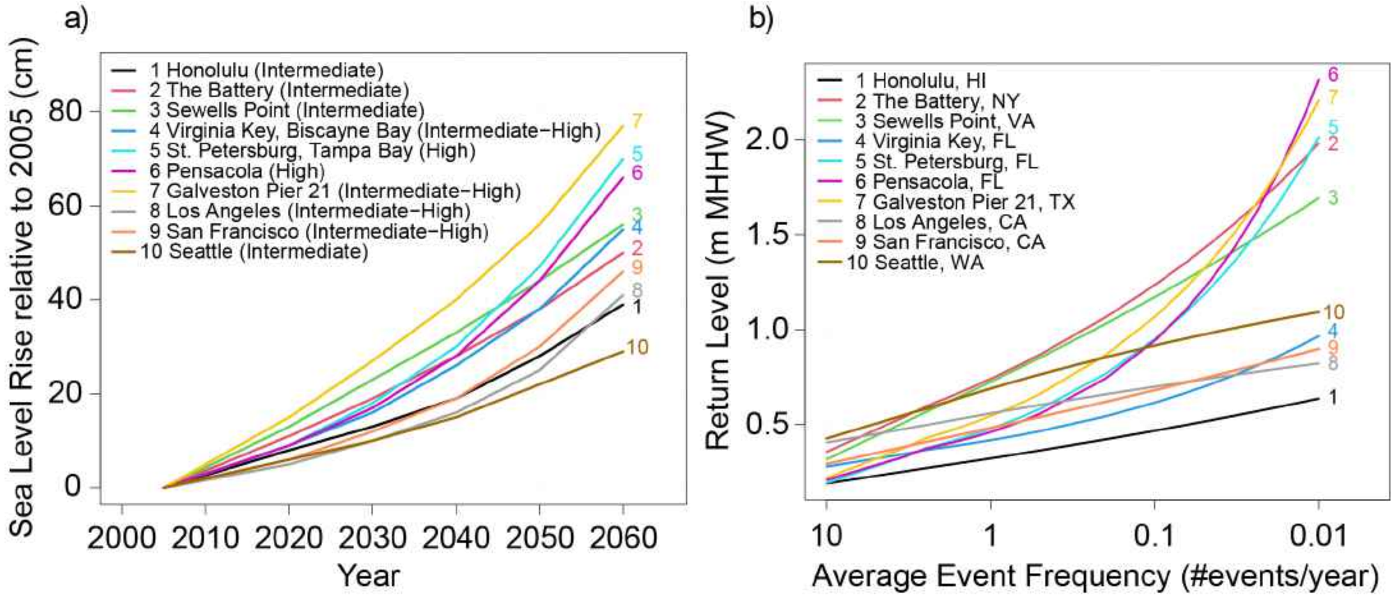


Figure 4.3: a) RSL projections for the scenarios providing the upper bound to observation-based extrapolations to 2060 for the selected tide gauges. The corresponding scenario for each tide gauge is shown in parentheses in the legend. b) RFA-based EWL (see Section 3) return level curves relative to the 1983–2001 MHHW tidal datum. Notes: (1) to be useful for decision-making, a conversion to land-based heights (e.g., geodetic datum such as NAVD88) should be made. (2) Average event frequency (x-axis label) is the reciprocal of average recurrence interval, which is also known as return period.

As shown in Figure 4.3a, 2005 is the reference year for the projection scenarios. However, the return level curves shown in Figure 4.3b are referenced to the year 2000. The return level curves are first adjusted to the year 2005 by raising the curves by an amount equivalent to the local trend in the flood index (u) from 2000 to 2005 (see Table A1.3). Alternatively, the RSL offsets (see Table A1.2) could be applied, with differences between the two insignificant to the results here.

Accounting for Time-Varying Relative Sea Level Rise

A particular scenario depicts the changes in RSL at a selected location. A common assumption is that as RSL rises, the EWLs also increase, and that must be accounted for in the changing behavior of the probability distribution of the EWLs. One approach for developing a time-varying extreme value distribution is to assume that one or more parameters (location, scale, and shape) are functions of time or some other covariate (e.g., El Niño–Southern Oscillation index; Coles, 2001; Menendez and Woodworth, 2010). When two or more parameters evolve with time (i.e., strong nonstationarity), the paradigm shifts from a "stationary" approach, typically used for planning infrastructure until recently, to one reflecting significant temporal change in the probability distribution. A common practice is to remove the trend in the extreme dataset and then to assume the distribution of the detrended extremes to be stationary. This approach is similar to the case when only the location parameter is varying with time and the other parameters are constant.

In the ensuing sections, it is assumed that only the location parameter (i.e., local index, u, in GPD) changes as a function of RSL (i.e., per the specified sea level scenario). This may be expressed as

$$F(z) = GPD(\mathrm{u}(RSL), \tilde{\sigma}, \xi)$$

where u is the RFA/GPD local index that is a function of RSL, and $\tilde{\sigma}$ and ξ are scale and shape parameters, respectively, which are assumed to be constant over time. However, this assumption does not preclude the analysis of using a higher degree of temporal variability (e.g., both u and $\tilde{\sigma}$ are functions of RSL or some other covariate). As a consequence of the above assumption, the local index u is adjusted by a magnitude δ (i.e., the regional mean sea level change from the reference year) obtained from a selected scenario.

For planning infrastructure using the scenario's RSL projections and the EWL probabilities, two approaches are illustrated: 1) recurrent flood frequency and 2) time-varying average recurrence interval (ARI; which is the reciprocal of average event frequency [AEF]) and risk.[39] While the infrastructure designs are based on a variety of factors, one or both of these approaches may be used to support that process (e.g., height of a seawall or base-flood elevation). In this use case, the term "flood" could pertain to a particular NOAA HTF level or an arbitrary probabilistic EWL level, although not necessarily to imply a meteorological (e.g., storm) event.

Designs Based on Recurrent Flood Frequency

In many U.S. coastal locations, the frequency of flooding is increasing, mostly due to rising sea levels (Sweet et al., 2021). A community may tolerate infrequent flooding initially, but at some point, when the sea level rise is significant, the flooding frequency will increase, which in turn may exceed that community's risk tolerance for flooding. Using the extreme value distributions and the sea level scenarios, it is possible to predict the time-varying change in frequency (e.g., as in Figure 3.9). In case of the GPD, the recurrent flood frequency (number of exceedances above a return level [z]) may be computed as (Buchanan et al., 2017)

$$N(z,\delta) = \lambda\left(1 + \frac{\xi(z-[u+\delta])}{\tilde{\sigma}}\right)^{\frac{-1}{\xi}} \text{ for } \xi \neq 0$$

where δ is the change in RSL (relative to the project construction year) obtained from Figure 4.3a.

In the example used here, the planning problem may be stated as follows: What should the initial return level (used for the design) be to ensure that the recurrent flood frequency is limited to a specified number of events at the end of the design life? It is now possible to lay this out graphically, as shown in Figure 4.4 for two tide gauges (Sewells Points, Virginia, and Galveston Pier 21, Texas).

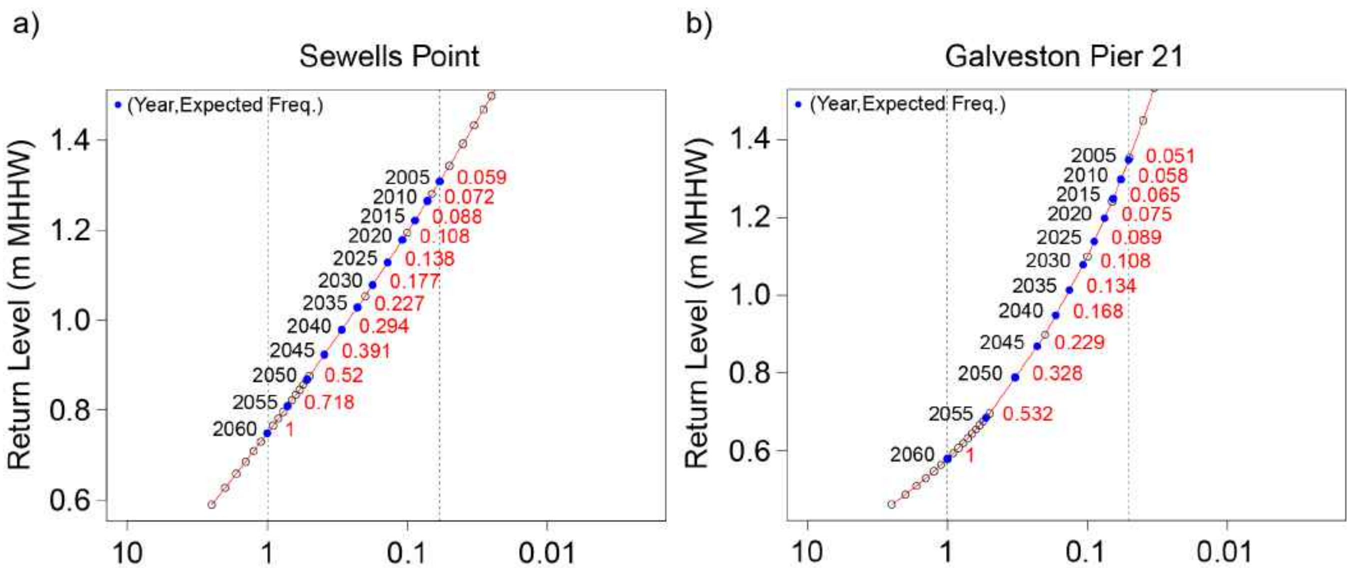


Figure 4.4: Recurrent flood frequency estimates for a) Sewells Point (Norfolk), Virginia, and b) Galveston Pier 21, Texas. For both, the relative sea level projection for the scenarios and the return level are the same as in Table 4.1. Note: to be useful for decision-making, a conversion of the return level to land-based heights (e.g., geodetic datum such as NAVD88) should be made.

In Figure 4.4, the number to the right of each point along the curve shows the recurrent flood frequency, N, corresponding to the year indicated on the left. For this example, it was assumed that by 2060, the desired value of N = 1, and the design AEF necessary for this criterion, is indicated in Figure 4.4 (AEF = 0.06 events/year for Sewells Point and AEF = 0.05 events/year for Galveston Pier 21). The corresponding design return levels are 1.31 m and 1.35 m, respectively, relative to MHHW datum. A summary of results for all 10 tide

[39] In the context of Section 4.2, risk is defined as the probability of one or more events exceeding a given height threshold over the life of a project.

gauges is shown in Table 4.2. The design average event frequency required in 2005 to meet the flood frequency criteria shows significant variability across the sites. The design return level depends on two factors: 1) the magnitude of the sea level rise from 2005 to 2060 (end of the design life); and 2) the slope (a function of the scale and shape parameters) of the return level curve (Figure 4.3b).

Table 4.2: Summary of design parameters to constrain the average event frequency, N, to 1 per year by 2060 (end-year of the design life). The 2005–2060 RSL projections are the local values associated with the scenarios providing the upper bound to the regional observation-based extrapolations shown in Table 2.2. Note: to be useful for decision-making, a conversion of the return level to land-based heights (e.g., geodetic datum such as NAVD88) should be made.

NOAA ID	Location	Relative Sea level rise (in meters from 2005 to 2060)	Return level (m above 1983–2001 MHHW) corresponding to AEF = 1 year	Return level (m above 1983–2001 MHHW) required in 2005 to ensure N = 1 by 2060	Design average event frequency (events/year) required in 2005 to achieve N = 1 by 2060
1612340	Honolulu, HI	0.39	0.33	0.72	<0.01
8518750	The Battery, NY	0.50	0.76	1.26	0.10
8638610	Sewells Point, VA	0.56	0.75	1.31	0.06
8723214	Virginia Key, FL	0.55	0.44	0.99	0.01
8726520	St. Petersburg, FL	0.70	0.49	1.19	0.05
8729840	Pensacola, FL	0.66	0.47	1.13	0.06
8771450	Galveston Pier 21, TX	0.77	0.58	1.35	0.05
9410660	Los Angeles, CA	0.41	0.57	0.98	<0.01
9414290	San Francisco, CA	0.46	0.49	0.95	<0.01
9447130	Seattle, WA	0.29	0.70	0.99	0.05

Design Based on Time-Varying Exceedance Probabilities

Average recurrence interval is used to describe EWL probabilities in the following examples to directly relate to and build off of a couple of recent, relevant focused studies on the topic. Interpretation of the results should follow guidelines of the U.S Army Corps of Engineers (USACE, 1994).

In current practice, the projects with a longer design life (> 25 years) typically use a low average event frequency (<0.1 events/year) or, equivalently, a high/long ARI (> 10 years or more). At high recurrence intervals, the peaks-over-threshold and the annual maxima recurrence intervals converge (Langbein, 1949), although not necessarily where tropical storm surges are present (Wahl et al., 2017). Revisiting the concepts of traditional ARI and risk concepts for annual maxima in time-varying frameworks has been addressed recently (e.g., Salas and Obeysekera, 2014). The application of time-varying ARI and risk concepts is illustrated by converting the GPD model to an equivalent annual maxima model, which in this case is the GEV distribution. The equivalent annual-maxima modeling approach, as used here, will also facilitate the direct application of emerging risk and recurrent interval concepts already developed for situations of time-varying extreme probabilities (Salas and Obeysekera, 2014; Salas et al., 2018; Obeysekera and Salas, 2020).

The cumulative distribution function (CDF) of the GEV model of annual maxima is expressed as

$$F(z) = exp\left\{-\left[1 + \xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}}\right\}$$

where μ, σ, ξ are the location, scale, and shape parameters of the GEV (Coles 2001).

For computing u, the local index is further adjusted to reflect the translation of the return level curve from 2000 to the reference year (i.e., 2005). The GEV scale parameter, $\sigma = \tilde{\sigma}\lambda^{\xi}$, where the at-site scale parameter $\tilde{\sigma}$, is computed as $\tilde{\sigma} = \sigma_{RFA}$*u. For this use case, the adjusted local index is computed as u_{adj} = u * s (2005–2000), where s is the trend of the local index u at the site (see Table A1.3). If desirable, other adjustment procedures may be used. Finally, the time-varying GEV model assumes that only the location parameter, μ, changes with sea level change, δ and the time varying annual extreme value distribution is given by

$$F^t(z,\delta) = exp\left\{-\left[1+\xi\left(\frac{z-(\mu+\delta)}{\sigma}\right)\right]^{-\frac{1}{\xi}}\right\}$$

The exceedance probability, p_t, which corresponds to an initial return level (z_{q0}, initial design), changes with time because of the rising RSL, δ (Figure 4.5). Consequently, the ARI is not a fixed measure but decreases with increasing sea level.

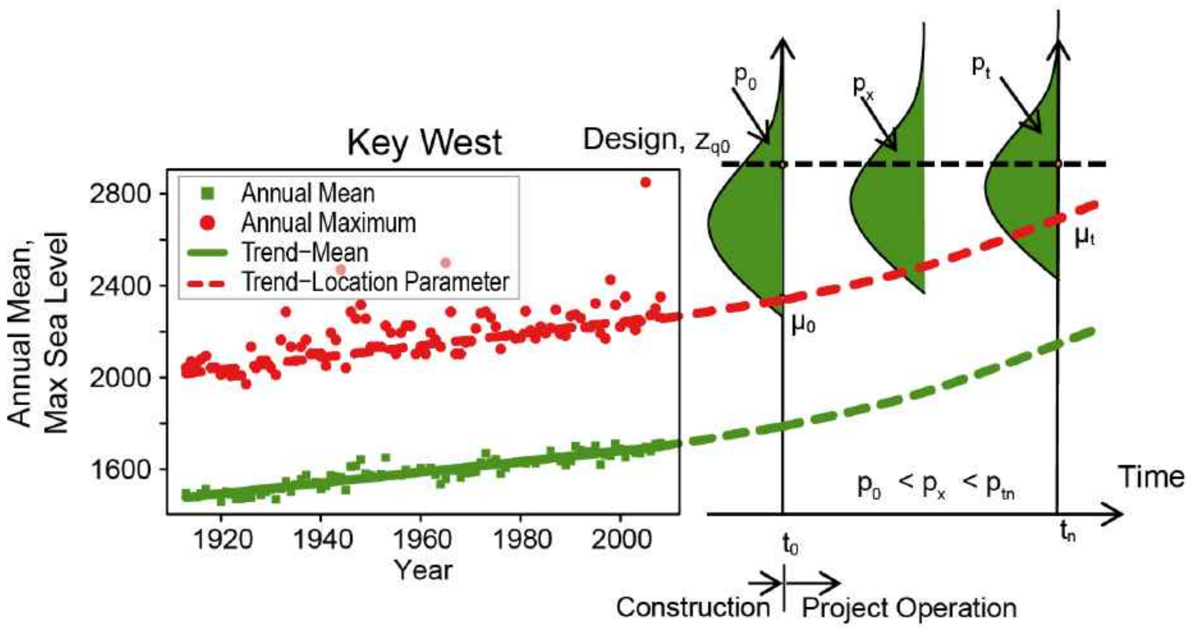


Figure 4.5: Conceptual illustration of increasing exceedance probability (hence decreasing average recurrence interval) that assumes that the location parameter is a function of the magnitude of the relative sea level rise.

The traditional concept of the ARI is the average waiting time for between two successive exceedances of the return level. Using the same definition but in a time-varying exceedance probability framework (Figure 4.5), an equivalent measure of ARI (T) may be derived as (Cooley, 2013; Salas and Obeysekera, 2014)

$$T = 1 + \sum_{x=1}^{\infty}\prod_{t=1}^{x}(1-p_t)$$

where $p_t = 1 - F^t(z, \delta)$ i is the time-varying exceedance probability. If a project is designed for a return period, $T_0[t = t_0]$, then $T < T_0$ implies that the actual recurrence interval due to rising RSL will be less.

The methods described in the preceding paragraphs are applied to the 10 tide-gauge locations shown in Figure 4.2. For illustration, it was assumed that the projection scenario for each tide gauge would continue beyond 2060. However, the methodology described above can be used with any other scenario. The derived GEV parameters for each gauge are shown in Table 4.3.

Table 4.3: The parameters of generalized extreme value computed using the peaks-over-threshold Generalized Pareto Distribution model (Coles 2001).

NOAA ID	Location	At-site scale parameter	Local index adjustment from 2000–2005 (m)	GEV location parameter	GEV scale parameter	GEV shape parameter
1612340	Honolulu, HI	0.054	0.007	0.330	0.058	0.066
8518750	The Battery, NY	0.142	0.016	0.757	0.173	0.179
8638610	Sewells Point, VA	0.167	0.023	0.748	0.179	0.067
8723214	Virginia Key, FL	0.048	0.026	0.444	0.063	0.251
8726520	St. Petersburg, FL	0.090	0.014	0.494	0.132	0.354
8729840	Pensacola, FL	0.073	0.012	0.474	0.118	0.456
8771450	Galveston Pier 21, TX	0.106	0.033	0.579	0.149	0.340
9410660	Los Angeles, CA	0.071	0.005	0.565	0.066	−0.063
9414290	San Francisco, CA	0.079	0.010	0.492	0.083	0.038
9447130	Seattle, WA	0.126	0.010	0.701	0.111	−0.110

The ARI curves, T, as a function of T_0, for all 10 tide gauge locations are shown in Figure 4.6a. This figure demonstrates that, in all cases, the actual ARI is less than the design recurrence interval. For instance, for a location near Pensacola, Florida, if a project is designed for T_0 = 100 years, the actual ARI, due to future RSL rise (Table 4.1, "Upper Bound" column), is only about 50 years. As another example, for a location near The Battery, New York City, a project may need to be designed for T_0 = 90 years if the desired ARI under its associated (Table 4.1, "Upper Bound" column) RSL rise scenario is 40 years.

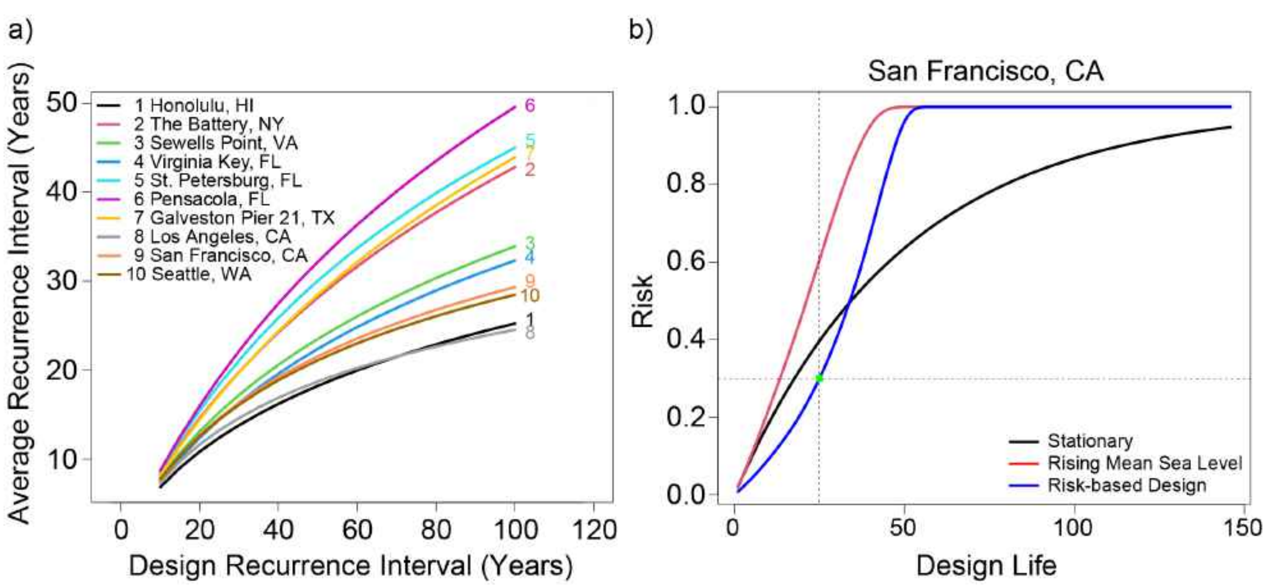


Figure 4.6: a) Average recurrence interval (due to rising RSL) curves (T versus T_0) at each tide gauge using the selected scenario's RSL projection (see Table 4.1). b) Risk curves as a function of design life: stationary (black curve), actual risk resulting from incorporating the site's RSL scenario projection (red curve), and risk curve for a specific risk (blue curve).

Risk-Based Design

Under stationary conditions, the risk (defined as the probability of one or more exceedances above the design elevation) is a function of the life of the project, n. The risk formula under stationarity is given by $R = 1 - (1 - 1/T_0)^n$. For example, there is about a (R = 0.26) 26% chance of experiencing an event with an ARI of (T_0) 100 years over the course of (n) 30 years under a non-changing (stationary statistical) environment. As the length of the design life increases, risk also increases. Under conditions of time-varying exceedance probability, p_t, the risk (R) formula is (Salas and Obeysekera, 2014)

$$R = 1 - \prod_{t=1}^{n} (1 - p_t)$$

With rising relative sea levels, p_t increases, and the risk is higher than that under stationarity. This increase in risk is illustrated for the San Francisco, California, tide gauge in Figure 4.6b when the initial design, $T_0 = 50$ years (the event level with a 50-year ARI). The black curve in Figure 4.6b shows the increasing risk as the design life becomes longer even under stationarity. For instance, if the design life, equals 25 years, this risk is about 0.4 (40%). However, when the local sea level rise scenario is incorporated, the risk over a given life of the project increases more rapidly, exceeding the corresponding risk under stationarity (see red curve in Figure 4.6b). In the above example, when n = 25 years, the risk will increase to about 60% due to the RSL scenario projection. Moreover, the RSL rise causes the risk to approach 100% (R = 1) when the design life is about 50 years or more. In the risk-based design approach, one can specify the tolerable risk and determine the initial design period (or return level).

One option is to design a project in such a way that the resulting increasing risk profile due to application of the scenario's RSL projection is at or below that under stationarity. While the risk-reduction approach described below is illustrated for a selected RSL scenario for the future, it can be implemented for multiple scenarios, leading to a variety of risk-reduction options depending on the future RSL scenarios. In such a broader application, a risk-based framing founded on risk tolerance may be adopted.

Considering uncertainty in the sea level rise projections, one may wish to approach the problem using concepts of dynamically adaptive planning. In the example shown in Figure 4.6b (blue curve), two parameters are specified to illustrate this concept. First, it is assumed that the project will be constructed in, for example, two or more phases. Considering such a planning assumption, phase I is 25 years long (i.e., n = 25 years), and the maximum tolerable risk during this phase is 0.3 (30%), as opposed to the 60% risk mentioned above. The blue curve shows the risk profile for such a design. This curve was computed by constraining R = 0.3 when n = 25, as shown by the green dot in Figure 4.6b. The implication of this adaptive approach is that the initial return level will need to increase from 0.84 m MHHW to 0.93 m MHHW (Table 4.4), and the corresponding initial ARI has to increase from 50 years to 125 years. In this approach, one must also assume that the project will be expanded after that initial period, and measures must be adopted to prevent locking in the design and preempting the planners from expanding it into a bigger project after the initial 25-year period. For example, the foundation design of the project may need to assume the eventual capacity expansion and allow for it in the initial design. This approach of dynamically adaptive planning is becoming increasingly popular as a way to deal with deep uncertainties associated with sea level rise.

Table 4.4 shows that with a relatively small increase in initial design elevation, the risk can be managed to a desirable level. In this example, however, the ultimate design (at the end of the full design life; e.g., 50 or 100 years) needs to be assessed to ensure that resources (e.g., land) that may be needed for the build-out are considered.

Table 4.4: Results of the risk-based design for all tide gauges shown in Figure 4.2. Average recurrence interval (ARI) is listed and is the reciprocal of average event frequency. Values in the last column have been rounded to the closest 5-year interval. Note: to be useful for decision-making, a conversion of the return level to land-based heights (e.g., geodetic datum such as NAVD88) should be made.

NOAA ID	Location	Design return level for T_0 = 50 years (m above MHHW)	Design return level to constrain risk to 30% over a 25-year period (m MHHW)	Average recurrence interval (ARI) of the design to constrain probability (risk) to 30% over a 25-year period
1612340	Honolulu, HI	0.59	0.69	>100
8518750	The Battery, NY	1.74	1.95	90
8638610	Sewells Point, VA	1.55	1.75	>100
8723214	Virginia Key, FL	0.78	1.00	>100
8726520	St. Petersburg, FL	1.61	1.88	80
8729840	Pensacola, FL	1.75	2.09	75
8771450	Galveston Pier 21, TX	1.79	2.13	85
9410660	Los Angeles, CA	0.79	0.86	>100
9414290	San Francisco, CA	0.84	0.93	>100
9447130	Seattle, WA	1.05	1.13	>100

4.3. Growing Risk to Combined Storm and Wastewater Systems from Sea Level Rise

Sea level rise is causing HTF to become more severe—more frequent, deeper, and more widespread—in terms of its impacts (Sweet et al., 2021). Coastal areas that are not exposed to HTF now may become so in the coming decades. As the footprint of flooding expands, water from adjacent estuaries and bays will flood into communities and encounter previously unaffected urban infrastructure.

Many places already see backflow from tidal waters through stormwater pipes that spill out of catch basins into neighborhood streets. Cities with combined sewer systems often have backflow preventers on their vulnerable outfall pipes (EPA, 1995a, 1995b). However, combined sewers will be open to inflow from surface flooding. If floodwater in the streets encounters a catch basin that connects to a combined sewer system, then high tide waters will enter the sewer. At best, the tide waters will be on their way to the sewage treatment plant; at worst, a combined sewer outflow would be triggered if the sewer pipes cannot handle the volume of water.

While Camden, New Jersey, has taken action to prevent runoff from entering its system,[40] tidal inflow is a novel problem. Identification of risks like this can provide lead time to take adaptation actions. Still, in some combined sewer communities, such as Camden, the onset of risk can arrive well before midcentury. Mapping shows that minor HTF at a height of 0.58 m above current MHHW tidal datum (Table A1.3) begins to have a footprint in Camden neighborhoods served by combined sewers (red shade in Figure 4.7, spanning from MHHW to 0.58 m [1.9 feet] above MHHW; locations are provided by the New Jersey Department of Environmental Protection[41]). By the time the tide reaches the moderate (0.86 m above MHHW) and major

[40] https://www.epa.gov/arc-x/camden-new-jersey-uses-green-infrastructure-manage-stormwater

[41] https://njdep.maps.arcgis.com/apps/Viewer/index.html?appid=70dd49de342949ca933e840d0c530fc7

(1.25 m above MHHW) HTF levels, the extent of flooding increases dramatically, and many intersections will be flooded.

The Camden region currently (circa 2020) experiences

- about 2 events/year (or about 4 days/year per Figure 3.8b) of minor HTF;
- 0.2 events/year of moderate HTF; and
- 0.03 events/year of major HTF,

based on the EWL_{local} directly across the Delaware River at the NOAA tide gauge in Philadelphia. The EWL-based probabilities support actual observations in 2020, when the Camden/Philadelphia region experienced 4 days of minor HTF, with 4–8 days projected to occur in 2021 (Sweet et al., 2021).

Considering the Intermediate scenario, which is the upper-bounding scenario for this region's RSL observation-based extrapolations (see Table 2.2), a rise of 0.19 m by 2030 (measured since 2005) is projected to result in

- 5–10 events/year (on the order of 10–20 days/year) of minor HTF,
- 0.6 events/year of moderate HTF, and
- 0.07 events/year of major HTF.

By 2050, a 0.38 m RSL rise is projected (above 2005 levels) for this area, resulting in

- >10 events/year (perhaps >20 days/year) of minor HTF,
- about 3 events/year (6 days/year) of moderate HTF, and
- 0.3 events/year of major HTF.

So, within about the next 30 years (by 2050), a surface flood regime shift with subsurface impacts is projected to occur in Camden, considering current RSL rise trajectories. By then, moderate and major HTF (flooding upwards of 0.9 m and 1.2 m above MHHW, respectively) is projected to occur with similar frequencies/probabilities as minor (about 0.6 m above MHHW) and moderate HTF occur today. With nearly 4 high tides per event (1 event lasts about 2 days; 2 high tides occur almost every day), this implies that by 2050, upwards of 80 tides per year or more at the minor HTF level are projected, with about 12 of those tides per year exceeding the moderate HTF level and a 0.3 events/year frequency of major HTF flooding. Any time street intersections are underwater, tidal waters could flow down catch basins into the combined system (Figure 4.7). Beyond 2050, HTF frequency, depth, and extent will continue to grow. It is unclear how this increased flood frequency will affect the combined sewer system's functionality and surrounding water quality.

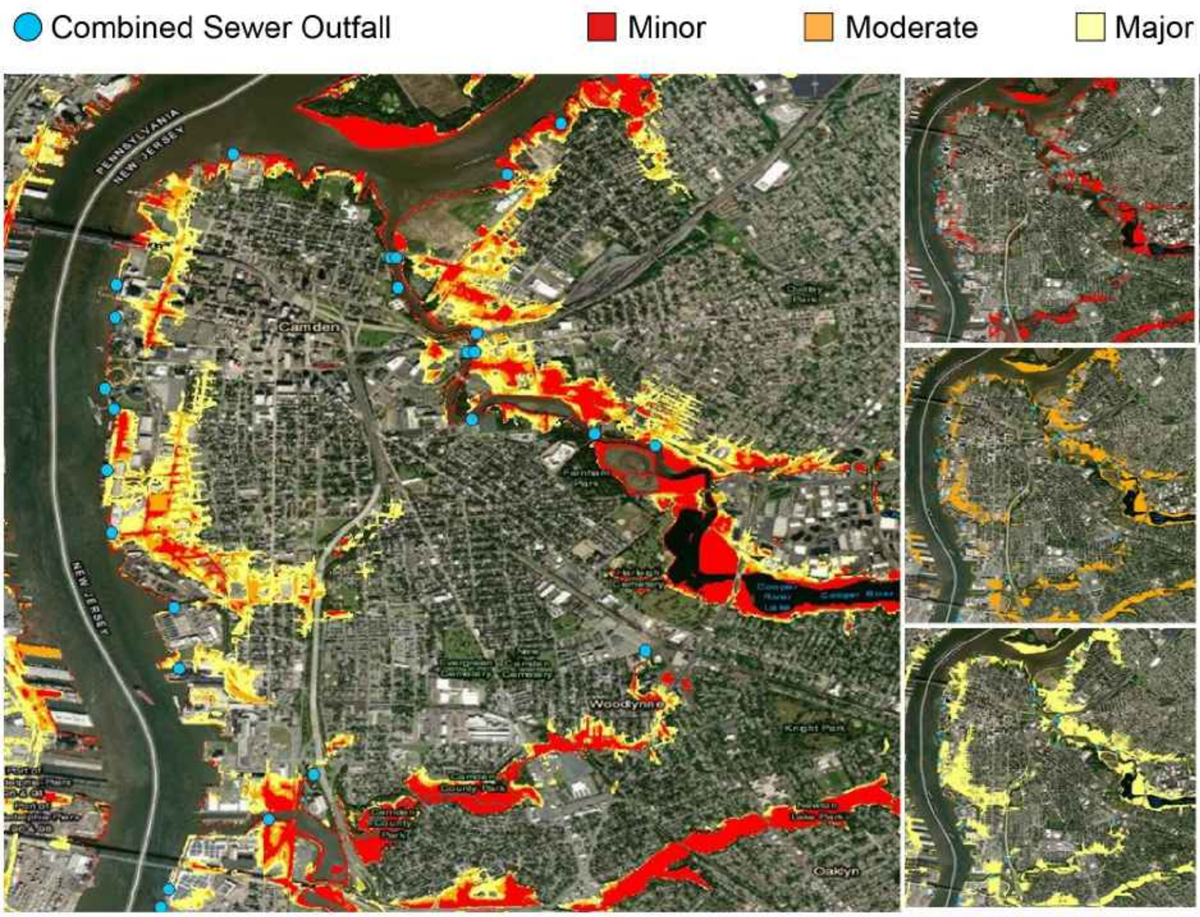


Figure 4.7: Location of combined stormwater and sewer system outfalls that are likely draining regions exposed to HTF within the Camden, New Jersey, region, with the minor (red: MHHW to 0.58 m [1.9 feet] above MHHW), moderate (orange: MHHW to 0.86 m [2.8 feet] above MHHW), and major (yellow: MHHW to 1.25 m [4.1 feet] above MHHW) HTF layers stacked in the enlarged map and individual layers mapped to the right. Note: heights are relative to the 1983–2001 tidal epoch, and to be useful for decision-making, a conversion to land-based heights (e.g., NAVD88) should be made.

4.4: Use of InSAR Technology for Determining Regional Vertical Land Motion and Its Suitability for Computing Long-Term Sea Level Rise Projections

Vertical land motion is an important component of RSL rise, leading to changes in the height of the ocean relative to land. Vertical land motion is not a singular phenomenon but instead results from various processes that display different patterns in space and time. These patterns have different impacts from place to place, especially in coastal settings where many of them operate at the same time and can serve to either increase RSL (subsidence) or decrease RSL (uplift). For much of the coastal United States, subsidence is driven on local scales by both natural processes, such as compaction of river sediments, and unnatural, human-caused reasons, such as groundwater and fossil fuel withdrawal; on larger scales, subsidence is driven by glacial isostatic adjustment (GIA). On the other hand, in some regions, such as southern Alaska, GIA leads to high rates of uplift in coastal regions. For example, Grand Isle, Louisiana, has experienced more than 0.9 m (3 feet) of RSL rise, whereas Juneau, Alaska, has experienced more than 1.2 m (4 feet) of RSL fall based on a 100-year historical linear rate value,[42] in large part due to VLM. For perspective, the national median RSL rise along U.S. coastlines during this 100-year period was about 0.25–0.30 m (see Figure 1.2b).

[42] https://tidesandcurrents.noaa.gov/sltrends/

Accurate future projections of VLM require an understanding of and accounting for the underlying processes and the time and space scales on which they vary. In this report, VLM projections are based in part on analysis of past observations. Vertical land motion rates are estimated at tide-gauge locations as well as at 1-degree grids using a statistical model of tide-gauge observations (Kopp et al., 2014; Sweet et al., 2017; Fox-Kemper et al., 2021; Garner et al., 2021). The model assesses RSL change across the global tide-gauge network[43] with data through about 2019 and separates the tide-gauge observations into 3 modes: 1) a global rise signal (Dangendorf et al., 2019), 2) a long-term linear—but regionally varying—rate, and 3) local effects that vary in time and by region. It is the second mode that defines this report's linear VLM rates, which have been incorporated into the RSL projections for each GMSL rise scenario. These rates are assumed to be linear over the past record and to persist linearly into the future over the length of the projected record. Assumed persistence may not necessarily be valid over the long term (e.g., if groundwater pumping ceases) but may be necessary due to a lack of data. As shown in Figure 4.8a, high rates of subsidence are estimated along the entire Gulf Coast, and moderate rates of subsidence are assessed along the entire East Coast. On the other hand, high rates of uplift are estimated for the southern coast of Alaska.

Over the past couple of decades, GPS stations have provided estimates of VLM in coastal areas across the United States. These GPS-based VLM estimates provide a comparison to the VLM rates in this report, albeit with a couple of caveats. First, the record lengths over which the GPS-based estimates are computed are significantly shorter than the tide-gauge data records used to infer the VLM rates in this report. Second, many tide-gauge locations do not have a co-located GPS station. While it is not possible to extend the record lengths of the available GPS measurements, the second challenge has been addressed using the GPS-imaging technique discussed in Hammond et al. (2021), which leverages the GPS network in coastal areas of the United States to generate VLM estimates at all tide-gauge locations (Figure 4.8b). Note that negative values of VLM reflect subsidence while positive values reflect uplift. To determine the VLM contribution to RSL at the coast, the negative and positive direction would be reversed. Broadly, the GPS-based estimates are consistent with the VLM estimates contained in this report. However, when subtracting the VLM rates in this report from the GPS-derived rates, differences become apparent (Figure 4.8c). The largest differences are found along the Southern Alaska coastlines, where rates of uplift are very large, and along the entire Gulf Coast, where subsidence rates are large. The rates are further compared in Figure 4.8d, which again reflects general agreement between the two sets of estimates, although at roughly 75% of the gauges, the tide-gauge-based VLM estimate in this report is greater (less negative in the case of subsidence) than that from GPS. In other words, there are generally higher rates of subsidence indicated in the GPS rates when compared to the VLM estimates in this report.

This comparison with the GPS is not intended to be an assessment of the accuracy of VLM rates and associated projections included in this report. Instead, it highlights some of the challenges associated with both estimating VLM rates at the coast and then projecting these into the future, particularly away from the tide-gauge and GPS stations. The spatial variability and local drivers of VLM are clear in Figure 4.8, and extending the tide-gauge-centered estimates to fill in spatial gaps either through the projection framework in this report or with GPS imaging is challenging to validate, particularly as these methods are not intended to capture VLM varying on small spatial scales. An opportunity is provided, however, by new technologies using satellite-based advanced Interferometric Synthetic Aperture Radar (InSAR) analysis, which can provide higher spatial resolution measurements of VLM rates. Calibrated to land GPS station estimates, measurements of land elevations over time by InSAR are producing VLM rates for large swaths or the U.S. coastal plain (e.g., Bekaert et al., 2017; Buzzanga et al., 2020; Bekaert et al., 2019; all InSAR VLM estimates are publicly available through references). Having a higher-resolution assessment of VLM rates can in turn help communities understand where VLM is now occurring at very fine scales (e.g., street block level) and help make informed decisions of how continued VLM will contribute to future RSL projections. Furthermore, InSAR provides an

[43] https://www.psmsl.org/data/

additional component to the coastal VLM observing network. Integrated assessments across tide gauges, GPS, and InSAR are likely to be most useful for inferring VLM rates and projecting these rates forward at the spatial scales key to coastal communities. Following is a case study of how the InSAR VLM connects to this VLM-observing network. In general, as there is the possibility of using a user-defined VLM rate within the RSL projections, we examine other sources of VLM that may offer options.

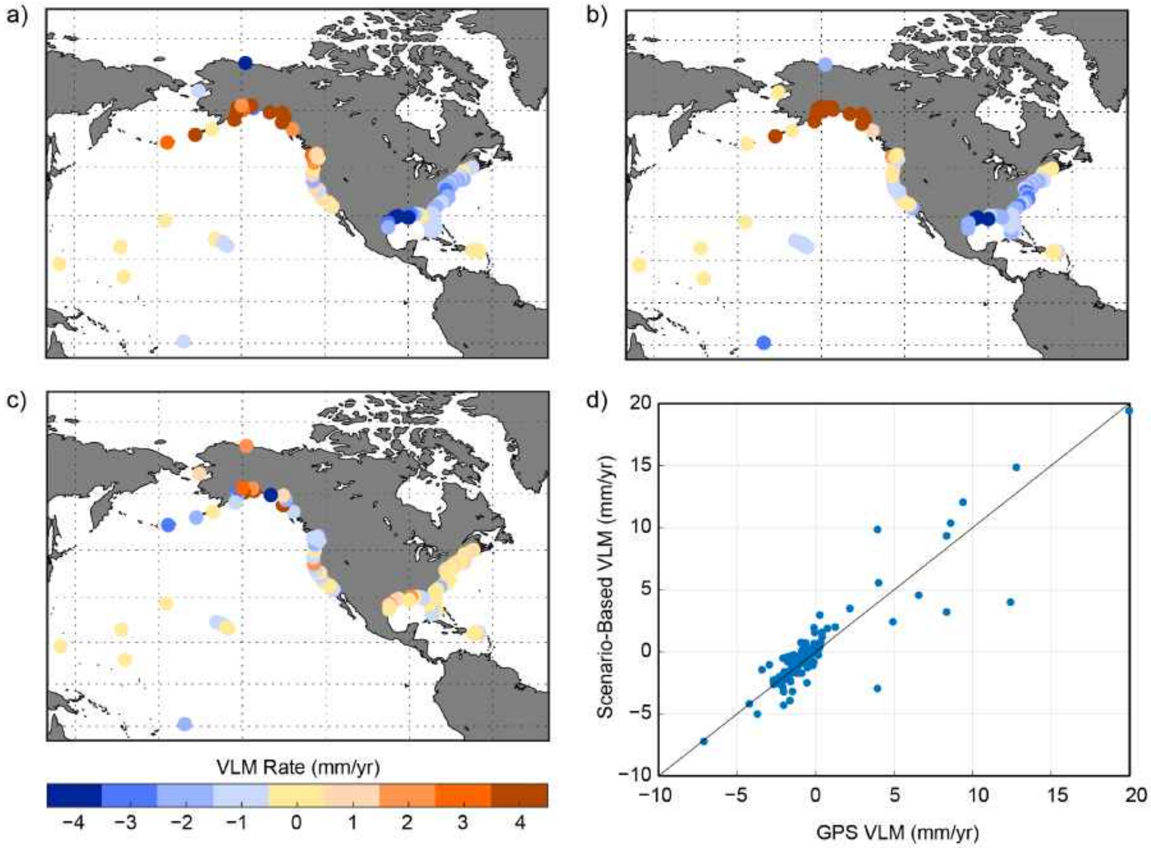


Figure 4.8: Comparison of vertical land motion (VLM) rate estimates (mm/year) from a) the scenario-based framework used in this report, and b) GPS-imaging estimates from Hammond et al. (2021). c) The difference between GPS-derived rates and scenario-derived rates and d) a comparison of the VLM estimates at the U.S. tide-gauge locations are also shown. Negative values of VLM reflect subsidence, while positive values reflect uplift.

Hampton Roads, Virginia

The historical long-term linear RSL rise rate at the Sewells Point, Virginia, tide gauge[44] is about 4.7 mm/year. More than half of this rate is estimated to be from downward VLM or subsidence with a rate of about 2.9 mm/year, which is close to previous estimates (Zervas, 2013; Kopp et al., 2014; Sweet et al., 2017). This subsidence is driven by both GIA and more localized groundwater withdrawal. If assumed to be linear and persistent into the future, VLM will contribute about 0.29 m to projections of RSL over the next 100 years. For example, by 2050 under the Intermediate-Low and Intermediate scenarios, the amount of RSL rise is projected to be between about 0.4 m and 0.45 m, respectively, with about 35% and 30% of that rise amount, respectively, from VLM.

However, VLM rates across the Hampton Roads region are not uniform. A past study (Eggleston and Pope, 2013) leveraged a variety of in situ observations to find a spatially varying pattern of subsidence ranging from 1.8 to 4.4 mm/year in the region from 1940 to 1971. The variations were connected to groundwater withdrawal in the region, which was captured via this assessment even with an effective spatial resolution on the order of tens of kilometers. More recently, InSAR rate maps have shown a range of subsidence from

[44] https://tidesandcurrents.noaa.gov/stationhome.html?id=8638610

about 1 mm to 5 mm/year in the region over the time period from 2014 to present, with locally higher rates (Figure 4.9; Buzzanga et al., 2020). Importantly, the satellite-based assessment revealed spatial variations on sub-kilometer scales, with some of the most prominent features in the spatial map connected to specific construction projects and land-use changes. With an average rate of subsidence around 3 mm/year over the course of the 21st century, VLM could contribute about 0.3 m to projected RSL, with locally higher amounts elsewhere in the region. Furthermore, comparing the InSAR-derived spatial pattern of VLM to that in either Eggleston and Pope (2013) or the gridded rates in this report provides important information about the linearity of VLM and the timescales on which VLM varies. There are considerable differences between the different assessments, indicating a shift in rates over the time periods considered. While it is necessary to consider the uncertainty in the VLM rate estimates and differences in measurement type, users of VLM information should assess land-use changes over the time periods considered along with the relevant processes driving VLM in the region. InSAR-derived VLM maps will play an increasingly key role in this assessment due to the spatial coverage and resolution provided by the satellites.

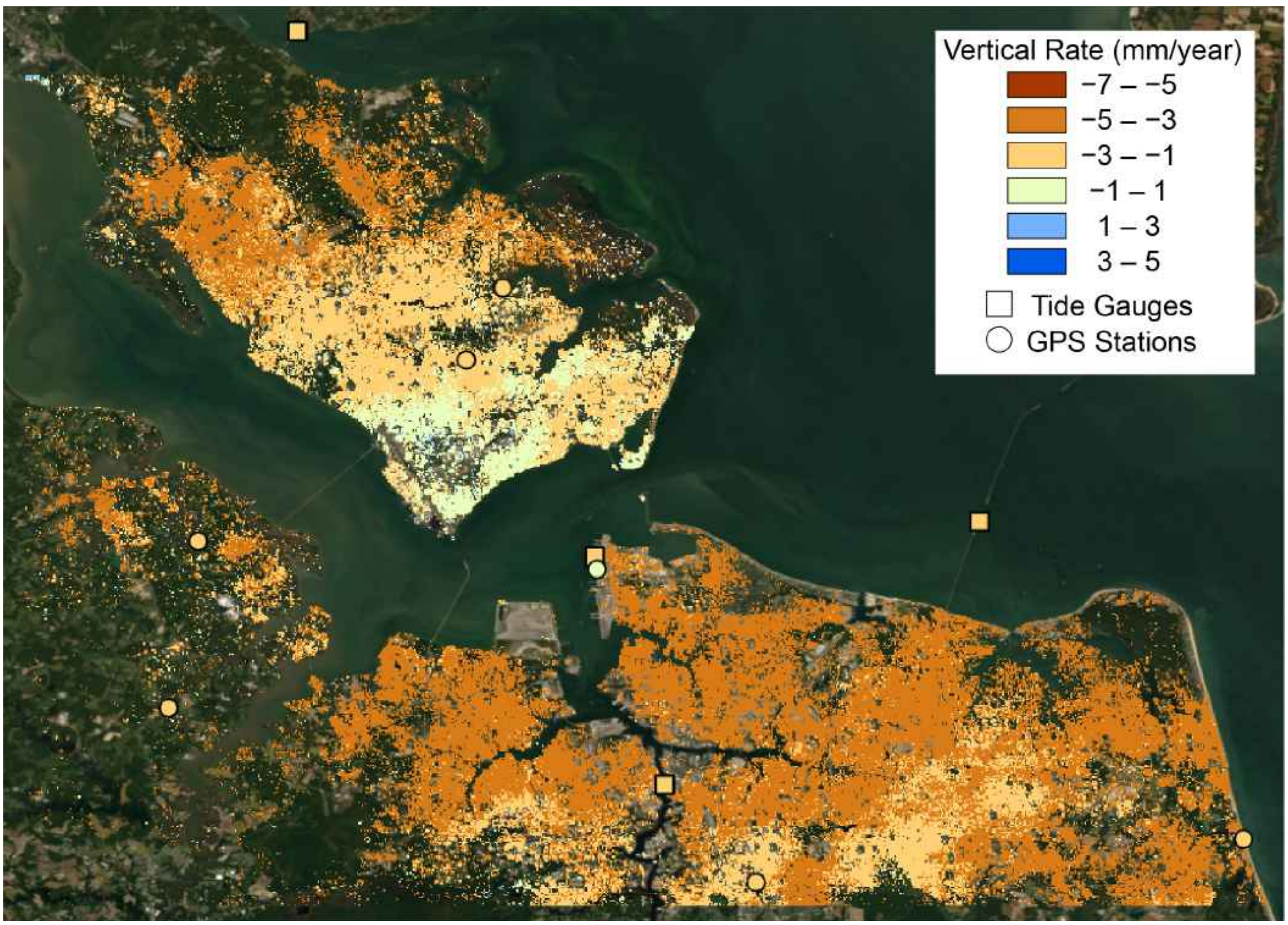


Figure 4.9: Map showing VLM rates (mm/year) for the Hampton Roads region displayed on top of satellite imagery. Higher rates of subsidence are indicated by darker orange colors. Of particular interest is the range of rates in such a small region (e.g., on the order of up to 5 mm/year difference in places). Based on Buzzanga et al. (2020).

Observing and Projecting Coastal Vertical Land Motion

While InSAR-measured VLM provides advantages over other measurement platforms in terms of spatial coverage and resolution, it should be considered in the context of the larger observing network when assessing VLM at the coast. In particular, InSAR serves two potential roles. First, InSAR can be used to provide ongoing monitoring of VLM at high spatial resolutions. InSAR has the potential to generate time series of VLM on a fine spatial scale. Subsidence "hotspots" can be identified along with abrupt shifts in VLM, which can assist in planning and executing adaptation efforts. For coastal communities attempting to alleviate subsidence in their region through efforts such as groundwater reinjection, InSAR provides a potentially better alternative to in situ monitoring to assess the effectiveness of these efforts. Second, InSAR can serve to assess spatial variability in VLM, filling in the gaps between tide gauges and GPS stations in coastal regions. The observations can then be combined in a statistical framework to provide more accurate projections of VLM with better estimates of uncertainty.

Assessing VLM with InSAR is not without challenges, however, although many of these are being addressed in ongoing and planned efforts. First, to be useful for assessing long-term VLM rates with the still relatively short satellite records, the shorter-term VLM rates can be calibrated and tied into the existing National Spatial Reference System (NSRS)[45] to improve accuracy and representativeness of long-term changes. Second, the availability and coverage of GPS in coastal regions impact the accuracy of VLM by InSAR. To provide a measurement of absolute VLM, InSAR needs to be tied to available GPS measurements. In areas with large gaps between GPS stations, this can lead to reduced accuracy of the InSAR estimates. Ideally, analysis would be conducted to determine optimal GPS station spacing for maintaining integrity of the InSAR-derived velocity field in various environments, including, but not limited to, regions of coastal subsidence, landslide/earthquake/volcanic activity, high plains aquifer depletion, and aquifer depletion in a tectonic area. Finally, InSAR VLM estimates are computationally expensive to perform over large regions, making national coverage a challenge. Efforts are underway, however, to generate a consistent surface displacement product (a preliminary step to estimating VLM) for the United States. A generalized approach for generating absolute VLM estimates from this product could then be created, paving the way for ongoing monitoring of VLM along the U.S. coastlines at high spatial resolutions.

To improve projections of VLM, InSAR alone is not sufficient. Instead, InSAR should be analyzed in tandem with available tide-gauge, GPS, and any other available in situ observations to assess both the spatial variability of VLM rates and potential non-linearities in the VLM rates estimated over these records. These non-linearities are critical for determining the future contribution of VLM to RSL. For example, the long-term rate assessed at a tide gauge as done in this report could differ significantly from the rate of VLM over the past decade because of a sustained land-use change. The comparison between the two types of VLM estimates in Figure 4.9 indicate that these shifts may be present at some locations along the U.S. coastlines and need to be assessed to improve projections of VLM.

---

[45] https://oceanservice.noaa.gov/education/tutorial_geodesy/geo08_spatref.html

Section 5: Conclusions

Sea level rise driven by global climate change is a clear and present risk to the United States, now and for the foreseeable future. It is the goal of the Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force to continue to provide projections and future scenarios to assist decision-makers for both planning and risk-bounding purposes. This report builds upon the progress made in Sweet et al. (2017), updating the GMSL scenarios and the associated local and regional RSL projections to reflect recent advances in sea level science, as well as expanding the types of scenario information provided to better serve stakeholder needs for coastal risk management and adaptation planning.

The major findings of this report are as follows:

Multiple lines of evidence provide increased confidence, regardless of the emissions pathway, in a narrower range of projected global, national, and regional sea level rise at 2050 than previously reported (Sweet et al., 2017).

Both trajectories assessed by extrapolating rates and accelerations estimated from historical tide-gauge observations, and model projections, fall within the same range in all cases, giving higher confidence in these relative sea level (RSL; land and ocean height changes) rise amounts by 2050. Specifically, RSL along the contiguous U.S. (CONUS) coastline is expected to rise, on average, as much over the next 30 years (0.25–0.30 m over 2020–2050) as it has over the last 100 years (1920–2020). Due to processes driving regional changes in sea level, the report found regional differences in both the modeled scenarios and observation-based extrapolations, with higher RSL rise along the East (0–5 cm higher on average than CONUS) and Gulf Coasts (10–15 cm higher) as compared to the West (10–15 cm lower) and Hawaiian/Caribbean (5–10 cm lower) Coasts.

For coastlines outside CONUS, and for individual regions and locations within CONUS, the projections can differ from the aforementioned mean values. In addition, it is important to note that the projections do not include natural year-to-year sea level variability that occurs along U.S. coastlines in response to climatic modes such as the El Niño–Southern Oscillation. Nevertheless, if we assume that regional sea level will keep following its present trajectory for the coming three decades, most U.S. regions are mostly tracking between the Intermediate-Low and Intermediate-High scenarios. Although the near-term observation-based extrapolations will continue to evolve over time with new observations and analyses, this updated information should help inform both near-term decisions and projects that may require decades' worth of planning prior to actual implementation.

By 2050, the expected relative sea level (RSL) will cause tide and storm surge heights to increase and will lead to a shift in U.S. coastal flood regimes, with major and moderate high tide flood events occurring as frequently as moderate and minor high tide flood events occur today. Without additional risk-reduction measures, U.S. coastal infrastructure, communities, and ecosystems will face significant consequences.

Minor/disruptive high tide flooding (HTF; about 0.55 m above mean higher high water [MHHW]) is projected to increase from a U.S average frequency of about 3 events/year in 2020 to >10 events/year by 2050. The projected increases for moderate/typically damaging (about 0.85 m above MHHW) and major/often destructive (about 1.20 m above MHHW) HTF are 0.3 events/year in 2020 to about 4 events/year in 2050 and 0.04 events/year in 2020 to 0.2 events/year by 2050, respectively. Across all severities (minor, moderate, major), HTF along the U.S. East and Gulf Coasts will largely continue to occur at or above the national average frequency.

In other words, much of the coastline is already close to a flood regime shift with respect to flood frequency and, consequently, damages. Only a small height difference (0.3–0.7 m) currently separates infrequent, damaging, or destructive HTF from the current regime of more frequent, so-called nuisance, flooding (whose impacts are in fact already remarkable throughout dozens of densely populated coastal cities). Decades ago, powerful storms were what typically caused coastal flooding, but due to RSL rise, even today's common wind events and seasonal high tides are already regularly flooding communities, and they will do so to an ever greater extent in the next few decades, affecting homes and businesses, overloading stormwater and wastewater systems, infiltrating coastal groundwater aquifers with saltwater, and stressing coastal wetlands and estuarine ecosystems.

Higher global temperatures increase the chances of higher sea level by the end of the century and beyond. The scenario projections of relative sea level (RSL) along the contiguous U.S. (CONUS) coastline are about 0.6–2.2 m in 2100 and 0.8–3.9 m in 2150 (relative to sea level in 2000); these ranges are driven by uncertainty in future emissions pathways and the response of the underlying physical processes.

With an increase in average global temperature of 2°C above preindustrial levels, and not considering the potential contributions from ice-sheet processes with limited agreement (low confidence) among modeling approaches, the probability of exceeding 0.5 m rise globally (0.7 m along the CONUS coastline) by 2100 is about 50%. With 3°–5°C of warming under high emissions pathways, this probability rises to >80% to >99%. The probability of exceeding 1 m globally (1.2 m CONUS) by 2100 rises from <5% with 3°C warming to almost 25% with 5°C warming. Considering low-confidence ice-sheet processes and high emissions pathways with warming approaching 5°C, these probabilities rise to about 50%, 20%, and 10% of exceeding 1.0 m, 1.5 m, or 2.0 m of global rise by 2100, respectively. While these low-confidence ice-sheet processes are unlikely to make significant contributions with 2°C of warming, how much warming might be required to trigger them is currently unknown.

In addition, as a result of improved understanding of the timing of possible large future contributions from ice-sheet loss, the "Extreme" scenario from the 2017 report (2.5 m GMSL rise by 2100) is now viewed as less plausible and has been removed from consideration. Nevertheless, the increased acceleration in the late 21st century and beyond means that the other high-end scenarios provide pathways that potentially reach this threshold in the decades immediately following 2100 (and continue rising). Regionally, the projections are near or higher than the global average in 2100 and 2150 for almost all U.S. coastlines due to vertical land motion (VLM); gravitational, rotational, and deformational effects due to land ice loss; and ocean circulation changes. Largely due to VLM, RSL projections are lower than the global amounts along the southern Alaska coast and are higher along the Eastern and Western Gulf coastlines.

Monitoring the sources of ongoing sea level rise and the processes driving changes in sea level is critical for assessing scenario divergence and tracking the trajectory of observed sea level rise, particularly during the time period when future emissions pathways lead to increased ranges in projected sea level rise.

Efforts are currently under way to narrow the uncertainties in ice-sheet dynamics and future sea level rise amounts in response to increasing greenhouse gas forcing and associated global warming. Early indicators of changes in sea level rise trajectories can serve to trigger adaptive management plans and are identified through continuous monitoring and assessment of changes in sea level (on global and local scales) and of the key drivers of sea level change that most affect U.S. coastlines, such as ocean heat content, ice-mass loss from Greenland and Antarctica, vertical land motion, and Gulf Stream system changes.

As emphasized in the summary findings above, beyond 2050 the amount of sea level rise is strongly affected by future global warming. By reducing greenhouse gas (GHG) emissions, severe and transformative impacts occurring later this century or early next century along U.S. coastlines are more likely to be avoided. As GHG emissions and global temperatures continue to rise, the likelihood of very high U.S. sea level rise does too. If global warming reaches 2°C (warming levels are already >1°C), corresponding to a 50% chance that U.S. sea level as a whole will rise at least 0.7 m by 2100 and 1.2 m by 2150 (measured since 2000), major HTF by 2100 would occur more often than minor HTF occurs today in many coastal communities if risk-reduction action is not taken. If global mean temperatures were to rise as high as about 3°–5°C, much larger amounts of sea level rise would become increasingly possible, as instabilities in ice-sheet dynamics would potentially come into play. Constant monitoring of global to local sea levels and their source contributions by Federal agencies, such as NOAA and NASA, will be key to help assess potential trajectory divergence for triggering adaptive management plans.

The updated sea level scenarios and the EWL probability datasets in this study are being delivered or planned via numerous agency data servers, tools, and associated guidance products. Additionally, this report is a key technical input to the Fifth National Climate Assessment (NCA5 currently under way), and the datasets and derived information are being delivered to the NCA5 author teams. In terms of next steps, the Task Force will continue to refine these sea level projections and extreme (e.g., high tides, storms) water level probabilities while working to improve understanding of the implications of these projections for coastal hazards (e.g., flooding, erosion, and rising water tables), societal exposure and risk, infrastructure vulnerability, ecosystem health (including habitat transformation/loss), and cascading societal impacts. In order to do so, additional and improved observations and more sophisticated modeling approaches that incorporate the relevant physical processes (e.g., waves; see Box 3.1) will be needed at the regional scale, with local granularity to assess the impacts of these coastal hazards. Such information is expected to ultimately feed into the next generation of interagency reports and assessments to enable informed climate adaptation planning.

Section 6: Acknowledgments

The authors appreciate the review and constructive comments from the following external reviewers*: Dr. Mark Merrifield (Scripps Institution of Oceanography), Dr. Gary Mitchum (University of South Florida), Dr. Claudia Tebaldi (Lawrence Berkeley National Laboratory), Dr. Thomas Wahl (University of Central Florida), Dr. Steve Nerem (University of Colorado), Abby Sullivan (Philadelphia Water Department), and David Behar (San Francisco Public Utilities Commission).

We also thank the following agencies and/or their personnel for the reviews provided: Dr. Davina Passeri (U.S. Geological Survey [USGS]), Dr. Erika Lentz (USGS), Dr. Rebecca Beavers (National Park Service), Heidi Stiller (NOAA), Jamie Carter (National Oceanic and Atmospheric Administration [NOAA]), Lisa Auermuller (Rutgers University), Dr. Renee Collini (Mississippi State University), Laura Engeman (Scripps Institution of Oceanography), Dr. Ian Miller, (University of Washington), Katy Hintzen (University of Hawai‘i), Jill Gambill (University of Georgia), Carey Schafer (EcoAdapt), and Rachel Johnson (NOAA). We would like to thank Sean Vitousek (model output) and Amy Foxgrover (figure illustration) of the USGS for Wave Call-out box support.

The contributions of Robert Kopp and Greg Garner were supported by the National Science Foundation (ICER-1663807, ICER-2103754) and the National Aeronautics and Space Administration (award 80NSSC20K1724 and JPL task 105393.509496.02.08.13.31). Contributions of John Marra, William Sweet, Jayantha Obeysekera, and Ayesha Genz were supported by the U.S. Department of Defense Strategic Environmental Research and Development Program through work carried out under Project RC-2644. The contributions of Benjamin Hamlington, Thomas Frederikse, Eric Larour, and David Bekaert were carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004). The contributions of Patrick Barnard were supported by the USGS Coastal and Marine Hazards and Resources Program.

Production Team

Brooke C. Stewart,
Science Editor, NC State University

Andrea L. McCarrick,
Technical Editor, NC State University

Jessicca Allen,
Lead Graphic Designer, NC State University

S. Elizabeth Love-Brotak,
Graphic Designer, NOAA

Deborah Misch,
Lead Graphic Designer, Innovative Consulting & Management Services, LLC

Sara W. Veasey,
Visual Communications Team Lead, NOAA

Jacquelyn Crossman,
Librarian, ZAI-MPF

**The identification of the external reviewers does not imply that they agreed with all of the content of this report.*

Section 7: References

Bamber, J.L. and W.P. Aspinall, 2013: An expert judgement assessment of future sea level rise from the ice sheets. *Nature Climate Change*, 3 (4), 424–427. https://doi.org/10.1038/nclimate1778

Bamber, J.L., M. Oppenheimer, R.E. Kopp, W.P. Aspinall, and R.M. Cooke, 2019: Ice sheet contributions to future sea-level rise from structured expert judgment. *Proceedings of the National Academy of Sciences of the United States of America*, 116 (23), 11195–11200. https://doi.org/10.1073/pnas.1817205116

Baranes, H.E., J.D. Woodruff, S.A. Talke, R.E. Kopp, R.D. Ray, and R.M. DeConto, 2020: Tidally driven interannual variation in extreme sea level frequencies in the Gulf of Maine. *Journal of Geophysical Research: Oceans*, 125 (10), e2020JC016291.
http://dx.doi.org/10.1029/2020JC016291

Barnard, P.L., L.H. Erikson, A.C. Foxgrover, J.A. Finzi Hart, P. Limber, A.C. O'Neill, M. van Ormondt, S. Vitousek, N. Wood, M.K. Hayden, and J.M. Jones, 2019: Dynamic flood modeling essential to assess the coastal impacts of climate change. Scientific reports, 9 (1), 1–13. https://doi.org/10.1038/s41598-019-40742-z

Befus, K.M., P.L. Barnard, D.J. Hoover, J.A. Finzi Hart, and C.I. Voss, 2020: Increasing threat of coastal groundwater hazards from sea-level rise in California. *Nature Climate Change*, 10 (10), 946–952.
https://doi.org/10.1038/s41558-020-0874-1

Bekaert, D.P.S., B.D. Hamlington, B. Buzzanga, and C.E. Jones, 2017: Spaceborne synthetic aperture radar survey of subsidence in Hampton Roads, Virginia (USA). Scientific Reports, 7 (1), 1–9.
https://doi.org/10.1038/s41598-017-15309-5

Bekaert, D.P.S., C.E. Jones, K. An, and M.-H. Huang, 2019: Exploiting UAVSAR for a comprehensive analysis of subsidence in the Sacramento Delta. *Remote Sensing of Environment*, 220, 124–134.
https://doi.org/10.1016/j.rse.2018.10.023

Bloemen, P., T. Reeder, C. Zevenbergen, J. Rijke, and A. Kingsborough, 2018: Lessons learned from applying adaptation pathways in flood risk management and challenges for the further development of this approach. *Mitigation and Adaptation Strategies for Global Change*, 23 (7), 1083–1108.
https://doi.org/10.1007/s11027-017-9773-9

Bodnar, A.N., 1981: Estimating Accuracies of Tidal Datums from Short Term Observations. Technical Report NOS CO-OPS 077. National Oceanic and Atmospheric Administration, National Ocean Service, Center for Operational Oceanographic Products and Services, Silver Spring, MD, 40 pp.
https://tidesandcurrents.noaa.gov/publications/NOAA_Technical_Report_NOS_COOPS_077.pdf

Boening, C., J.K. Willis, F.W. Landerer, R.S. Nerem, and J. Fasullo, 2012: The 2011 La Niña: So strong, the oceans fell. *Geophysical Research Letters*, 39 (19). https://doi.org/10.1029/2012GL053055

Bos, M.S., R.M.S. Fernandes, S.D.P. Williams, and L. Bastos, 2013: Fast error analysis of continuous GNSS observations with missing data. *Journal of Geodesy*, 87 (4), 351–360.
http://dx.doi.org/10.1007/s00190-012-0605-0

Bos, M.S., S.D.P. Williams, I.B. Araújo, and L. Bastos, 2014: The effect of temporal correlated noise on the sea level rate and acceleration uncertainty. *Geophysical Journal International*, 196 (3), 1423–1430.
http://dx.doi.org/10.1093/gji/ggt481

Bromirski, P.D., A.J. Miller, R.E. Flick, and G. Auad, 2011: Dynamical suppression of sea level rise along the Pacific coast of North America: Indications for imminent acceleration. *Journal of Geophysical Research*, 116, C07005. https://doi.org/10.1029/2010jc006759

Buchanan, M.K., M. Oppenheimer, and R.E. Kopp, 2017: Amplification of flood frequencies with local sea level rise and emerging flood regimes. *Environmental Research Letters*, 12 (6), 064009. https://doi.org/10.1088/1748-9326/aa6cb3

Buzzanga, B., D.P.S. Bekaert, B.D. Hamlington, and S.S. Sangha, 2020: Toward sustained monitoring of subsidence at the coast using InSAR and GPS: An application in Hampton Roads, Virginia. *Geophysical Research Letters*, 47 (18), e2020GL090013. https://doi.org/10.1029/2020GL090013

Calafat, F.M., D.P. Chambers, and M.N. Tsimplis, 2012: Mechanisms of decadal sea level variability in the eastern North Atlantic and the Mediterranean Sea. *Journal of Geophysical Research: Oceans*, 117, C09022. https://doi.org/10.1029/2012JC008285

Calafat, F.M. and M. Marcos, 2020: Probabilistic reanalysis of storm surge extremes in Europe. *Proceedings of the National Academy of Sciences*, 117 (4), 1877–1883. http://dx.doi.org/10.1073/pnas.1913049117

CCRM, 2019: Recommendations for Sea Level Rise Projections: A Report for the Governor's Coastal Climate Resiliency Plan. Center for Coastal Resources Management, Virginia institute of Marine Science, Gloucester Point, VA, 6 pp. https://www.naturalresources.virginia.gov/media/governorvirginiagov/secretary-of-natural-resources/images/1c.-Sea-level-rise-projections-for-Virginia-planning-purposes-(2)-FINAL-10_31.pdf

Chao, B.F., Y.-H. Wu, and Y.S. Li, 2008: Impact of artificial reservoir water impoundment on global sea level. *Science*, 320 (5873), 212–214. https://doi.org/10.1126/science.1154580

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter13_FINAL.pdf

Coles, S., 2001: *An Introduction to Statistical Modeling of Extreme Values*. Springer-Verlag, London, 224 pp.

Coles, S.G., and M.J. Dixon, 1999: Likelihood-based inference for extreme value models. *Extremes*, 2, 5–23. https://doi.org/10.1023/A:1009905222644

Cooley, D., 2013: Return periods and return levels under climate change. In: *Extremes in a Changing Climate*. AghaKouchak, A., D. Easterling, K. Hsu, S. Schubert, and S. Sorooshian, Eds. Springer, Dordrecht, Netherlands, 97–114.

Dalrymple, T. (1960). Flood Frequency Analyses, Manual of Hydrology: Part 3. U.S. Geological Survey Water-Supply Paper 1543-A. U.S. Geological Survey, Reston, VA, 86 pp. https://doi.org/10.3133/wsp1543A

Dangendorf, S., C. Hay, F.M. Calafat, M. Marcos, C.G. Piecuch, K. Berk, and J. Jensen, 2019: Persistent acceleration in global sea-level rise since the 1960s. *Nature Climate Change*, 9 (9), 705–710. https://doi.org/10.1038/s41558-019-0531-8

DeConto, R.M., D. Pollard, R.B. Alley, I. Velicogna, E. Gasson, N. Gomez, S. Sadai, A. Condron, D.M. Gilford, E.L. Ashe, R.E. Kopp, D. Li, and A. Dutton, 2021: The Paris Climate Agreement and future sea-level rise from Antarctica. *Nature*, 593 (7857), 83–89. https://doi.org/10.1038/s41586-021-03427-0

Dokka, R.K., 2011: The role of deep processes in late 20th century subsidence of New Orleans and coastal areas of southern Louisiana and Mississippi. *Journal of Geophysical Research*, 116, B06403. https://doi.org/10.1029/2010JB008008

Edwards, T.L., S. Nowicki, B. Marzeion, R. Hock, H. Goelzer, H. Seroussi, N.C. Jourdain,D.A. Slater, F.E. Turner, C.J. Smith, C.M. McKenna, E. Simon, A. Abe-Ouchi, J.M. Gregory, E. Larour, W.H. Lipscomb, A.J. Payne, A. Shepherd, C. Agosta, P. Alexander, T. Albrecht, B. Anderson, X. Asay-Davis, A. Aschwanden, A. Barthel, A. Bliss, R. Calov, C. Chambers, N. Champollion, Y. Choi, R. Cullather, J. Cuzzone, C. Dumas, D. Felikson, X. Fettweis, K. Fujita, B.K. Galton-Fenzi, R. Gladstone, N.R. Golledge, R. Greve, T. Hattermann, M.J. Hoffman, A. Humbert, M. Huss, P. Huybrechts, W. Immerzeel, T. Kleiner, P. Kraaijenbrink, S. Le clec'h, V. Lee, G.R. Leguy, C.M. Little, D.P. Lowry, J.-H. Malles, D.F. Martin, F. Maussion, M. Morlighem, J.F. O'Neill, I. Nias, F. Pattyn, T. Pelle, S.F. Price, A. Quiquet, V. Radić, R. Reese, D.R. Rounce, M. Rückamp, A. Sakai, C. Shafer, N.-J. Schlegel, S. Shannon, R.S. Smith, F. Straneo, S. Sun, L. Tarasov, L.D. Trusel, J. Van Breedam, R. van de Wal, M. van den Broeke, R. Winkelmann, H. Zekollari, C. Zhao, T. Zhang, and T. Zwinger, 2021: Projected land ice contributions to twenty-first-century sea level rise. *Nature*, 593 (7857), 74–82. https://doi.org/10.1038/s41586-021-03302-y

Eggleston, J. and J. Pope, 2013: Land Subsidence and Relative Sea-Level Rise in the Southern Chesapeake Bay Region. Circular 1392. U.S. Geological Survey, Reston, VA, 30 pp., http://dx.doi.org/10.3133/cir1392

EPA, 1995a: Combined Sewer Overflows: Guidance for Long-Term Control Plan. EPA/832-B-95-002. U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC, 201 pp. https://www.epa.gov/sites/default/files/2015-10/documents/owm0272_0.pdf

EPA, 1995b: Combined Sewer Overflows: Guidance for Nine Minimum Controls. EPA 832-B-95-003. U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC, 69 pp. https://www.epa.gov/sites/default/files/2015-10/documents/owm0030_2.pdf

Farrell, W.E. and J.A. Clark, 1976: On postglacial sea level. *Geophysical Journal International*, 46 (3), 647–667. https://doi.org/10.1111/j.1365-246X.1976.tb01252.x.

Fasullo, J. T., Boening, C., Landerer, F. W., & Nerem, R. S. (2013). Australia's unique influence on global sea level in 2010–2011. Geophysical Research Letters, 40 (16), 4368–4373. https://doi.org/10.1002/grl.50834

Fasullo, J.T. and R.S. Nerem, 2018: Altimeter-era emergence of the patterns of forced sea-level rise in climate models and implications for the future. *Proceedings of the National Academy of Sciences*, 115 (51), 12944–12949. https://doi.org/10.1073/pnas.1813233115

FEMA, 2016a: Guidance for Flood Risk Analysis Mapping: Coastal Flood Frequency and Extreme Value Analysis. Guidance Document 76. Federal Emergency Management Agency, Hyattsville, MD, 22 pp. https://www.fema.gov/sites/default/files/2020-02/Coastal_Flood_Frequency_and_Extreme_Value_Analysis_Guidance_Nov_2016.pdf

FEMA, 2016b: Guidance for Flood Risk Analysis Mapping: Statistical Simulation Methods. Guidance Document 77. Federal Emergency Management Agency, Hyattsville, MD, 37 pp. https://www.fema.gov/sites/default/files/documents/fema_coastal-statistical-simulation-methods_nov-2016.pdf

Fox-Kemper, B., H.T. Hewitt, C. Xiao, G. Aðalgeirsdóttir, S.S. Drijfhout, T.L. Edwards, N.R. Golledge, M. Hemer, R.E. Kopp, G. Krinner, A. Mix, D. Notz, S. Nowicki, I.S. Nurhati, L. Ruiz, J.-B. Sallée, A.B.A. Slangen, and Y. Yu, 2021: Ocean, Cryosphere and Sea Level Change. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [MassonDelmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. https://www.ipcc.ch/report/ar6/wg1/

Frau, R., M. Andreewsky, and P. Bernardara, 2018: The use of historical information for regional frequency analysis of extreme skew surge. *Natural Hazards and Earth System Sciences*, 18 (3), 949–962. https://doi.org/10.5194/nhess-18-949-2018

Frederikse, T., K. Simon, C.A. Katsman, and R. Riva, 2017: The sea-level budget along the Northwest Atlantic coast: GIA, mass changes, and large-scale ocean dynamics. *Journal of Geophysical Research: Oceans*, 122, 5486–5501. https://doi.org/10.1002/2017JC012699

Frederikse, T., F. Landerer, L. Caron, S. Adhikari, D. Parkes, V.W. Humphrey, S. Dangendorf, P. Hogarth, L. Zanna, L. Cheng, and Y.-H. Wu, 2020: The causes of sea-level rise since 1900. *Nature*, 584 (7821), 393–397. https://doi.org/10.1038/s41586-020-2591-3

Fu, X., 2020: Measuring local sea-level rise adaptation and adaptive capacity: A national survey in the United States. *Cities*, 102, 102717. https://doi.org/10.1016/j.cities.2020.102717.

Garner, G.G., T. Hermans, R.E. Kopp, A.B.A. Slangen, T.L. Edwards, A. Levermann, S. Nowikci, M.D. Palmer, C. Smith, B. Fox-Kemper, H.T. Hewitt, C. Xiao, G. Aðalgeirsdóttir, S.S. Drijfhout, T.L. Edwards, N.R. Golledge, M. Hemer, R.E. Kopp, G. Krinner, A. Mix, D. Notz, S. Nowicki, I. S. Nurhati, L. Ruiz, J-B. Sallée, Y. Yu, L. Hua, T. Palmer, and B. Pearson, 2021. IPCC AR6 Sea-Level Rise Projections. Version 20210809. PO.DAAC, CA, USA. Dataset accessed [2021-09-01]. https://podaac.jpl.nasa.gov/announcements/2021-08-09-Sea-level-projections-from-the-IPCC-6th

Gill, S., G. Hovis, K. Kriner, and M. Michalski, 2014: Implementation of Procedures for Computation of Tidal Datums in Areas with Anomalous Trends of Relative Mean Sea Level. NOAA Technical Report NOS CO-OPS 068. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 58 pp. https://tidesandcurrents.noaa.gov/publications/NOAA_Technical_Report_NOS_COOPS_68.pdf

Guza, R.T. and E.B. Thornton, 1982: Swash oscillations on a natural beach. *Journal of Geophysical Research*, 87 (C1), 483–491. https://doi.org/10.1029/JC087iC01p00483

Haasnoot, M., J.H. Kwakkel, W.E. Walker, and J. ter Maat, 2013: Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, 23 (2), 485–498. https://doi.org/10.1016/j.gloenvcha.2012.12.006

Haasnoot, M., S. Brown, P. Scussolini, J.A. Jimenez, A.T. Vafeidis, and R.J. Nicholls, 2019: Generic adaptation pathways for coastal archetypes under uncertain sea-level rise. *Environmental Research Communications*, 1 (7), 071006. https://doi.org/10.1088/2515-7620/ab1871

Habel, S., C.H. Fletcher, T.R. Anderson, and P.R. Thompson, 2020: Sea-level rise induced multi-mechanism flooding and contribution to urban infrastructure failure. *Scientific Reports*, 10 (1), 3796. http://dx.doi.org/10.1038/s41598-020-60762-4

Hall, J.A., S. Gill, J. Obeysekera, W. Sweet, K. Knuuti, and J. Marburger, 2016: Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Coastal Sites Worldwide. U.S. Department of Defense, Strategic Environmental Research and Development Program, Alexandria, VA, 224 pp. https://climateandsecurity.files.wordpress.com/2014/01/regional-sea-level-scenarios-for-coastal-risk-management_managing-uncertainty-of-future-sea-level-change-and-extreme-water-levels-for-department-of-defense.pdf

Hall, J.W., H. Harvey, and L.J. Manning, 2019: Adaptation thresholds and pathways for tidal flood risk management in London. *Climate Risk Management*, 24, 42–58. https://doi.org/10.1016/j.crm.2019.04.001

Hamlington, B.D., A.S. Gardner, E. Ivins, J.T.M. Lenaerts, J.T. Reager, D.S. Trossman, E.D. Zaron, S. Adhikari, A. Arendt, A. Aschwanden, B.D. Beckley, D.P.S. Bekaert, G. Blewitt, L. Caron, D.P. Chambers, H.A. Chandanpurkar, K. Christianson, B. Csatho, R.I. Cullather, R.M. DeConto, J.T. Fasullo, T. Frederikse, J.T. Freymueller, D.M. Gilford, M. Girotto, W.C. Hammond, R. Hock, N. Holschuh, R.E. Kopp, F. Landerer, E. Larour, D. Menemenlis, M. Merrifield, J.X. Mitrovica, R.S. Nerem, I.J. Nias, V. Nieves, S. Nowicki, K. Pangaluru, C.G. Piecuch, R.D. Ray, D.R. Rounce, N.-J. Schlegel, H. Seroussi, M. Shirzaei, W.V. Sweet, I. Velicogna, N. Vinogradova, T. Wahl, D.N. Wiese, and M.J. Willis, 2020a: Understanding of contemporary regional sea-level change and the implications for the future. *Reviews of Geophysics*, 58 (3), e2019RG000672. https://doi.org/10.1029/2019RG000672

Hamlington, B.D., C.G. Piecuch, J.T. Reager, H. Chandanpurkar, T. Frederikse, R.S. Nerem, J.T. Fasullo, and S.-H. Cheon, 2020b: Origin of interannual variability in global mean sea level. *Proceedings of the National Academy of Sciences*, 117 (25), 13983. http://dx.doi.org/10.1073/pnas.1922190117

Hamlington, B.D., T. Frederikse, P.R. Thompson, J.K. Willis, R.S. Nerem, and J.T. Fasullo, 2021: Past, present, and future Pacific sea-level change. *Earth's Future*, 9 (4), e2020EF001839. https://doi.org/10.1029/2020EF001839

Hammond, W.C., G. Blewitt, C. Kreemer, and R.S. Nerem, 2021: GPS imaging of global vertical land motion for studies of sea level rise. *Journal of Geophysical Research: Solid Earth*, 126 (7), e2021JB022355. https://doi.org/10.1029/2021JB022355

Hawley, W.B., C.C. Hay, J.X. Mitrovica, and R.E. Kopp., 2020: A spatially variable time series of sea level change due to artificial water impoundment. *Earth's Future*, 8 (7), e2020EF001497. https://doi.org/10.1029/2020EF001497

Hemer, Mark A., Y. Fan, N. Mori, A. Semedo, and X.L. Wang, 2013: Projected changes in wave climate from a multi-model ensemble. *Nature Climate Change*, 3 (5), 471–476. https://doi.org/10.1038/nclimate1791

Hinkel, J., J.C.J.H. Aerts, S. Brown, J.A. Jiménez, D. Lincke, R.J. Nicholls, P. Scussolini, A. Sanchez-Arcilla, A. Vafeidis, and K.A. Addo, 2018: The ability of societies to adapt to twenty-first-century sea-level rise. *Nature Climate Change*, 8 (7), 570–578. https://doi.org/10.1038/s41558-018-0176-z

Hosking, J.R.M. and J. R. Wallis, 1997: *Regional Frequency Analysis: An Approach Based on L-Moments*. Cambridge University Press, Cambridge, U.K, 224 pp.

IPCC, 2021a: Climate Change 2021: *The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. https://www.ipcc.ch/report/ar6/wg1/

IPCC, 2021b: *Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [MassonDelmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. https://www.ipcc.ch/report/ar6/wg1/

Karegar, M.A., T.H. Dixon, and S.E. Engelhart, 2016: Subsidence along the Atlantic Coast of North America: Insights from GPS and late Holocene relative sea level data. *Geophysical Research Letters*, 43, 3126–3133. https://doi.org/10.1002/2016GL068015

King, D., D. Schrag, Z. Dadi, Q. Ye, and A. Gosh, 2015: Climate Change: A Risk Assessment. Hynard, J. and T. Rodger, Eds. Centre for Science and Policy, Cambridge, UK, 154 pp. www.csap.cam.ac.uk/projects/climate-change-risk-assessment/

Kirwan, M.L. and K.B. Gedan, 2019: Sea-level driven land conversion and the formation of ghost forests. *Nature Climate Change*, 9 (6), 450–457. https://doi.org/10.1038/s41558-019-0488-7

Konikow, L.F., 2011: Contribution of global groundwater depletion since 1900 to sea-level rise. *Geophysical Research Letters*, 38 (17). https://doi.org/10.1029/2011GL048604

Kopp, R.E., R.M. Horton, C.M. Little, J.X. Mitrovica, M. Oppenheimer, D.J. Rasmussen, B.H. Strauss, and C. Tebaldi, 2014: Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future*, 2 (8), 383–406. https://doi.org/10.1002/2014EF000239

Kopp, R.E., R.M. DeConto, D.A. Bader, C.C. Hay, R.M. Horton, S. Kulp, M. Oppenheimer, D. Pollard, and B.H. Strauss, 2017: Evolving understanding of Antarctic ice-sheet physics and ambiguity in probabilistic sea-level projections." *Earth's Future*, 5 (12), 1217–1233. https://doi.org/10.1002/2017EF000663

Kopp, R.E., E.A. Gilmore, C.M. Little, J. Lorenzo-Trueba, V.C. Ramenzoni, and W.V. Sweet, 2019: Usable science for managing the risks of sea-level rise. *Earth's Future*, 7, 1235–1269. https://doi.org/10.1029/2018EF001145

Krasting, J.P., J.P. Dunne, R.J. Stouffer, and R.W. Hallberg, 2016: Enhanced Atlantic sea-level rise relative to the Pacific under high carbon emission rates. *Nature Geoscience*, 9 (3), 210–214. http://dx.doi.org/10.1038/ngeo2641

Langbein W.B., 1949: Annual floods and the partial-duration flood series. *Eos, Transactions American Geophysical Union*, 30 (6), 879–881. https://doi.org/10.1029/TR030i006p00879

Larsen, C.F., R.J. Motyka, J.T. Freymueller, K.A. Echelmeyer, and E.R. Ivins, 2004: Rapid uplift of southern Alaska caused by recent ice loss. *Geophysical Journal International*, 158 (3), 1118–1133. http://dx.doi.org/10.1111/j.1365-246X.2004.02356.

Levermann, A., R. Winkelmann, T. Albrecht, H. Goelzer, N.R. Golledge, R. Greve, P. Huybrechts J. Jordan, G. Leguy, D. Martin, M. Morlighem, F. Pattyn, D. Pollard, A. Quiquet, C. Rodehacke, H. Seroussi, J. Sutter, T. Zhang, J. Van Breedam, R. Calov, R. DeConto, C. Dumas, J. Garbe, G.H. Gudmundsson, M.J. Hoffman, A. Humbert, T. Kleiner, W.H. Lipscomb, M. Meinshausen, E. Ng, S.M.J. Nowicki, M. Perego, S.F. Price, F. Saito, N.J. Schlegel, S. Sun, and R.S.W. van de Wal, 2020: Projecting Antarctica's contribution to future sea level rise from basal ice shelf melt using linear response functions of 16 ice sheet models (LARMIP-2). *Earth System Dynamics*, 11 (1), 35–76. https://doi.org/10.5194/esd-11-35-2020

Longuet-Higgins, M.S. and R.W. Stewart, 1963: A note on wave set-up. *Journal of Marine Research*, 21 (4), 4–10. https://images.peabody.yale.edu/publications/jmr/jmr21-01-01.pdf

Lyu, K., X. Zhang, J.A. Church, A.B.A. Slangen, and J. Hu. 2014: Time of emergence for regional sea-level change. *Nature Climate Change*, 4 (11), 1006–1010. https://doi.org/10.1038/nclimate2397

Marzeion, B., A.H. Jarosch, and M. Hofer, 2012: Past and future sea-level change from the surface mass balance of glaciers. *The Cryosphere*, 6 (6), 1295–1322. https://doi.org/10.5194/tc-6-1295-2012

Marzeion, B., R. Hock, B. Anderson, A. Bliss, N. Champollion, K. Fujita, M. Huss, W.W. Immerzeel, P. Kraaijenbrink, J.-H. Malles, F. Maussion, V. Radić, D.R. Rounce, A. Sakai, S. Shannon, R. van de Wal, and H. Zekollari, 2020: Partitioning the uncertainty of ensemble projections of global glacier mass change. *Earth's Future*, 8 (7), e2019EF001470. https://doi.org/10.1029/2019EF001470

McCallum, B.E., S.M. Wicklein, R.G. Reiser, R. Busciolano, J. Morrison, R.J. Verdi, J.A. Painter, E.R. Frantz, and A.J. Gotvald, 2013: Monitoring Storm Tide and Flooding from Hurricane Sandy along the Atlantic Coast of the United States, October 2012. Open File Report 2013-1043. U.S. Geological Survey, Reston, VA, 42 pp. http://dx.doi.org/10.3133/ofr20131043

McKenzie, T., S. Habel, and H. Dulai, 2021: Sea-level rise drives wastewater leakage to coastal waters and storm drains. *Limnology and Oceanography Letters*, 6, 154–163. https://doi.org/10.1002/lol2.10186

Menéndez, M., and P.L. Woodworth, 2010: Changes in extreme high water levels based on a quasi-global tide-gauge data set. *Journal of Geophysical Research: Oceans*, 115, C10011. https://doi.org/10.1029/2009JC005997

Merrifield, M.A., A.S. Genz, C.P. Kontoes, and J.J. Marra, 2013: Annual maximum water levels from tide gauges: Contributing factors and geographic patterns. *Journal of Geophysical Research: Oceans*, 118 (5), 2535–2546. https://doi.org/10.1002/jgrc.20173

Milne, G.A. and J.X. Mitrovica, 1998: Postglacial sea-level change on a rotating Earth. *Geophysical Journal International*, 133 (1), 1–19. https://doi.org/10.1046/j.1365-246X.1998.1331455.x

Mitrovica, J.X., M.E. Tamisiea, J.L. Davis, and G.A. Milne, 2001: Recent mass balance of polar ice sheets inferred from patterns of global sea-level change. *Nature*, 409 (6823), 1026–1029. https://doi.org/10.1038/35059054

Moftakhari, H. R., Jay, D. A., & Talke, S. A. (2016). Estimating river discharge using multiple-tide gauges distributed along a channel. *Journal of Geophysical Research: Oceans*, 121 (4), 2078–2097. https://doi.org/10.1002/2015JC010983

Moore, F.C. and N. Obradovich, 2020: Using remarkability to define coastal flooding thresholds. *Nature Communications*, 11 (1), 1–8. https://doi.org/10.1038/s41467-019-13935-3

Muis, S., M. Verlaan, H.C. Winsemius, J.C.J.H. Aerts, and P.J. Ward, 2016: A global reanalysis of storm surges and extreme sea levels. *Nature Communications*, 7 (1), 11969. http://dx.doi.org/10.1038/ncomms11969

Nadal-Caraballo, N.C., M.O. Campbell, V.M. Gonzalez, M.J. Torres, J.A. Melby, and A.A. Taflanidis, 2020: Coastal Hazards System: A probabilistic coastal hazard analysis framework. *Journal of Coastal* Research, 95 (SI), 1211–1216. http://dx.doi.org/10.2112/SI95-235.1

NGS, 2001: Geodetic Program Needs of Louisiana and Wisconsin: Report to Congress. National Oceanic and Atmospheric Administration, National Ocean Service, National Geodetic Survey, Silver Spring, MD, 38 pp. https://www.ngs.noaa.gov/PUBS_LIB/NGSreport_823.pdf

NOAA, 2003: Computational Techniques for Tidal Datums Handbook. NOAA Special Publication NOS CO-OPS 2. National Oceanic and Atmospheric Administration, National Ocean Service, Center for Operational Oceanographic Products and Services, Silver Spring, MD, 113 pp. https://tidesandcurrents.noaa.gov/publications/Computational_Techniques_for_Tidal_Datums_handbook.pdf

NOAA, 2020: Surf Zone Forecast and Coastal/Lakeshore Hazard Services. National Weather Service Instruction 10-320. National Oceanic and Atmospheric Administration, National Weather Service, 38 pp. http://www.nws.noaa.gov/directives/sym/pd01003020curr.pdf

NOAA NOS and U.S. Census Bureau, 2013: National Coastal Population Report: Population Trends from 1970 to 2020. National Oceanic and Atmospheric Administration, National Ocean Service, and U.S. Census Bureau, Silver Spring, MD, 22 pp. https://aambpublicoceanservice.blob.core.windows.net/oceanserviceprod/facts/coastal-population-report.pdf

Obeysekera, J. and J. Salas, 2020: Hydrologic designs for extreme events under nonstationarity. In: *Engineering Methods for Precipitation under a Changing Climate*. Olsen, J.R. and K.T. Adamec, Eds. American Society of Civil Engineers, 63–82. http://dx.doi.org/10.1061/9780784415528.ch04

One Climate Future, 2019: One Climate Future Climate Change Vulnerability Assessment. One Climate Future, Cities of Portland and South Portland, 181 pp. https://www.oneclimatefuture.org/wp-content/uploads/2020/12/OneClimateFuture_VulnerabilityAssessment_Final.pdf

Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, 2019: Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In Press. https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/08_SROCC_Ch04_FINAL.pdf

Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss, 2012: Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Report OAR CPO-1. National Oceanic and Atmospheric Administration, Climate Program Office, 37 pp. https://repository.library.noaa.gov/view/noaa/11124

Perica, S., S. Pavlovic, M. St. Laurent, C. Trypaluk, D. Unruh, and O. Wilhite, 2018: Precipitation-Frequency Atlas of the United States. Volume 11, Version 2.0 Texas. National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, MD. https://repository.library.noaa.gov/view/noaa/22619

Piecuch, C. G. and, & Quinn, K. J. 2016: El Niño, La Niña, and the global sea level budget. *Ocean Science*, 12 (6), 1165–1177. https://doi.org/10.5194/os-12-1165-2016

Reguero, B.G., M. Menéndez, F.J. Méndez, R. Mínguez, and I.J. Losada. 2012: A Global Ocean Wave (GOW) calibrated reanalysis from 1948 onwards. *Coastal Engineering*. 65, 38–55. https://doi.org/10.1016/j.coastaleng.2012.03.003

Richter, K., B. Meyssignac, A.B.A. Slangen, A. Melet, J.A. Church, X. Fettweis, B. Marzeion, C. Agosta, S.R.M. Ligtenberg, G. Spada, M.D. Palmer, C.D. Roberts, and N. Champollion, 2020: Detecting a forced signal in satellite-era sea-level change. *Environmental Research Letters*, 15 (9), 094079. https://doi.org/10.1088/1748-9326/ab986e

Rydlund, P. H. Jr., B. J. Densmore (2012). Methods of practice and guidelines for using survey-grade Global Navigation Satellite Systems (GNSS) to establish vertical datum in the United States Geological Survey. Chapter 1 of Section D, Field Survey Methods, Book 11, *Collection and Delineation of Spatial Data*. U.S. Geological Survey, Reston, Virginia, 102 pp. with appendixes. http://pubs.usgs.gov/tm/11d1/

Salas, J.D., and J. Obeysekera, 2014: Revisiting the concepts of return period and risk for nonstationary hydrologic extreme events. *Journal of Hydrologic Engineering*, 19 (3) 554–568. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000820

Salas, J.D., J. Obeysekera, and R. Vogel, 2018: Techniques for assessing water infrastructure for nonstationary extreme events: A review. *Hydrologic Science Journal*, 63 (3), 325–352. https://doi.org/10.1080/02626667.2018.1426858

Salas, J.D. and J. Obeysekera, 2019: Probability distribution and risk of the first occurrence of k extreme hydrologic events. *Journal of Hydrologic Engineering*, 24 (10), 04019032. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001809

Slangen, A.B.A., M. Carson, C.A. Katsman, R.S.W. van de Wal, A. Köhl, L.L.A. Vermeersen, and D. Stammer, 2014: Projecting twenty-first century regional sea-level changes. *Climatic Change*, 124 (1), 317–332. http://dx.doi.org/10.1007/s10584-014-1080-9

Stockdon H.F., R.A. Holman, P.A. Howd, and A.H. Sallenger, Jr., 2006: Empirical parameterization of setup, swash, and runup. *Coastal Engineering*, 53 (7), 573–588. https://doi.org/10.1016/j.coastaleng.2005.12.005

Sutton, R.T., 2019: Climate science needs to take risk assessment much more seriously. *Bulletin of the* American *Meteorological Society*, 100 (9), 1637–1642. https://doi.org/10.1175/BAMS-D-18-0280.1

Sweeney, B. and A. Becker, 2020: Considering future sea level change in maritime infrastructure design: A survey of US Engineers. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 146 (4), 04020019. http://dx.doi.org/10.1061/(ASCE)WW.1943-5460.0000583

Sweet, W.V. and J. Park, 2014: From the extreme to the mean: Acceleration and tipping points of coastal inundation from sea level rise. *Earth's Future*, 2 (12), 579–600. https://doi.org/10.1002/2014EF000272

Sweet, W.V., J. Park, S. Gill, and J. Marra, 2015: New ways to measure waves and their effects at NOAA tide gauges: A Hawaiian-network perspective. *Geophysical Research Letters*, 42 (21), 9355–9361. https://doi.org/10.1002/2015GL066030

Sweet, W.V., R.E. Kopp, C.P. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, and C. Zervas, 2017: Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083. National Oceanic and Atmospheric Administration, National Ocean Service, Center for Operational Oceanographic Products and Services, Silver Spring, MD, 75 pp. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

Sweet, W.V., G. Dusek, J. Obeysekera, and J.J. Marra, 2018: Patterns and Projections of High Tide Flooding Along the U.S. Coastline Using a Common Impact Threshold. NOAA Technical Report NOS CO-OPS 086. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 44 pp. https://tidesandcurrents.noaa.gov/publications/techrpt86_PaP_of_HTFlooding.pdf

Sweet, W.V., G. Dusek, G. Carbin, J.J. Marra, D. Marcy, and S. Simon, 2020a: 2019 State of U.S. High Tide Flooding with a 2020 Outlook. NOAA Technical Report NOS CO-OPS 092. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 24 pp. https://tidesandcurrents.noaa.gov/publications/Techrpt_092_2019_State_of_US_High_Tide_Flooding_with_a_2020_Outlook_30June2020.pdf

Sweet, W.V., A.S. Genz, J. Obeysekera, and J.J. Marra. 2020b: A regional frequency analysis of tide gauges to assess Pacific coast flood risk. *Frontiers in Marine Science*, 7, 883. https://doi.org/10.3389/fmars.2020.581769

Sweet, W.V., S. Simon, G. Dusek, D. Marcy, W. Brooks, M. Pendleton, and J. Marra, 2021: 2021 State of High Tide Flooding and Annual Outlook. NOAA High Tide Flooding Report. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 28 pp. https://tidesandcurrents.noaa.gov/publications/2021_State_of_High_Tide_Flooding_and_Annual_Outlook_Final.pdf

Tebaldi, C., B.H. Strauss, and C.E. Zervas, 2012: Modelling sea level rise impacts on storm surges along US coasts. *Environmental Research Letters*, 7 (1), 014032. https://doi.org/10.1088/1748-9326/7/1/014032

Thompson, P.R., M.J. Widlansky, B.D. Hamlington, M.A. Merrifield, J.J. Marra, G.T. Mitchum, and W. Sweet, 2021: Rapid increases and extreme months in projections of United States high-tide flooding. *Nature Climate Change*, 1–7. https://doi.org/10.1038/s41558-021-01077-8

USACE, 1994: Engineering and Design: Hydrologic Frequency Estimates. ER 1110-2-1450. U.S. Army Corps of Engineers, Washington, DC, 8 pp. https://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1110-2-1450.pdf

USACE. 2014. Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation. Technical Letter 1100-2-1. U.S. Army Corps of Engineers, Washington, DC, 254 pp. https://www.publications.usace.army.mil/portals/76/publications/engineertechnicalletters/etl_1100-2-1.pdf

USACE MRG&P, 2017: 2015 Updated Atlas of U.S. Army Corps of Engineers Historic Daily Tide Data in Coastal Louisiana. MRG&P Report No. 14. U.S. Army Corps of Engineers, Mississippi River Geomorphology and Potamology Program, New Orleans, LA, 41 pp. https://erdc-library.erdc.dren.mil/jspui/bitstream/11681/25484/1/MRG%26P%20Report%20No%2014.pdf

USGCRP, 2017: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp. doi:10.7930/J0J964J6

USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi:10.7930/NCA4.2018

Vitousek, S., P.L. Barnard, C.H. Fletcher, N. Frazer, L. Erikson, and C.D. Storlazzi, 2017: Doubling of coastal flooding frequency within decades due to sea-level rise. *Scientific Reports*, 7 (1), 1–9. http://dx.doi.org/10.1038/s41598-017-01362-7

Vousdoukas, M.I., L. Mentaschi, E. Voukouvalas, M. Verlaan, S. Jevrejeva, L.P. Jackson, and L. Feyen, 2018: Global probabilistic projections of extreme sea levels show intensification of coastal flood hazard. *Nature Communications*, 9 (1), 2360. http://dx.doi.org/10.1038/s41467-018-04692-w

Wada, Y., L.P.H. Van Beek, F.C. Sperna Weiland, B.F. Chao, Y.-H. Wu, and M.F.P. Bierkens, 2012: Past and future contribution of global groundwater depletion to sea-level rise. *Geophysical Research Letters*, 39 (9). https://doi.org/10.1029/2012GL051230

Wada, Y., M.-H. Lo, P.J.F. Yeh, J.T. Reager, J.S. Famiglietti, R.-J. Wu, and Y.-H. Tseng, 2016: Fate of water pumped from underground and contributions to sea-level rise. *Nature Climate Change*, 6 (8), 777–780. http://dx.doi.org/10.1038/nclimate3001

Wahl, T., I.D. Haigh, R.J. Nicholls, A. Arns, S. Dangendorf, J. Hinkel, and A.B. Slangen, 2017: Understanding extreme sea levels for broad-scale coastal impact and adaptation analysis. *Nature Communications*, 8 (1), 16075. http://dx.doi.org/10.1038/ncomms16075

Wang, J., Church, J. A., Zhang, X., & Chen, X. (2021). Reconciling global mean and regional sea level change in projections and observations. *Nature Communications*, 12 (1), 1–12. https://doi.org/10.1038/s41467-021-21265-6

WCRP Global Sea Level Budget Group, 2018: Global sea-level budget 1993–present. *Earth System Science Data*, 10, 1551–1590. http://dx.doi.org/10.5194/essd-10-1551-2018

Weaver, C.P., R.H. Moss, K.L. Ebi, P.H. Gleick, P.C. Stern, C. Tebaldi, R.S. Wilson, and J.L. Arvai, 2017: Reframing climate change assessments around risk: Recommendations for the US National Climate Assessment. *Environmental Research Letters*, 12 (8), 080201. https://doi.org/10.1088/1748-9326/aa7494

Werners, S.E., R.M. Wise, J.R.A. Butler, E. Totin, and K. Vincent, 2021: Adaptation pathways: A review of approaches and a learning framework. *Environmental Science & Policy*, 116, 266–275. https://doi.org/10.1016/j.envsci.2020.11.003

Yin, J., M.E. Schlesinger, and R.J. Stouffer, 2009: Model projections of rapid sea-level rise on the northeast coast of the United States. *Nature Geoscience*, 2 (4), 262–266. https://doi.org/10.1038/ngeo462

Zervas, C., 2013: Extreme Water Levels of the United States 1893–2010. NOAA Technical Report NOS CO-OPS 067. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 212 pp. https://tidesandcurrents.noaa.gov/publications/NOAA_Technical_Report_NOS_COOPS_067a.pdf

Section A1: Tables and Figures

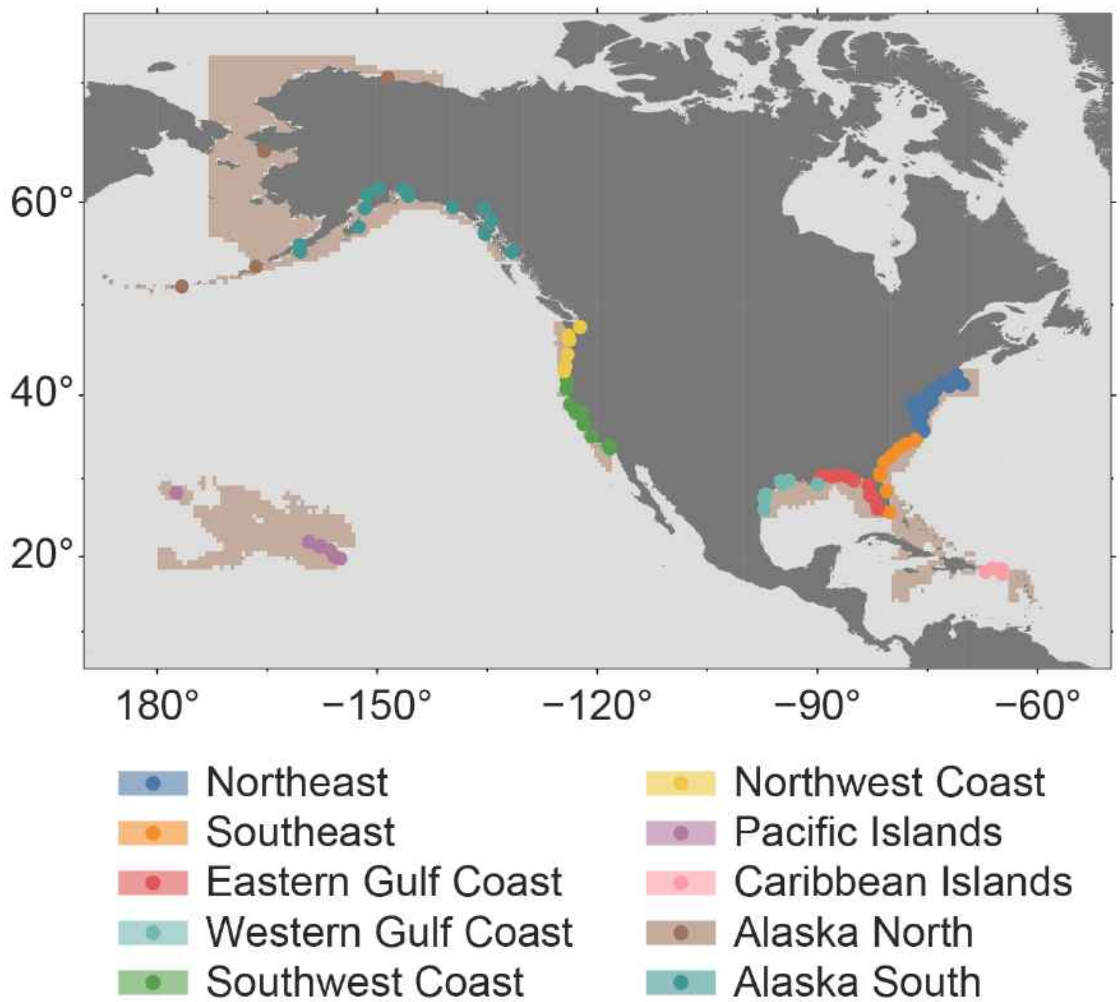


Figure A1.1: Region definitions for observation-based extrapolations and scenarios in Section 2. These regions are used both to group tide gauges and also to generate regional averages for the gridded scenarios. A bathymetry mask is used to define the regions for the gridded scenarios.

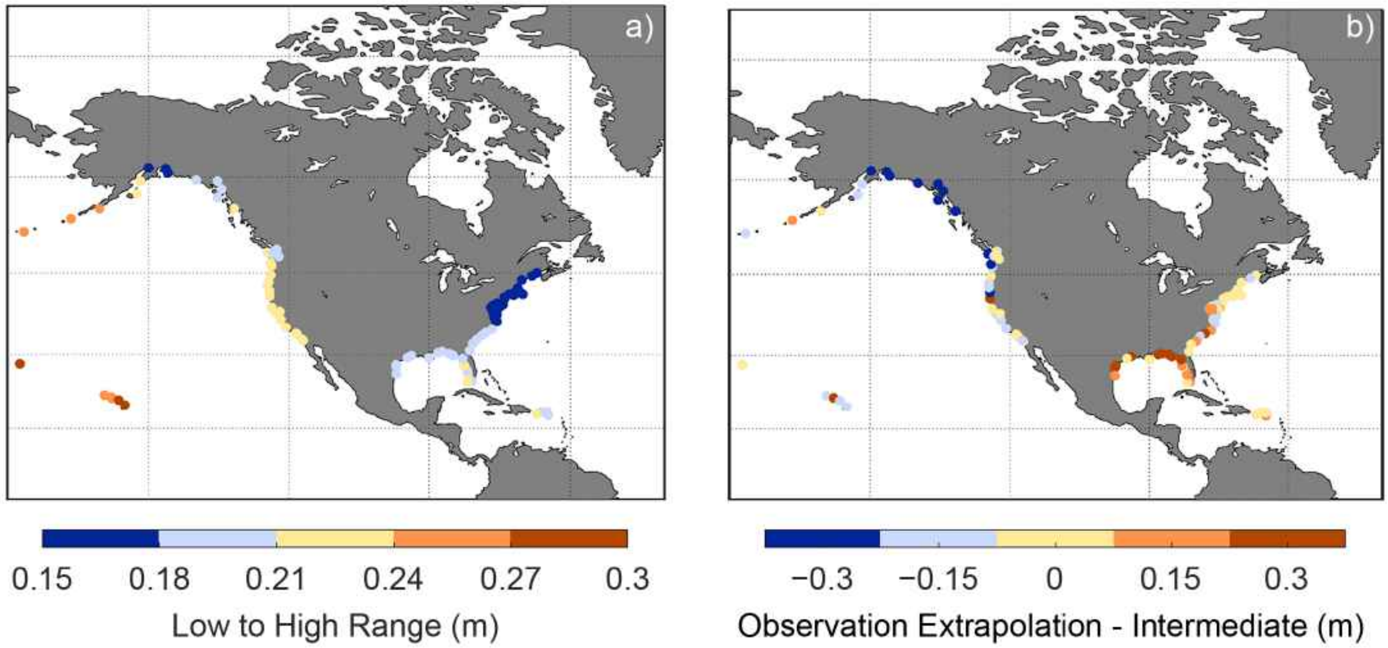


Figure A1.2. Shown for each tide gauge record with at least 30 years of record length between 1970 and 2020 are a) range, in meters, between median projection of Low and High Scenarios in 2050, and b) difference, in meters, between median observation-based extrapolation and Intermediate scenario in 2050.

Table A1.1: Projections methods employed.

Driver of GMSL or RSL change	Kopp et al. (2014) projection method (used in Sweet et al., 2017)	AR6 (Fox-Kemper et al., 2021) projection methods (used here)
Thermal expansion	CMIP5 ensemble drift-corrected zostoga	Two-layer model with climate sensitivity calibrated to the IPCC assessment and expansion coefficients calibrated to emulate CMIP6 models
Greenland ice sheet	*Likely* range from IPCC AR5, with shape of tails based on structured expert judgment (Bamber and Aspinall, 2013)	1. Emulated ISMIP6 simulations through 2100 (Edwards et al., 2021), extended after 2100 based on constant post-2100 rates 2. Structured expert judgment (Bamber et al., 2019)
Antarctic ice sheet	*Likely* range from IPCC AR5, with shape of tails based on structured expert judgment (Bamber and Aspinall, 2013)	1. Emulated ISMIP6 simulations through 2100 (Edwards et al., 2021), extended after 2100 with constant rates based on the IPCC AR5 parametric Antarctic Ice Sheet model (Church et al., 2013) 2. LARMIP-2 simulations (Levermann et al., 2020) augmented by AR5 surface mass balance model (Church et al., 2013), extended past 2100 based on constant rates 3. Single ice-sheet model incorporated marine ice cliff instability (DeConto et al., 2021) 4. Structured expert judgment (Bamber et al., 2019)
Glaciers	Distribution based on Marzeion et al. (2012) surface mass balance model	Emulated GlacierMIP (Marzeion et al., 2020; Edwards et al., 2021) extended after 2100 with IPCC AR5 parametric model refit to GlacierMIP (Marzeion et al., 2020)
Land water storage	Groundwater depletion: Population/ groundwater depletion relationship calibrated based on Konikow (2011) and Wada et al. (2012) Water impoundment: Population/dam impoundment relationship calibrated based on Chao et al. (2008)	Groundwater depletion: Updated population/groundwater depletion relationship calibrated based on Konikow (2011) and Wada et al. (2012, 2016) Water impoundment: Population/dam impoundment relationship calibrated based on Chao et al. (2008), adjusted for new construction, following Hawley et al. (2020) for 2020 to 2040
Ocean dynamic sea level	Distribution derived from CMIP5 ensemble zos field	Distribution derived from CMIP6 ensemble zos field after linear drift removal
Gravitational, rotational, and deformational effects	Sea-level equation solver (Mitrovica et al., 2011) driven by projections of ice-sheet and glacier changes	Sea-level equation solver (Slangen et al., 2014) driven by projections of ice-sheet, glacier, and land water storage changes
GIA and other drivers of VLM	Spatiotemporal statistical model of tide-gauge data	Spatiotemporal statistical model of tide-gauge data (updated from Kopp et al., 2014)

Table A1.2: Offsets, in meters, for different time periods and for each region considered in Section 2. These offsets are assessed using the trajectory determined from the available tide-gauge data in each region.

	1992–2000	2000–2005	2005–2020
Contiguous U.S.	0.02	0.03	0.08
Northeast	0.03	0.02	0.09
Southeast	0.03	0.02	0.09
Eastern Gulf	0.03	0.02	0.1
Western Gulf	0.05	0.04	0.14
Southwest	0.01	0.01	0.05
Northwest	0.01	0.01	0.04
Hawaiian Islands	0.02	0.02	0.06
Caribbean	0.02	0.01	0.06

Table A1.3: Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
Pacific	39509	1611400	Nawiliwili, HI	21.95	−159.36	0.558	0.244	1.7	1983–2001	0.522	0.817	1.192
	39511	1612340	Honolulu, HI	21.31	−157.87	0.580	0.248	1.3	1983–2001	0.523	0.817	1.193
	39511	1612480	Mokuoloe, HI	21.43	−157.79	0.646	0.265	2.0	1983–2001	0.526	0.819	1.196
	39153	1615680	Kahului, HI	20.90	−156.48	0.686	0.252	2.1	1983–2001	0.527	0.821	1.197
	39154	1617433	Kawaihae, HI	20.04	−155.83	0.659	0.237	7.9	1983–2001	0.526	0.820	1.196
	38795	1617760	Hilo, HI	19.73	−155.06	0.731	0.272	3.1	1983–2001	0.529	0.822	1.199
	37704	1619000	Johnston Atoll	16.74	−169.53	0.674	0.295	2.2	1983–2001	0.527	0.820	1.197
	42004	1619910	Midway Islands	28.21	−177.36	0.381	0.303	1.9	1983–2001	0.515	0.811	1.185
	36941	1630000	Apra Harbor, Guam	13.44	144.65	0.715	0.249	4.2	1983–2001	0.529	0.821	1.199
	36941	1631428	Pago Bay, Guam	13.43	144.80	0.525	0.287	4.2	1983–2001	0.521	0.816	1.191
	26574	1770000	American Samoa	−14.28	189.32	0.848	0.338	3.8	1983–2001	0.497	0.788	1.167
	35169	1820000	Kwajalein	8.73	167.74	1.194	0.446	3.1	1983–2001	0.548	0.836	1.218
	39117	1890000	Wake Island	19.29	166.62	0.718	0.295	2.1	1983–2001	0.529	0.822	1.199
NE	47859	8410140	Eastport, ME	44.90	−66.98	5.874	0.930	2.1	1983–2001	0.735	0.976	1.405
	47858	8411250	Cutler Naval Base, ME	44.64	−67.30	4.133	0.716	2.4	1983–2001	0.665	0.924	1.335
	47857	8413320	Bar Harbor, ME	44.39	−68.21	3.465	0.657	2.1	1983–2001	0.639	0.904	1.309
	47496	8418150	Portland, ME	43.66	−70.25	3.019	0.605	1.9	1983–2001	0.621	0.891	1.291
	47496	8419317	Wells, ME	43.32	−70.56	2.914	0.667	3.5	1983–2001	0.617	0.887	1.287
	47496	8423898	Fort Point, NH	43.07	−70.71	2.864	0.662	3.5	1983–2001	0.615	0.886	1.285
	47136	8443970	Boston, MA	42.35	−71.05	3.131	0.634	2.8	1983–2001	0.625	0.894	1.295
	46777	8447386	Fall River, MA	41.70	−71.16	1.456	0.566	3.5	1983–2001	0.558	0.844	1.228
	46778	8447930	Woods Hole, MA	41.52	−70.67	0.672	0.446	3.2	1983–2001	0.527	0.820	1.197
	46778	8449130	Nantucket Island, MA	41.29	−70.10	1.089	0.418	3.8	1983–2001	0.544	0.833	1.214
	46777	8452660	Newport, RI	41.51	−71.33	1.174	0.478	2.8	1983–2001	0.547	0.835	1.217

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
NE (cont.)	46777	8452944	Conimicut Light, RI	41.72	−71.34	1.398	0.560	3.5	1983–2001	0.556	0.842	1.226
	46777	8454000	Providence, RI	41.81	−71.40	1.476	0.549	2.3	1983–2001	0.559	0.844	1.229
	46777	8454049	Quonset Point, RI	41.59	−71.41	1.249	0.547	3.5	1983–2001	0.550	0.837	1.220
	46776	8461490	New London, CT	41.36	−72.09	0.930	0.468	2.6	1983–2001	0.537	0.828	1.207
	46776	8465705	New Haven, CT	41.28	−72.91	2.045	0.603	3.5	1983–2001	0.582	0.861	1.252
	46775	8467150	Bridgeport, CT	41.17	−73.18	2.231	0.555	3.0	1983–2001	0.589	0.867	1.259
	46777	8510560	Montauk, NY	41.05	−71.96	0.771	0.487	3.4	1983–2001	0.531	0.823	1.201
	46416	8514560	Port Jefferson, NY	40.95	−73.08	2.181	0.527	2.5	1983–2001	0.587	0.865	1.257
	46416	8516945	Kings Point, NY	40.81	−73.76	2.378	0.638	2.5	1983–2001	0.597	0.873	1.267
	46415	8518750	The Battery, NY	40.70	−74.01	1.542	0.546	3.1	1983–2001	0.562	0.846	1.232
	46415	8519483	Bergen Point, NY	40.64	−74.14	1.681	0.549	4.4	1983–2001	0.567	0.850	1.237
	46415	8531680	Sandy Hook, NJ	40.47	−74.01	1.593	0.552	2.7	1983–2001	0.564	0.848	1.234
	46056	8534720	Atlantic City, NJ	39.36	−74.42	1.403	0.534	4.1	1983–2001	0.556	0.842	1.226
	45697	8536110	Cape May, NJ	38.97	−74.96	1.659	0.486	4.7	1983–2001	0.566	0.850	1.236
	46055	8537121	Ship John Shoal, NJ	39.31	−75.38	1.894	0.578	3.5	1983–2001	0.576	0.857	1.246
	46055	8540433	Marcus Hook, PA	39.81	−75.41	1.871	0.563	3.5	1983–2001	0.575	0.856	1.245
	46055	8545240	Philadelphia, PA	39.93	−75.14	2.039	0.462	3.1	1983–2001	0.582	0.861	1.252
	46055	8551762	Delaware City, DE	39.58	−75.59	1.830	0.540	3.5	1983–2001	0.573	0.855	1.243
	46055	8551910	Reedy Point, DE	39.56	−75.57	1.779	0.423	4.1	1983–2001	0.571	0.853	1.241
	45696	8555889	Brandywine Shoal, DE	38.99	−75.11	1.676	0.616	3.5	1983–2001	0.567	0.850	1.237
	45696	8557380	Lewes, DE	38.78	−75.12	1.418	0.530	3.5	1983–2001	0.557	0.843	1.227
	45696	8570280	Ocean City, MD	38.33	−75.08	1.187	0.413	3.5	1983–2001	0.547	0.836	1.217
	45696	8570283	Ocean City Inlet, MD	38.33	−75.09	0.751	0.360	3.5	1983–2001	0.530	0.823	1.200
	45695	8571421	Bishops Head, MD	38.22	−76.04	0.624	0.503	3.5	1983–2001	0.525	0.819	1.195

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
NE (cont.)	45695	8571892	Cambridge, MD	38.57	−76.07	0.622	0.414	4.9	1983–2001	0.525	0.819	1.195
	46054	8573364	Tolchester Beach, MD	39.21	−76.25	0.527	0.484	2.5	1983–2001	0.519	0.814	1.189
	46055	8573927	Chesapeake City, MD	39.53	−75.81	0.980	0.470	3.8	1983–2001	0.539	0.829	1.209
	46054	8574070	Havre De Grace, MD	39.54	−76.09	0.746	0.482	3.5	1983–2001	0.530	0.822	1.200
	46054	8574680	Baltimore, MD	39.27	−76.58	0.506	0.443	3.2	1983–2001	0.520	0.815	1.190
	45695	8575512	Annapolis, MD	38.98	−76.48	0.438	0.430	3.7	1983–2001	0.518	0.813	1.188
	45695	8577330	Solomons Island, MD	38.32	−76.45	0.449	0.398	6.0	1983–2001	0.518	0.813	1.188
	45694	8594900	Washington, DC	38.87	−77.02	0.965	0.461	3.3	1983–2001	0.539	0.829	1.209
	45337	8631044	Wachapreague, VA	37.61	−75.69	1.376	0.508	5.4	1983–2001	0.564	0.850	1.234
	45337	8632200	Kiptopeke, VA	37.17	−75.99	0.896	0.435	4.7	1983–2001	0.536	0.827	1.206
	45695	8635150	Colonial Beach, VA	38.25	−76.96	0.591	0.406	4.7	1983–2001	0.524	0.818	1.194
	45336	8635750	Lewisetta, VA	38.00	−76.46	0.458	0.420	5.6	1983–2001	0.518	0.814	1.188
	45336	8636580	Windmill Point, VA	37.62	−76.29	0.424	0.419	5.2	1983–2001	0.532	0.828	1.202
	45336	8637689	Yorktown, VA	37.23	−76.48	0.786	0.567	3.5	1983–2001	0.531	0.824	1.201
	44977	8638610	Sewells Point, VA	36.95	−76.33	0.841	0.502	4.6	1983–2001	0.534	0.825	1.204
	44977	8638863	CBBT, VA	36.97	−76.11	0.885	0.503	6.0	1983–2001	0.535	0.827	1.205
	44977	8639348	Money Point, VA	36.78	−76.30	0.977	0.528	5.6	1983–2001	0.539	0.829	1.209

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
SE	44978	8651370	Duck, NC	36.18	−75.75	1.124	0.494	4.6	1983–2001	0.545	0.834	1.215
	44619	8652587	Oregon Inlet, NC	35.80	−75.55	0.360	0.384	4.6	1983–2001	0.514	0.811	1.184
	44619	8654400	Cape Hatteras, NC	35.22	−75.64	1.056	0.412	3.2	1983–2001	0.542	0.832	1.212
	44619	8654467	USCG Hatteras, NC	35.21	−75.70	0.186	0.598	3.2	1983–2001	0.507	0.806	1.177
	44259	8656483	Beaufort, NC	34.72	−76.67	1.079	0.362	3.8	1983–2001	0.543	0.832	1.213
	44258	8658120	Wilmington, NC	34.23	−77.95	1.427	0.327	2.3	1983–2001	0.557	0.843	1.227
	44258	8658163	Wrightsville Beach, NC	34.21	−77.79	1.366	0.564	3.2	1983–2001	0.555	0.841	1.225
	43898	8661070	Springmaid Pier, SC	33.66	−78.92	1.707	0.493	2.9	1983–2001	0.568	0.851	1.238
	43897	8662245	Oyster Landing, SC	33.35	−79.19	1.561	0.496	3.2	1983–2001	0.562	0.847	1.232
	43538	8665530	Charleston, SC	32.78	−79.93	1.757	0.453	3.3	1983–2001	0.570	0.853	1.240
	43537	8670870	Fort Pulaski, GA	32.03	−80.90	2.287	0.500	3.3	1983–2001	0.591	0.869	1.261
	42818	8720030	Fernandina Beach, FL	30.67	−81.47	1.999	0.473	2.3	1983–2001	0.580	0.860	1.250
	42818	8720218	Mayport, FL	30.40	−81.43	1.508	0.378	2.6	1983–2001	0.557	0.842	1.227
	42818	8720357	St Johns River, FL	30.19	−81.69	0.312	0.333	3.2	1983–2001	0.512	0.809	1.182
	42459	8720587	St. Augustine Beach, FL	29.86	−81.26	1.569	0.531	3.2	1983–2001	0.563	0.847	1.233
	42101	8721604	Trident Pier, FL	28.42	−80.59	1.193	0.407	5.1	1983–2001	0.537	0.825	1.207
	41024	8723214	Virginia Key, FL	25.73	−80.16	0.667	0.317	5.1	1983–2001	0.518	0.811	1.188
	40664	8723970	Vaca Key, FL	24.71	−81.11	0.297	0.249	4.2	1983–2001	0.512	0.809	1.182
	40664	8724580	Key West, FL	24.56	−81.81	0.551	0.262	2.5	1983–2001	0.522	0.817	1.192

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
E. Gulf	41382	8725110	Naples, FL	26.13	−81.81	0.875	0.323	2.9	1983–2001	0.535	0.826	1.205
	41382	8725520	Fort Myers, FL	26.65	−81.87	0.401	0.325	3.1	1983–2001	0.516	0.812	1.186
	41740	8726384	Port Manatee, FL	27.64	−82.56	0.669	0.260	6.6	1983–2001	0.527	0.820	1.197
	41740	8726520	St Petersburg, FL	27.76	−82.63	0.688	0.337	2.8	1983–2001	0.528	0.821	1.198
	41740	8726607	Old Port Tampa, FL	27.86	−82.55	0.749	0.304	3.2	1983–2001	0.530	0.822	1.200
	41740	8726667	Mckay Bay Entrance, FL	27.91	−82.43	0.814	0.320	3.2	1983–2001	0.533	0.824	1.203
	41740	8726724	Clearwater Beach, FL	27.98	−82.83	0.841	0.294	7.1	1983–2001	0.540	0.831	1.210
	42457	8727520	Cedar Key, FL	29.14	−83.03	1.157	0.415	2.2	1983–2001	0.546	0.835	1.216
	42456	8728690	Apalachicola, FL	29.73	−84.98	0.492	0.390	3.0	1983–2001	0.520	0.815	1.190
	42814	8729108	Panama City, FL	30.15	−85.67	0.409	0.368	2.5	1983–2001	0.516	0.812	1.186
	42814	8729210	Panama City Beach, FL	30.21	−85.88	0.420	0.348	4.3	1983–2001	0.517	0.813	1.187
	42812	8729840	Pensacola, FL	30.40	−87.21	0.383	0.345	2.4	1983–2001	0.515	0.811	1.185
	42812	8732828	Mobile Bay, AL	30.42	−87.83	0.490	0.519	4.3	1983–2001	0.520	0.815	1.190
	42811	8735180	Dauphin Island, AL	30.25	−88.08	0.367	0.354	4.3	1983–2001	0.512	0.808	1.182
	42811	8736897	Mobile, AL	30.65	−88.06	0.517	0.535	4.3	1983–2001	0.521	0.816	1.191
	42811	8737048	Mobile State Docks, AL	30.71	−88.04	0.501	0.439	4.3	1983–2001	0.520	0.815	1.190
	42811	8741533	Pascagoula NOAA Lab, MS	30.37	−88.56	0.466	0.494	4.3	1983–2001	0.519	0.814	1.189
	42810	8747437	Bay Waveland Yacht Club, MS	30.33	−89.33	0.529	0.498	4.6	1983–2001	0.522	0.816	1.192

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
W. Gulf	42092	8760922	Pilots Station East, SW Pass, LA	28.93	−89.41	0.356	0.399	4.3	2012–2016	0.514	0.811	1.184
	42451	8761724	Grand Isle, LA	29.26	−89.96	0.323	0.309	7.8	2012–2016	0.428	0.725	1.098
	42809	8761927	New Canal Station, LA	30.03	−90.11	0.164	0.485	5.6	1983–2001	0.507	0.805	1.177
	42450	8762075	Port Fourchon, LA	29.11	−90.20	0.368	0.298	4.3	2012–2016	0.515	0.811	1.185
	42449	8764227	Amerada Pass, LA	29.45	−91.34	0.487	0.535	4.3	1983–2001	0.519	0.815	1.189
	42449	8765251	Cypremort Point, LA	29.71	−91.88	0.518	0.458	4.3	1983–2001	0.521	0.816	1.191
	42448	8766072	Freshwater Canal Locks, LA	29.56	−92.31	0.657	0.696	4.3	1983–2001	0.526	0.820	1.196
	42806	8767816	Lake Charles, LA	30.22	−93.22	0.427	0.494	4.3	1983–2001	0.517	0.813	1.187
	42447	8768094	Calcasieu Pass, LA	29.77	−93.34	0.589	0.465	6.1	1983–2001	0.524	0.818	1.194
	42447	8770570	Sabine Pass North, TX	29.73	−93.87	0.488	0.368	6.1	1983–2001	0.520	0.815	1.190
	42446	8770613	Morgans Point, TX	29.68	−94.99	0.398	0.488	3.1	1983–2001	0.535	0.831	1.205
	42446	8771013	Eagle Point, TX	29.48	−94.92	0.338	0.331	13.8	1983–2001	0.494	0.790	1.164
	42446	8771341	Galveston Bay Entrance, TX	29.36	−94.72	0.510	0.499	6.1	1983–2001	0.520	0.815	1.190
	42446	8771450	Galveston Pier 21, TX	29.31	−94.79	0.429	0.366	6.5	1983–2001	0.517	0.813	1.187
	42446	8771510	Galveston Pleasure Pier, TX	29.29	−94.79	0.622	0.425	6.5	1983–2001	0.525	0.819	1.195
	42086	8772440	Freeport, TX	28.95	−95.31	0.536	0.391	9.0	1983–2001	0.521	0.816	1.191
	42086	8772447	USCG Freeport, TX	28.94	−95.30	0.549	0.460	6.1	1983–2001	0.522	0.816	1.192
	42084	8774770	Rockport, TX	28.02	−97.05	0.111	0.336	5.7	2002–2006	0.504	0.803	1.174
	41725	8775870	Corpus Christi, TX	27.58	−97.22	0.497	0.391	4.8	1983–2001	0.529	0.824	1.199
	41366	8779770	Port Isabel, TX	26.06	−97.22	0.418	0.337	4.0	1983–2001	0.517	0.813	1.187

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
SW	43500	9410170	San Diego, CA	32.71	−117.17	1.745	0.490	2.2	1983–2001	0.570	0.852	1.240
	43500	9410230	La Jolla, CA	32.87	−117.26	1.624	0.468	2.1	1983–2001	0.565	0.849	1.235
	43858	9410660	Los Angeles, CA	33.72	−118.27	1.674	0.472	1.0	1983–2001	0.567	0.850	1.237
	44217	9410840	Santa Monica, CA	34.01	−118.50	1.654	0.489	1.8	1983–2001	0.566	0.850	1.236
	44216	9411340	Santa Barbara, CA	34.41	−119.69	1.645	0.485	0.6	1983–2001	0.566	0.849	1.236
	44574	9412110	Port San Luis, CA	35.18	−120.76	1.623	0.449	1.0	1983–2001	0.565	0.849	1.235
	44932	9413450	Monterey, CA	36.61	−121.89	1.627	0.431	1.6	1983–2001	0.565	0.849	1.235
	45290	9414290	San Francisco, CA	37.81	−122.47	1.780	0.375	1.9	1983–2001	0.571	0.853	1.241
	45290	9414523	Redwood City, CA	37.51	−122.21	2.501	0.400	2.7	1983–2001	0.600	0.875	1.270
	45290	9414750	Alameda, CA	37.77	−122.30	2.010	0.411	0.4	1983–2001	0.580	0.860	1.250
	45290	9414863	Richmond, CA	37.93	−122.40	1.846	0.359	3.1	1983–2001	0.574	0.855	1.244
	45290	9415020	Point Reyes, CA	38.00	−122.98	1.758	0.447	2.1	1983–2001	0.570	0.853	1.240
	45649	9415144	Port Chicago, CA	38.06	−122.04	1.498	0.388	1.4	1983–2001	0.560	0.845	1.230
	45648	9416841	Arena Cove, CA	38.91	−123.71	1.787	0.500	0.6	1983–2001	0.573	0.856	1.243
	46365	9418767	North Spit, CA	40.77	−124.22	2.090	0.491	4.8	1983–2001	0.584	0.863	1.254
	46724	9419750	Crescent City, CA	41.75	−124.18	2.095	0.548	-0.8	1983–2001	0.584	0.863	1.254
	47083	9431647	Port Orford, OR	42.74	−124.50	2.220	0.594	0.2	1983–2001	0.572	0.850	1.242
	47442	9432780	Charleston, OR	43.35	−124.32	2.323	0.586	1.1	1983–2001	0.593	0.870	1.263
	47801	9435380	South Beach, OR	44.63	−124.04	2.543	0.579	1.7	1983–2001	0.602	0.876	1.272
	48161	9437540	Garibaldi, OR	45.55	−123.92	2.536	0.597	2.4	1983–2001	0.601	0.876	1.271
	48520	9439040	Astoria, OR	46.21	−123.77	2.624	0.629	−0.2	1983–2001	0.605	0.879	1.275

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
NW	48520	9440910	Toke Point, WA	46.71	−123.97	2.720	0.807	0.6	1983–2001	0.609	0.882	1.279
	48519	9441102	Westport, WA	46.90	−124.11	2.786	0.670	1.9	1983–2001	0.611	0.884	1.281
	48878	9442396	La Push, WA	47.91	−124.64	2.577	0.766	1.9	1983–2001	0.603	0.877	1.273
	49237	9443090	Neah Bay, WA	48.37	−124.61	2.425	0.688	−1.7	1983–2001	0.597	0.873	1.267
	49238	9444090	Port Angeles, WA	48.13	−123.44	2.153	0.562	0.2	1983–2001	0.586	0.865	1.256
	49239	9444900	Port Townsend, WA	48.11	−122.76	2.597	0.538	1.7	1983–2001	0.604	0.878	1.274
	48880	9446484	Tacoma, WA	47.27	−122.41	3.595	0.517	3.4	1983–2001	0.644	0.908	1.314
	48880	9447130	Seattle, WA	47.60	−122.34	3.462	0.541	2.1	1983–2001	0.639	0.904	1.309
	49239	9449424	Cherry Point, WA	48.86	−122.76	2.788	0.585	0.4	1983–2001	0.612	0.884	1.282
	49238	9449880	Friday Harbor, WA	48.55	−123.01	2.364	0.554	1.2	1983–2001	0.595	0.871	1.265
Alaska	51743	9450460	Ketchikan, AK	55.33	−131.63	4.708	1.086	−0.4	1983–2001	2.059	2.359	2.759
	52099	9451054	Port Alexander, AK	56.25	−134.65	3.329	0.738	−5.8	1983–2001	1.031	1.331	1.731
	52457	9451600	Sitka, AK	57.05	−135.34	3.029	0.768	−2.4	1983–2001	0.883	1.183	1.583
	52817	9452210	Juneau, AK	58.30	−134.41	4.970	1.152	−15.1	2012–2016	2.319	2.619	3.019
	53175	9452400	Skagway, AK	59.45	−135.33	5.100	1.218	−19.9	2012–2016	2.456	2.756	3.156
	52815	9452634	Elfin Cove, AK	58.19	−136.35	3.360	1.149	−5.8	1983–2001	1.048	1.348	1.748
	53171	9453220	Yakutat, Yakutat Bay, AK	59.55	−139.73	3.070	0.891	−10.7	2012–2016	0.902	1.202	1.602
	53524	9454050	Cordova, AK	60.56	−145.75	3.838	0.937	0.8	1983–2001	1.344	1.644	2.044
	53882	9454240	Valdez, AK	61.13	−146.36	3.702	0.878	−5.8	1983–2001	1.253	1.553	1.953
	53520	9455090	Seward, AK	60.12	−149.43	3.238	0.884	−4.0	1983–2001	0.983	1.283	1.683
	53159	9455500	Seldovia, AK	59.44	−151.72	5.499	1.350	−9.8	2012–2016	2.906	3.206	3.606
	53518	9455760	Nikiski, AK	60.68	−151.40	6.262	1.254	−9.9	2012–2016	NaN	NaN	NaN
	53879	9455920	Anchorage, AK	61.24	−149.89	8.889	1.269	−2.7	1983–2001	NaN	NaN	NaN
	52440	9457292	Kodiak Island, AK	57.73	−152.51	2.675	0.715	−9.2	2012–2016	0.743	1.043	1.443

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
Alaska (cont.)	52079	9457804	Alitak, AK	56.90	−154.25	3.578	0.908	−5.8	2012–2016	1.174	1.474	1.874
	51714	9459450	Sand Point, AK	55.34	−160.50	2.204	0.737	1.4	1983–2001	0.615	0.915	1.315
	51712	9459881	King Cove, AK	55.06	−162.33	2.082	0.753	−5.8	1983–2001	0.592	0.892	1.292
	50262	9461380	Adak Island, AK	51.86	−176.63	1.131	NaN	NaN	NaN	0.572	0.872	1.272
	50623	9461710	Atka, AK	52.23	−174.17	1.041	0.424	−5.8	1983–2001	0.584	0.884	1.284
	50629	9462450	Nikolski, AK	52.94	−168.87	1.213	0.537	−5.8	1983–2001	0.563	0.863	1.263
	50990	9462620	Unalaska, AK	53.88	−166.54	1.098	NaN	NaN	NaN	0.576	0.876	1.276
	51714	9463502	Port Moller, AK	55.99	−160.57	3.175	0.697	−5.8	1983–2001	0.952	1.252	1.652
	52422	9464212	Village Cove, AK	57.13	−170.29	1.005	NaN	NaN	NaN	0.589	0.889	1.289
	54940	9468756	Nome, AK	64.50	−165.43	0.464	NaN	NaN	NaN	0.719	1.019	1.419
	56018	9491094	Red Dog Dock, AK	67.58	−164.07	0.269	NaN	NaN	NaN	0.787	1.087	1.487
	57111	9497645	Prudhoe Bay, AK	70.40	−148.53	0.214	NaN	NaN	NaN	0.808	1.108	1.508
Carib	38168	9751364	St. Croix, VI	17.75	−64.71	0.226	0.205	2.4	1983–2001	0.509	0.807	1.179
	38527	9751381	St. John, VI	18.32	−64.72	0.252	0.210	2.4	1983–2001	0.510	0.808	1.180
	38168	9751401	Lime Tree Bay, VI	17.69	−64.75	0.216	0.154	3.0	1983–2001	0.509	0.806	1.179
	38527	9751639	Charlotte Amalie, VI	18.34	−64.92	0.240	0.172	2.3	1983–2001	0.510	0.807	1.180
	38526	9752695	Vieques Island, PR	18.09	−65.47	0.225	0.190	2.4	1983–2001	0.509	0.807	1.179
	38525	9755371	San Juan, PR	18.46	−66.12	0.481	0.191	2.4	1983–2001	0.519	0.814	1.189
	38165	9759110	Magueyes Island, PR	17.97	−67.05	0.204	0.157	1.9	1983–2001	0.508	0.806	1.178
	38524	9759938	Mona Island, PR	18.09	−67.94	0.247	0.257	2.4	1983–2001	0.510	0.807	1.180

Section A2: Methods Appendix: Extreme Water Levels and Alaska Coastal Flood Height

A2.1: Data and Regional Frequency Analysis

A regional frequency analysis (RFA) of NOAA tide gauges is used to estimate extreme water levels (EWLs) along U.S. coastlines at and away from tide gauges. The RFA method (Hosking and Wallis, 1997) is based on the assumption that similar physical forcing across a region will produce a similar frequency of events and a probability density up to a local index (u), which is a local scaling factor that captures response peculiarities (Dalrymple, 1960). An RFA uses regional sets of data that have been locally normalized by their respective local index with a statistical heterogeneity test (H value) to assess the extent that the data are sufficiently similar. Using statistical L-moments, heterogeneity is a measure of the variation between sites of a location's summary distribution statistics and the amount of dispersion expected if the locations were indeed a homogeneous region (Hosking and Wallis, 1997). If $H < 1$, the region is considered acceptably homogeneous. If $1 \leq H < 2$, the region is considered possibly heterogeneous but acceptable for our study. If $H \geq 2$, then the tide-gauge group is definitely heterogeneous and not suitable for analysis. Once the regional bounds are established whose data are acceptably homogeneous, the aggregated data are fit with an extreme value distribution.

This study uses hourly and "top ten" data from all NOAA tide gauges[46] with at least 10 years of record (Figure A2.1). Water levels are put onto the mean higher high water (MHHW) tidal datum and detrended (the trend value is retained and shown in Table A1.3) relative to the midpoint of the current national datum tidal epoch (1983–2001), which is similar for NOAA EWL procedures using a single-gauge analysis (Zervas, 2013; Extreme Water Levels[47]). From the datasets, daily highest water levels are picked and declustered at each tide gauge using a 4-day storm window to ensure event independence. The 98th percentile of the

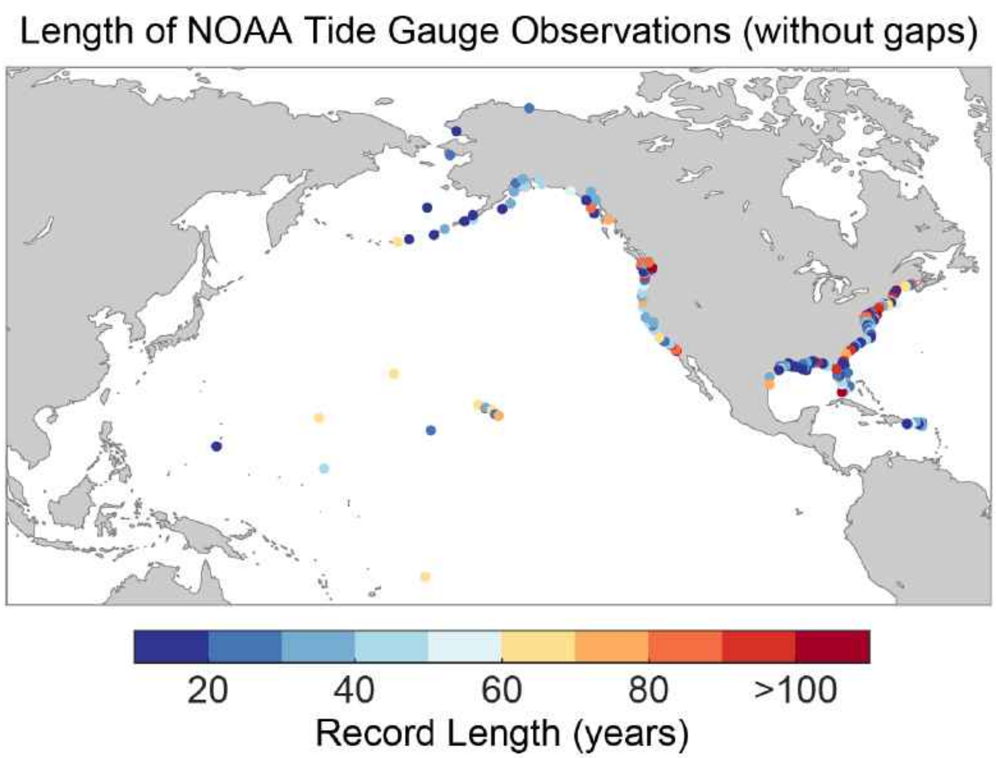


Figure A2.1: NOAA tide gauges used in the regional frequency analysis to generate extreme water level probabilities for U.S. coastlines.

[46] https://tidesandcurrents.noaa.gov/
[47] https://tidesandcurrents.noaa.gov/est/

declustered daily highest levels at each tide gauge is used as the local index (u) to normalize the data for the RFA process.

To form regions, the tide-gauge data is aggregated across a 400 km radius, similar to methods of Hall et al. (2016) but from the midpoint of a continuous set of coastline-intersecting 1-degree grids instead of site-specific installations. A maximum of 10 and a minimum of 3 tide gauges are included for each grid. Next, the regional data are spatially declustered with an additional 4-day event (i.e., storm) window to ensure that only the maximum water level within a region is retained (keep only the highest peak water levels for a particular event). Then, the statistical heterogeneity measure is estimated to ensure that the grouped tide-gauge data are sufficiently homogeneous (H < 2). In some instances, when a region surrounding a grid centroid

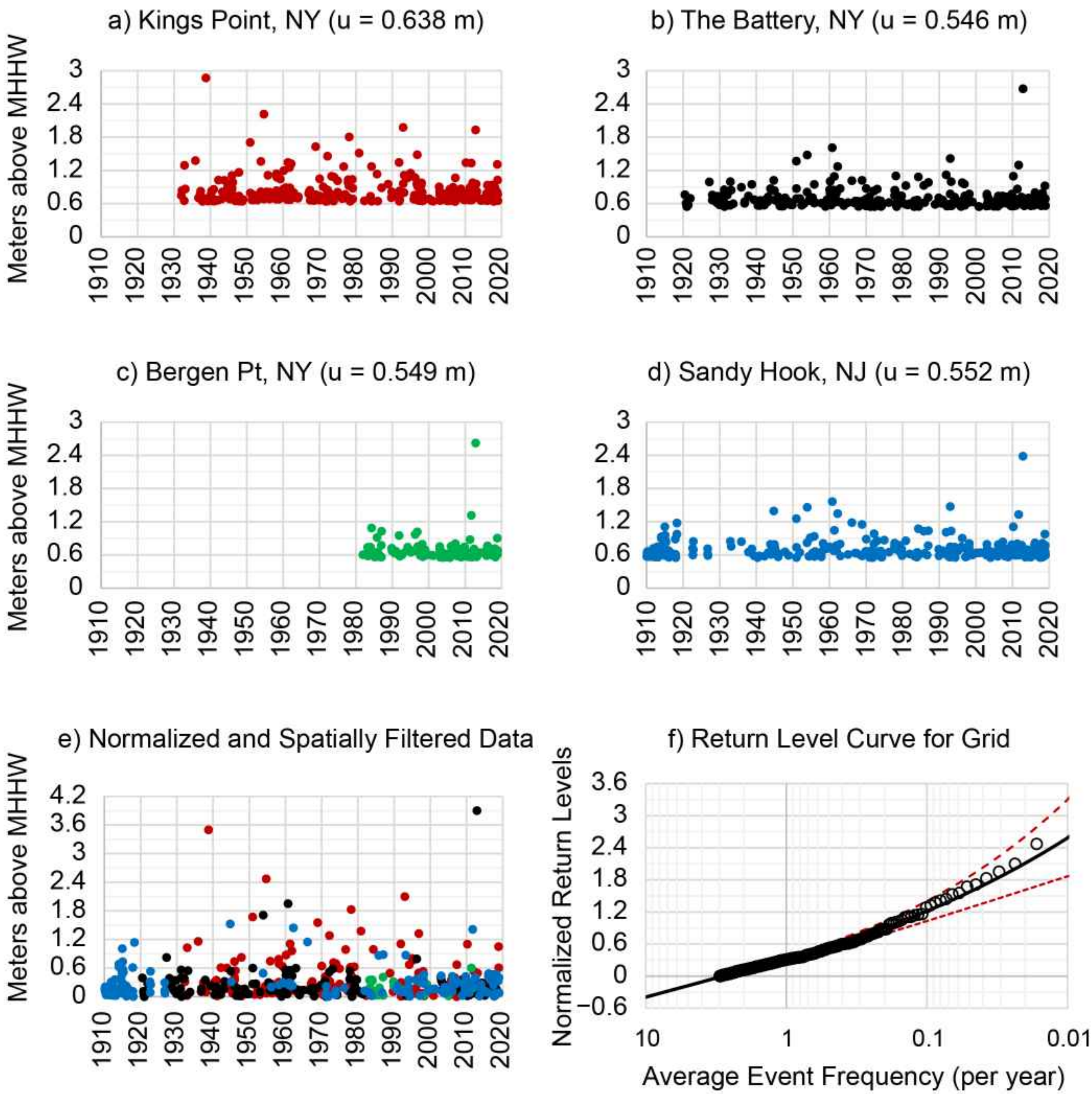


Figure A2.2: Example of data from grid number 46415 showing exceedances above each local index (u) relative to the 1983–2001 mean higher high water (MHHW) tidal datum at a) Kings Point, New York; b) The Battery, New York; c) Bergen Point, New York; and d) Sandy Hook, New Jersey, which are e) aggregated into a single dataset and f) fit by a Generalized Pareto Distribution to form a return level interval curve for the grid.

has H ≥ 2, tide gauges farthest away are sequentially dropped until homogeneity is achieved. In the end, all 1-degree grids along the contiguous United States (CONUS) had H < 2 (considered acceptably homogeneous) except a grid (number 48519) along the Northwest Pacific coastline, which, along with the Hawaiian and other U.S. Pacific Islands, uses the much larger physical-process regions identified and quantified in Sweet et al. (2020b). Grids along the Alaska coastline are fairly well resolved by the RFA except along the western and northern coasts.

An example is shown for grid number 46415, which is where the NOAA tide gauge at The Battery in New York City (NYC) is located (Figure A2.2). Four tide gauges are included in this grid (Kings Point, New York; The Battery, New York; Bergen Point, New York; and Sandy Hook, New Jersey [Figure A2.2a–d]), and their data are considered homogeneous (H value of 0.32). After the 4-day spatial filtering for events, each of the tide-gauge datasets is normalized by (divided by) its respective local index (u) value and aggregated as shown in Figure A2e.

A2.2: Gridded (Regional) Extreme Water Level Probabilities

With the tide gauges identified for each 1-degree grid, the aggregated and normalized datasets are fit with a Generalized Pareto Distribution (GPD; Coles, 2001). Using the penalized maximum likelihood method (Coles and Dixon, 1999; Frau et al., 2018; Sweet et al., 2020b), expected and 95% confidence interval (2.5th% and 97.5th% levels) values are estimated for the gridded EWL probabilities and defined as:

1) $$G\,(Z;\, u, \alpha, \xi) \;=\; \lambda\left[1 + \,\xi\left(\tfrac{z-u}{\alpha}\right)\right]^{-1/\xi}$$

where G is the exceedance probability (P[Z > z]), λ is the probability of an individual (normalized) observation exceeding the local index (u), α is the scale parameter, and ξ is the shape parameter. It is assumed that the distribution of the number of exceedances per year follows a Poisson distribution and that the return level for an EWL of height (Z) is given by:

2) $$Z_N = u + \tfrac{\alpha}{\xi}\left[\left(N n_y \lambda\right)^{\xi} - 1\right]$$

where N is the average recurrence interval (referred to in this study as the average event frequency, which is the reciprocal value), n_y is number of days per year (365.25), and λ is the average number of event exceedances per year (about 3 on average across all tide gauges in the study). To estimate EWLs with return levels with a 10 events/year frequency, we extrapolate the gridded GPD model with a logarithmic fit for return levels between the 0.5–3 events/year frequencies. A return level interval curve fit to the aggregated data (Figure A2.2e) for the grid where NYC is located is shown in Figure A2.2f.

A2.3: Localized Extreme Water Level Probabilities

When fitting a GPD to the RFA of aggregated tide-gauge data, the local EWL (EWL_{local}) probabilities including the model of expected values and their 95% confidence interval at a particular location are given as

3) $$EWL_{local} = EWL_{gridded} * u_{local} + u_{local}$$

where $EWL_{gridded}$ is the gridded return level for a particular coastal 1-degree grid and u_{local} is the local index used in both the RFA and GPD processes. The value of u is a height (98th percentile of 4-day event filtered daily highest water level) above the local MHHW tidal datum for the current (1983–2001) national tidal datum epoch (NTDE) or for a modified 5-year epoch. The associated uncertainty of the $EWL_{gridded}$ estimated during the RFA is expressed as $\sigma_{gridded.}$ When localized at a tide gauge used in the formulation of the grids (see Figure A1), u is assumed to have no uncertainty. However, just as the location parameters in generalized extreme value (GEV) have time-dependent characteristics (Menéndez and Woodworth, 2010), it is recognized that u would experience similar behavior, but that is not quantified in this study.

In this RFA framework, it is possible to estimate EWL_{local} from the $EWL_{gridded}$ probabilities (expected values and 95% confidence interval) through the use of other sources of data. Specifically, the local indices needed to localize the $EWL_{gridded}$ values can either be 1) obtained from short-term tide-gauge data (or by targeted deployments) within a particular grid that is not included in the RFA formulation (<10 years; Figure A2.3) or 2) based on an underlying relationship between regional sets of local index (u) values and tide range available from, for example, NOAA VDatum.[48] In both cases, we establish large U.S. coastal regions (note: these are slightly different than the regions discussed in Sections 2 and 3 of the report and shown in Figure A1.1) that encompass several 1-degree grids to quantify information needed to obtain local indices and/or estimate variance/uncertainties (e.g., RMSE). These alternative methods, which are discussed below, may be of interest to coastal communities that are not co-located to a tide gauge used in this study but have predictions of tide range or have access to or are planning temporary tide-gauge installations to establish tidal datums and/or EWLs.

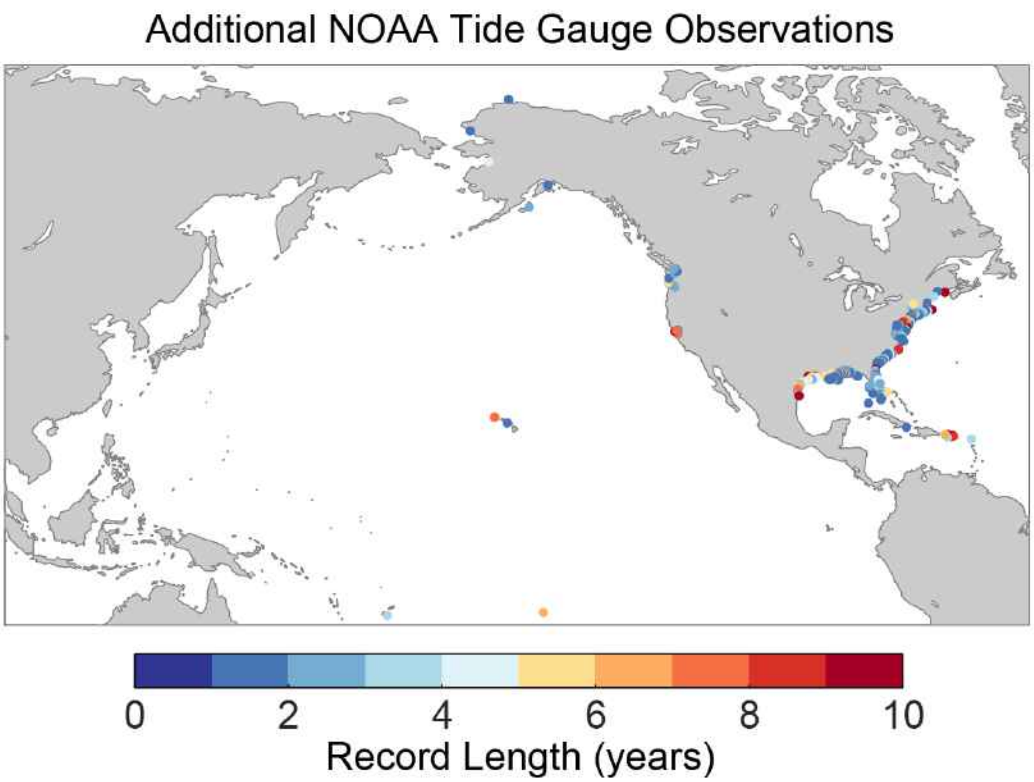


Figure A2.3: Additional tide-gauge data available from NOAA that can be used to localize the 1-degree gridded set of regional frequency analysis-based extreme water level probabilities. See https://tidesandcurrents.noaa.gov/.

A2.3.1: Local Index Estimates from Short-Term Installations

When other sets of tide/water level data are available, a local index can be directly estimated to obtain EWL_{local} probabilities from the $EWL_{gridded}$ probabilities. The first step for using data that are not from NOAA would be to estimate a local MHHW tidal datum using, for example, NOAA's online datum tool.[49] Following Equation 3 above, there will be some uncertainty in the local index value that is dependent on record length (e.g., 1–10 years). To account for short-record uncertainty in the local indices (u), RMSE (1 standard error) is estimated for regional estimates of u for the tide gauges used in the RFA (see Figure A2.1). Root mean square error is estimated using a logarithmic fit over a 19-year record length (Figure A4). To compute the RMSE, the maximum absolute differences are computed between u derived over the entire record and for progressively longer consecutive record lengths between 2001 and 2019 at each tide gauge (e.g., 19 discrete 1-year

[48] https://vdatum.noaa.gov/
[49] https://access.co-ops.nos.noaa.gov/datumcalc/

records; 18 consecutive 2-year records). The maximum (absolute) difference is used to account for interannual variability that can be significant (e.g., during phases of El Niño–Southern Oscillation [ENSO]). This difference is considered the error in estimating u for shorter records, and the average of the absolute differences across the regional set of tide gauges is considered the bias. The standard deviation of the absolute differences is also computed across all tide gauges, and an estimate of the RMSE is then computed as the square

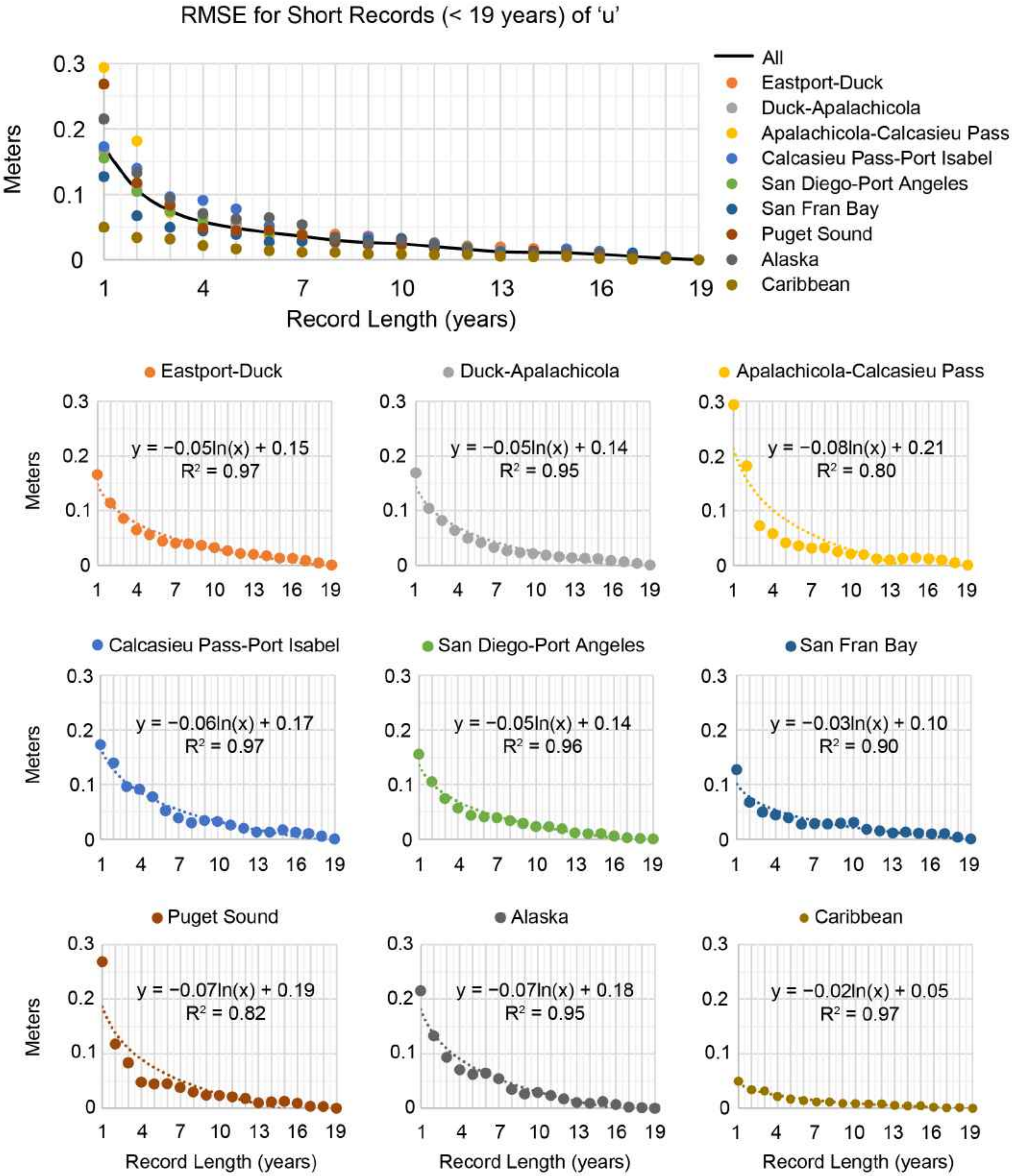


Figure A2.4: Root mean square error for regional estimates of flood indices (u) based on 1–19 years of consecutive data over the 2001–2019 period, based on regional sets of tide gauges used in this study. Note: these regions are not the same as those shown in Figure A1.1 and used to describe results in Sections 2 and 3 of the report.

root of the sum of the square of the bias and the standard deviation (variance). The estimates for Hawaiian and U.S. Pacific Islands follow estimates of Sweet et al. (2020b).

A2.3.2: Obtaining a Local Index from Tide Range Information

Another method to obtain an estimate of a local index (u) and its uncertainty is based on a dependency (correlation) that exists with tide range (great diurnal [GT]) along most coastal regions similar to findings of Merrifield et al. (2013). In essence, tide range (GT), which represents the spread between MHHW and mean lower low water (MLLW), partially quantifies the variance of the daily highest water level distribution and the height of the local index u. Figure A2.5 illustrates the regression-based relationships between tide range and u along U.S. coastal regions (these are the same regions used in Figure A2.4). All regressions are significant above the 90% significance level (p values < 0.1) and applicable for the 1983–2001 tidal epoch. For the Hawaiian and U.S. Pacific Islands, the Pacific-wide regression of Sweet et al. (2020b) is used.

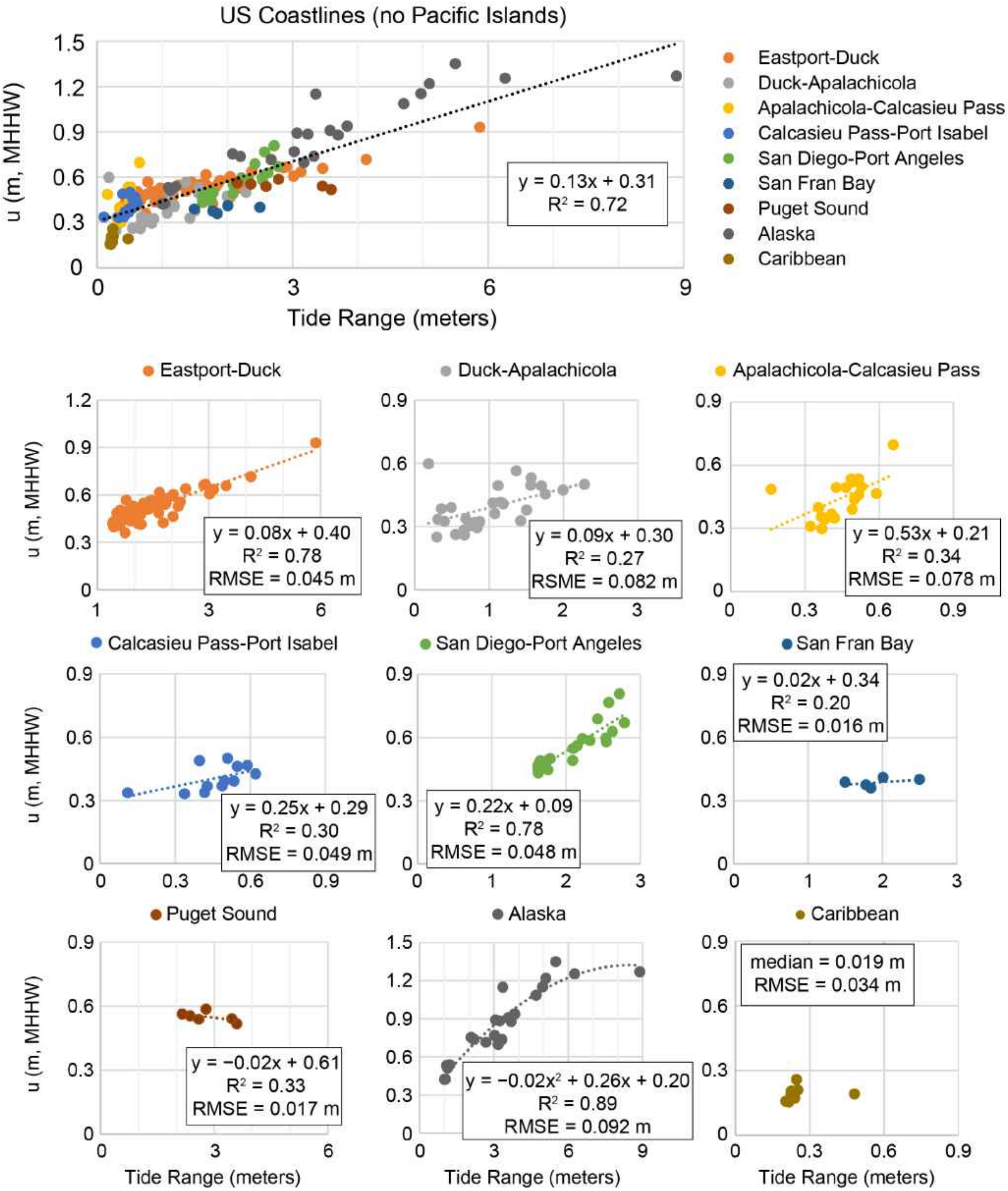


Figure A2.5: Tide range to local index (u) regressions with equations, goodness of fit (R^2), and root mean squared error (RMSE) shown by regions. Note: all local indices (u) are relative to the 1983–2001 tidal datum epoch. In the equations, y represents the local index (u) and x represents tide range.

A2.3.3: Uncertainties Using Alternative Methods to Estimate EWL_{local} Probabilities

When using either alternative method (tide range or short-record estimates) to obtain a local index (u), the uncertainty estimates of EWL_{local} probabilities will include additional uncertainty in u (σ_u). Following methods of Sweet et al. (2020b), it can be shown that

4) $$\sigma_{EWL(local)} = [(1 + \mu_{EWLgridded})^2 + \sigma^2_{EWLgridded}]\sigma_u^2 + \mu_u^2\sigma^2_{EWLgridded}$$

where $\mu_{EWLgridded}$ and μ_u are the expected values of the gridded return levels and the expected value of u, for example, estimated by the tide-range and u dependency (see Figure A2.5), respectively, σ_u^2 is the uncertainty inherent to any u-prediction relationship (e.g., RMSE). Thus, there is an additive uncertainty in u as estimated from this relationship, which would introduce additional uncertainty in estimates of EWL_{local}.

A2.3.4: Adjusting Local Extreme Water Level Probabilities to Time Periods

To adjust the EWL_{local} probabilities to a different sea level other than the current tidal epoch (e.g., from 1992 to 2000 or 2005 so as to apply the sea level rise scenarios), RSL estimates using the trends inherent to the hourly data used to compute the local index (u) should be applied (Table A1.3) to the epoch-specific EWL_{local} probabilities themselves. For tide gauges used in the RFA analysis and with more than 20 years of data, the local u trend can be used; otherwise, a median regional trend as defined in Figures A2.4 and A2.5 can be used. Alternatively, the RSL offsets derived from the regional observational RSL data (Table A1.2) could be used with differences between methods considered insignificant. For example, to estimate probabilities for the year 2000, the EWL_{local} probabilities values would be increased by an amount equal to the trend in u (or the median u trend value for the region) multiplied by 8 years (since 1992, which is the midpoint of the 1983–2001 epoch). The same procedure should be followed to adjust EWL_{local} probabilities for a given location estimated via the tide range regression (see Figure A5). In the case of a short-term estimate of u, similar procedures should be followed if local tidal datums have been computed and adjusted to the national tidal datum epoch (e.g., using the CO-OPS Tidal Analysis Datum Calculator[50]); in the case where no epoch can be established (see the CO-OPS Tidal Analysis Datum Calculator for guidance), then the measurements will be assumed to be referenced to the period of collection, and trend adjustment may be less straightforward.

A2.4: Alaska Coastal Flood Heights

To assess flood exposure, the coastal high tide flooding (HTF) heights of Sweet et al. (2018) are used for all U.S. coastlines outside of Alaska. Used in NOAA annual outlooks (e.g., Sweet et al., 2021; The State of High Tide Flooding and Annual Outlook[51]), these heights are a best-fit solution (regression) to the dozens of National Weather Service (NWS) emergency response warning thresholds established at many (but not all) NOAA tide gauges along the country's coastline. The NWS thresholds are used to communicate expected or ongoing coastal flood hazards to the public (NOAA, 2020), but often their depth-severity thresholds vary according to specific features near the tide gauge that affect both the associated flood frequency and the degree of broader vulnerabilities. Along the Alaska coastline, we follow the methodologies of Sweet et al. (2020b), who used a slight modification to assess "damaging flood heights" for the Pacific Basin coastlines. Here, the Alaska flood heights are based on a quadratic regression model using only Pacific Coast NWS minor flood heights and considered for only tide ranges below 6 meters (Figure A2.6a). To obtain moderate and major flood heights for Alaska, 0.3 m and 0.7 m are added to the regression, which is approximately the median difference between these heights and those for minor flooding along CONUS (Sweet et al., 2018). With flood heights defined nationally, minor, moderate, and major HTF are defined as occurring when water levels reach or exceed heights of about (median values) 0.55 m, 0.85 m, and 1.2 m above MHHW, respectively, and linearly vary with tide range (Figures A2.6b–d).

[50] https://access.co-ops.nos.noaa.gov/datumcalc/index.jsp
[51] https://tidesandcurrents.noaa.gov/HighTideFlooding_AnnualOutlook.html

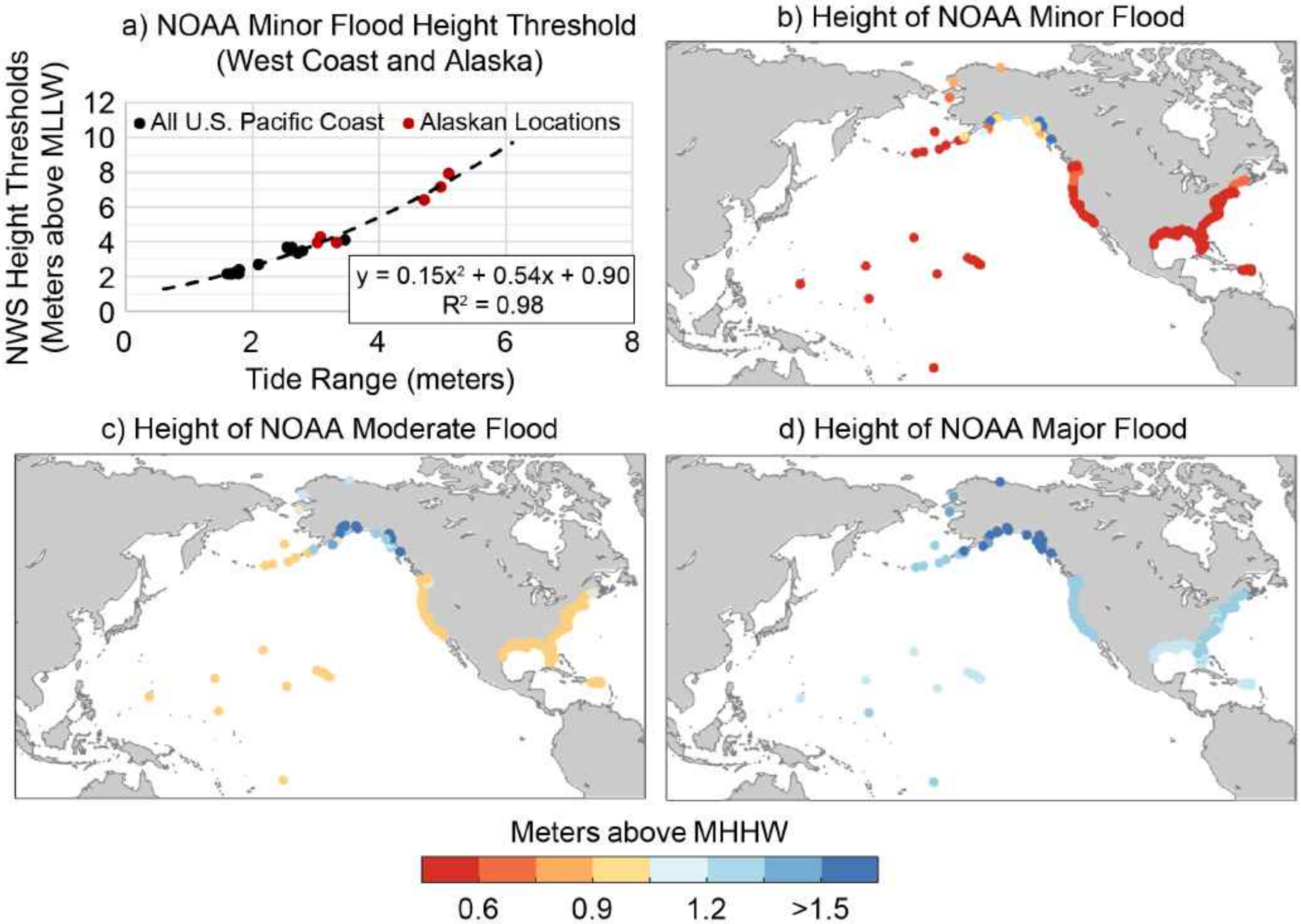


Figure A2.6: a) Quadratic regression of U.S. West Coast minor flood heights of NOAA's National Weather Service, following methods of Sweet et al. (2020b), to obtain a minor HTF definition for Alaska's coastline. The NOAA flood heights for b) minor, c) moderate, and d) major HTF are shown relative to mean higher high water.

8. Acronyms

Note: state abbreviations have been omitted

AIS: Antarctic ice sheet
AEF: average event frequency
AMOC: Atlantic meridional overturning circulation
AR5: [IPCC] Fifth Assessment Report
AR6: [IPCC] Sixth Assessment Report
ARI: average return interval
C: celsius
CDF: cumulative distribution function
cm: centimeter
CMIP5: Coupled Model Intercomparison Project Phase 5
CMIP6: Coupled Model Intercomparison Project Phase 6
CONUS: contiguous United States
CO-OPS: Center for Operational Oceanographic Products and Services
CoSMoS: Coastal Storm Modeling System
DRSL: Department of Defense Regional Sea Level [database]
ENSO: El Niño–Southern Oscillation
EPA: Environmental Protection Agency
EWL: extreme water level
FEMA: Federal Emergency Management Agency
FFRD: Future of Flood Risk Data
GCM: global climate model
GEV: generalized extreme value
GHG: greenhouse gas
GIA: glacial isostatic adjustment
GlacierMIP: Glacier Model Intercomparison Project
GMSL: global mean sea level
GPD: Generalized Pareto Distribution
GPS: Global Positioning System
GRD: gravitational, rotational, and deformational
GT: great diurnal tide range
HTF: high tide flood, flooding
HUC: hydrologic unit code
InSAR: Interferometric Synthetic Aperture Radar
IPCC: Intergovernmental Panel on Climate Change
ISMIP6: Ice Sheet Model Intercomparison Project for CMIP6
JPM–OS: joint probability method–optimal sampling [procedure]
LARMIP-2: Linear Antarctic Response Model Intercomparison Project [version 2]
m: meter
MHHW: mean higher high water
MICI: marine ice cliff instability
MLLW: mean lower low water
mm: millimeter
NASA: National Aeronautics and Space Administration
NAVD88: North American Vertical Datum of 1988
NCA: National Climate Assessment
NCA5: Fifth National Climate Assessment
NCA4: Fourth National Climate Assessment
NOAA: National Oceanic and Atmospheric Administration
NOC: National Ocean Council

NSRS: National Spatial Reference System
NTDE: national tidal datum epoch
NWS: National Weather Service
NYC: New York City
PDO: Pacific Decadal Oscillation
R^2: goodness of fit
RFA: regional frequency analysis
RMSE: root mean square error
RSL: relative sea level
SOST: Subcommittee on Ocean Sciences and Technology
SSP: Shared Socioeconomic Pathway
USACE: U.S. Army Corps of Engineers
USGCRP: U.S. Global Change Research Program
USGS: U.S. Geological Survey
VDatum: Vertical Datum Transformation
VLM: vertical land motion

US Army Corps of Engineers

USGS
science for a changing world

RUTGERS
UNIVERSITY | NEW BRUNSWICK

FEMA

FIU | Institute of Environment
FLORIDA INTERNATIONAL UNIVERSITY

State of Washington
DEPARTMENT OF FISH AND WILDLIFE
Mailing Address: P.O. Box 43158, Olympia, WA 98504-3158 • (360) 902-8300 • TDD (360) 902-2207
Office Location: 600 Capitol Way North, Olympia, WA

April 1, 2022

Betsy Stevenson
Senior Planner
Skagit County Planning and Development Services

Dear Betsy,

Please find Washington Department of Fish and Wildlife's comments on the Skagit County Shoreline Master Program public review draft. These comments are in addition to those provided by Bob Warinner, Assistant Regional Habitat Program Manager, on June 22, 2021, and are in support of agency actions of hatcheries and water access and wildlife areas.

If you have any questions, please don't hesitate to contact me or Bob Warinner.

Sincerely,

Shannon Brenner

Shannon Brenner
Washington Department of Fish and Wildlife
Environmental Planner
Capital Asset Management Program (CAMP)

- 6C-8.5

Sediment transport is a normal physical process that maintains salmonid habitat and removing sediment from a river system can contribute to habitat degradation. Please consider the disposal of dredge material within the river channel migration zone as a form of mitigation when it does not fill wetlands or result in other negative impacts.

- 6C-11.4

Please clarify if this is limited to new instream structure proposals or if it also applies to the maintenance of existing instream structures. If it applies to maintenance, please be clear if the enhancement of ecological functions or improvement to ecological processes is required only when there are adverse impacts requiring mitigation or if it is required in all scenarios.

- Table 14.26.405-1.

-WDFW facilities include water access sites and wildlife areas that provide recreational and educational opportunities. Per the SMA policy contained in RCW 98.50.020, SMPs should increase public access to publicly owned areas of the shoreline. The RCW also includes the following:

> "In the implementation of this policy, the public's opportunity to enjoy the physical and aesthetic qualities of natural shorelines of the state shall be preserved to the greatest extent feasible consistent with the overall best interest of the state and the people generally. To this end, uses shall be preferred which are consistent with control of pollution and prevention of damage to the natural environment or are unique to or dependent upon use of the state's shoreline. Alterations of the natural condition of the shorelines of the state, in those limited instances when authorized, shall be given priority for single-family residences, ports, and shoreline recreational uses. These recreational uses include, but are not limited to, parks, marinas, piers, and other improvements facilitating public access to shorelines of the state, industrial and commercial developments which are particularly dependent on their location on or their use of the shorelines of the state, and other developments that will provide an opportunity for substantial numbers of people to enjoy the shorelines of the state."

The Skagit SMP also includes the following policy:

> 6C-14.1. b. Skagit County should recognize that state-owned shorelines are particularly adapted to providing wilderness beaches, ecological study areas, and other recreational uses for the public.

In managing access areas, WDFW will need to replace structures as they become dilapidated and make other improvements as necessary. Some of these improvements may fit within the exemption allowances for maintenance and repair; however, some may not.

In the matrix table under Recreational, water-oriented uses are allowed with a CU or SD/E in all environmental designations including the Natural environmental designation. Recreational water-oriented uses include recreational uses that are water dependent. A dock, launch ramp, and float are water-dependent forms of recreation.

Given the allowance in the matrix table for recreation uses, it appears that for those improvements that would not be exempt, they could still be allowed through a permitting process. And the review under the permitting process would establish that all protective and mitigation measures required in the SMP have been met. However, under Boating Facilities there are prohibitions for docks and launch ramps in the Natural environmental designation. Because a dock or launch is also a recreational use, it is not clear if they are prohibited or allowed in the Natural environment.

Please clarify that public access and recreation, including public docks and launches, on publicly owned land is allowed in all environmental designations when sited appropriately and meeting all protective measures of the SMP to preserve the resources and ecology of the shoreline.

-Please consider dredge disposal in CMZ and Aquatic environment without a CU when proposed as mitigation for a permitted action that will benefit stream ecology. This is not unlike disposal allowed for restoration.

- 14.26.415(4)(b)

What if the parcel is entirely encumbered by the buffer?

- 14.26.435(2)(c)

Please recognize that maintenance dredging is necessary to remove accumulated sediment that would impair the functionality of in-water structures that are part of WDFW managed finfish hatcheries. The sediment removal is restricted to reestablishing the existing contours in the immediate vicinity of the structure and necessary to maintain a preferred water-dependent use and lawfully established use.

- 14.26.435(2)(g)

Please consider dredge disposal as mitigation for dredging when designed to benefit habitat and maintain sediment supply and transport.

future wise
816 Second Ave, Suite 200, Seattle, WA 98104
p. (206) 343-0681
futurewise.org

April 1, 2021

Planning and Development Services
Comments on "Skagit County's Shoreline Master Program Update"
1800 Continental Place
Mount Vernon, Washington 98273

Dear County Commissioners and Planning and Development Services staff:

Subject: Comments on the Skagit County Shoreline Master Program Comprehensive Update and Periodic Review BOCC Public Hearing Draft (February 15, 2022).
Sent via email to: pdscomments@co.skagit.wa.us

Thank you for the opportunity to comment on the Skagit County Shoreline Master Program Comprehensive Update and Periodic Review. While Futurewise supports periodic reviews and updates and appreciates that Skagit County has resumed the update, we do have concerns and suggestions to provide for the recovery of important fish and wildlife resources such as the Chinook salmon and southern resident orcas and to begin addressing the adverse effects of global warming including sea level rise. Futurewise also strongly supports the comments and recommendations from Evergreen Islands, the Washington Environmental Council, RE Sources, and the Guemes Island Planning Advisory Committee.

Futurewise works throughout Washington State to support land-use policies that encourage healthy, equitable and opportunity-rich communities, and that protect our most valuable farmlands, forests, and water resources. Futurewise has members and supporters throughout Washington State including Skagit County.

Incorporate regulations to address accelerating sea level rise.

The Shoreline Management Act and Shoreline Master Program (SMP) Guidelines require shoreline master programs to address the flooding that will be caused by sea level rise.[1] RCW 90.58.100(2)(h) requires that shoreline master programs "shall include" "[a]n element that gives consideration to the statewide interest in the prevention and minimization of flood damages …" WAC 173-26-221(3)(b) provides in part that "[o]ver the long term, the most effective means of flood hazard reduction is to prevent or remove development in flood-prone areas …" "Counties and cities should consider the following when designating and classifying frequently flooded areas … [t]he potential effects of tsunami, high tides with strong winds, sea level rise, and extreme weather events, including those

[1] Although the Shoreline Master Program (SMP) Guidelines are called "guidelines," they are actually binding state agency rules and shoreline management program updates must comply with them. RCW 90.58.030(3)(b) & (c); RCW 90.58.080(1) & (7).

potentially resulting from global climate change …."[2] The areas subject to sea level rise are flood prone areas just the same as areas along bays, rivers, or streams that are within the 100-year flood plain. As the State of Washington Department of Ecology's (Ecology) *Shoreline Master Program Handbook Appendix A: Addressing Sea Level Rise in Shoreline Master Programs* states "SMPs must address flood hazards and seek to reduce the damage caused by floods. Goals and policies addressing flood hazards are another opportunity to address sea level rise and the increased threat from flooding that will accompany it."[3]

RCW 90.58.100(1) and WAC 173-26-201(2)(a) also require "that the 'most current, accurate, and complete scientific and technical information' and 'management recommendations' [shall to the extent feasible] form the basis of SMP provisions."[4] This includes the current science on sea level rise.

Sea level rise is a real problem that is happening now. Sea level is rising and floods and erosion are increasing. In 2012 the National Research Council concluded that global sea level had risen by about seven inches in the 20th Century.[5] A recent analysis of sea-level measurements for tide-gage stations, including the Seattle, Washington tide-gauge, shows that sea level rise is accelerating.[6] The "tide gauge records from 2021 were remarkably consistent with data from the previous year, with acceleration in rates of sea-level rise at 27 of our 32 stations."[7] The Seattle tide gage was one of the 27 that had an accelerating rate of sea level rise.[8]

The report *Projected Sea Level Rise for Washington State – A 2018 Assessment* projects that for a low greenhouse gas emission scenario there is a 50 percent probability that sea level rise will reach or exceed 1.6 feet by 2100 in Skagit County at Latitude 48.3 degrees north and Longitude -122.4 degrees west.[9] *Projected Sea Level Rise for Washington State – A 2018 Assessment* projects that for a higher

---

[2] WAC 365-190-110(2) underlining added. This regulation is part of the State of Washington Department of Commerce Minimum Guidelines to Classify Agriculture, Forest, Mineral Lands and Critical Areas.

[3] State of Washington Department of Ecology, *Shoreline Master Program Handbook Appendix A: Addressing Sea Level Rise in Shoreline Master Programs* p. 8 (Publication Number 11-06-010: rev. 12/17) last accessed on March 31, 2022, at: https://apps.ecology.wa.gov/publications/SummaryPages/1106010.html and enclosed with Futurewise's June 21, 2021, letter on the SMP Update. The appendix is also at this Dropbox Link https://www.dropbox.com/sh/hr5kxb0sitoxfk8/AAC_br6R66ByUaVpKScKOC8Ra?dl=0 with the filename: "1106010part19.pdf."

[4] *Taylor Shellfish Company, Inc., et al., v. Pierce County and Ecology (Aquaculture II)*, Final Decision and Order Central Puget Sound Region Growth Management Hearings Board Case No. 18-3-0013c (June 17, 2019), at 10 of 81 footnote omitted.

[5] National Research Council, *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* p. 23, p. 156, p. 96, p. 102 (2012) last accessed on March 31, 2022, at: https://www.nap.edu/download/13389 and at the Dropbox link in footnote 3 of this letter with the filename: "13389.pdf."

[6] William and Mary Virginia Institute of Marine Science, *U.S. West Coast Sea-Level Trends & Processes Trend Values for 2021* last accessed on April 1, 2022, at: https://www.vims.edu/research/products/slrc/compare/west_coast/index.php and at the Dropbox link in footnote 3 of this letter with the filename: "Sea-Level West Coast Trends 2021.pdf."

[7] David Malmquist, *2050 projections offer localized guidance for 32 U.S. coastal localities* Virginia Institute of Marine Science website (Feb. 15, 2022) last accessed on April 1, 2022, at: https://www.vims.edu/newsandevents/topstories/2022/slrc_2021.php and at the Dropbox link in footnote 3 of this letter with the filename with the filename: "2050 projections offer localized guidance for 32 U.S. coastal localities.pdf."

[8] William and Mary Virginia Institute of Marine Science, *U.S. West Coast Sea-Level Trends & Processes Trend Values for 2021*.

[9] University of Washington Climate Impacts Group, *Visualization #1: Projected sea level change by year for Projected sea level change by year Lat 48.3 Long 122.4 Skagit County*, accessed on April 1, 2022, at: https://cig.uw.edu/our-work/applied-

emission scenario there is a 50 percent probability that sea level rise will reach or exceed 2.1 feet by 2100 in Skagit County at Latitude 48.3 degrees north and Longitude -122.4 degrees west.[10] Projections are available for all of the marine shorelines in Skagit County and Washington State.[11]

The extent of the sea level rise currently projected for Skagit County can be seen on the NOAA Office for Coastal Management Digitalcoast Sea Level Rise Viewer available at: https://coast.noaa.gov/digitalcoast/tools/slr.html. A copy of the map from the viewer showing two feet of sea level rise is at the Dropbox link in footnote 3 of this letter with the filename: "Skagit Cty 2 ft Sea Level Rise.pdf."

Projected sea level rise will substantially increase flooding. As Ecology writes, "[s]ea level rise and storm surge[s] will increase the frequency and severity of flooding, erosion, and seawater intrusion—thus increasing risks to vulnerable communities, infrastructure, and coastal ecosystems."[12] Not only our marine shorelines will be impacted, as Ecology writes "[m]ore frequent extreme storms are likely to cause river and coastal flooding, leading to increased injuries and loss of life."[13]

Zillow recently estimated that 31,235 homes in Washington State may be underwater by 2100, 1.32 percent of the state's total housing stock. The value of the submerged homes is an estimated $13.7 billon.[14] Zillow wrote:

> It's important to note that 2100 is a long way off, and it's certainly possible that communities [may] take steps to mitigate these risks. Then again, given the enduring popularity of living near the sea despite its many dangers and drawbacks, it may be that even more homes will be located closer to the water in a century's time, and these estimates could turn out to be very conservative. Either way, left unchecked, it

---

research/wcrp/sea-level-rise-data-visualization/ and at the Dropbox link in footnote 3 of this letter with the filename: "Projected sea level change by year Lat 48.3 Long -122.4 Skagit Cty.pdf." The methodology used for these projections is available in Miller, I.M., Morgan, H., Mauger, G., Newton, T., Weldon, R., Schmidt, D., Welch, M., Grossman, E, *Projected Sea Level Rise for Washington State – A 2018 Assessment* (A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project: updated 07/2019) last accessed on April 1, 2022, at: https://cig.uw.edu/wp-content/uploads/sites/2/2019/07/SLR-Report-Miller-et-al-2018-updated-07_2019.pdf and at the Dropbox link in footnote 3 of this letter with the filename: "SLR-Report-Miller-et-al-2018-updated-07_2019.pdf."

[10] University of Washington Climate Impacts Group, *Visualization #1: Projected sea level change by year for Projected sea level change by year Lat 48.3 Long 122.4 Skagit County*.

[11] Miller, I.M., Morgan, H., Mauger, G., Newton, T., Weldon, R., Schmidt, D., Welch, M., Grossman, E,. *Projected Sea Level Rise for Washington State – A 2018 Assessment* p. 6 & p. 9 of 24 (A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project: updated 07/2019).

[12] State of Washington Department of Ecology, *Preparing for a Changing Climate Washington State's Integrated Climate Response Strategy* p. 90 (Publication No. 12-01-004: April 2012) last accessed on April 1, 2022, at: https://fortress.wa.gov/ecy/publications/publications/1201004.pdf and at the Dropbox link in footnote 3 of this letter with the filename: "1201004.pdf."

[13] *Id.* p. 17.

[14] Krishna Rao, *Climate Change and Housing: Will a Rising Tide Sink all Homes?* ZILLOW webpage (Jun. 2, 2017) last accessed on April 1, 2022, at: http://www.zillow.com/research/climate-change-underwater-homes-12890/.

> is clear the threats posed by climate change and rising sea levels have the potential to destroy housing values on an enormous scale.[15]

Sea level rise will have an impact beyond rising seas, floods, and storm surges. The National Research Council wrote that:

> Rising sea levels and increasing wave heights will exacerbate coastal erosion and shoreline retreat in all geomorphic environments along the west coast. Projections of future cliff and bluff retreat are limited by sparse data in Oregon and Washington and by a high degree of geomorphic variability along the coast. Projections using only historic rates of cliff erosion predict 10–30 meters [33 to 98 feet] or more of retreat along the west coast by 2100. An increase in the rate of sea-level rise combined with larger waves could significantly increase these rates. Future retreat of beaches will depend on the rate of sea-level rise and, to a lesser extent, the amount of sediment input and loss.[16]

These impacts are why the Washington State Department of Ecology recommends "[l]imiting new development in highly vulnerable areas."[17]

Unless wetlands and shoreline vegetation can migrate landward, their area and ecological functions will decline.[18] If development regulations are not updated to address the need for vegetation to migrate landward in feasible locations, wetlands and shoreline vegetation will decline. According to Ecology "[d]evelopment of coastal areas and shoreline armoring (e.g., bulkheads, seawalls) prevent habitat areas from reestablishing inland" in response to sea level rise.[19] Ecology provides more detailed documentation of these adverse impacts:

> The prospect of more flooding, erosion, and storm damage may lead communities and property owners to seek to build seawalls, dikes, and tidal barriers. The construction and placement of these structures will have a direct and immediate impact on natural shoreline environments. These structures will also lead to the progressive loss of beach and marsh habitat as those areas are squeezed between the rising sea and a more intensively engineered shoreline. Predicted decreases in size or

---

[15] *Id.*
[16] National Research Council, *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* p. 135 (2012).
[17] State of Washington Department of Ecology, *Preparing for a Changing Climate Washington State's Integrated Climate Response Strategy* p. 90 (Publication No. 12-01-004: April 2012).
[18] Christopher Craft, Jonathan Clough, Jeff Ehman, Samantha Joye, Richard Park, Steve Pennings, Hongyu Guo, and Megan Machmuller, *Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services* FRONT ECOL ENVIRON 2009; 7, doi:10.1890/070219 p. *6 last accessed on April 1, 2022, at: http://nsmn1.uh.edu/steve/CV/Publications/Craft%20et%20al%202009.pdf. Frontiers in Ecology and the Environment is a peer-reviewed scientific journal. Frontiers in Ecology and the Environment Journal Overview webpage last accessed on Feb. 26, 2021 at: https://esajournals.onlinelibrary.wiley.com/journal/15409309. Both at the Dropbox link in footnote 3 of this letter with the filename: "Craft et al 2009.pdf" and "Frontiers in Ecology and the Environment - Journal Overview" respectively.
[19] Washington State Department of Ecology, *Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy* p. 68 (Publication No. 12-01-004: April 2012).

> transitions in tidal marshes, salt marshes, and tidal flats will affect the species these habitats support. It is predicted that while some species may be able to locate alternate habitats or food sources, others will not (Glick, 2007).
>
> Shellfish, forage fish, shorebirds, and salmon are among those identified as examples of species at risk (Glick, 2007). Sea level rise will also lead to other changes in coastal ecosystems, such as shifting of stream mouths and tidal inlets, reconfigured estuaries and wetlands, and more frequently disturbed riparian zones.[20]

"Loss of salt marsh and related habitats may be significant in systems constrained by surrounding development."[21] This loss of shoreline vegetation will harm the environment. It will also deprive marine shorelines of the vegetation that protects property from erosion and storm damage by modifying soils and accreting sediment.[22] This will increase damage to upland properties. Enclosed with this letter are maps showing the extent of wetlands at mean higher high water and at two feet of sea level rise in western Skagit County.[23] A comparison of these maps shows that there will be migration of wetlands in Skagit County if the wetlands are not blocked by development.

Flood plain regulations are not enough to address sea level rise for three reasons. *Projected Sea Level Rise for Washington State – A 2018 Assessment* explains two of them:

> Finally, it is worth emphasizing that sea level rise projections are different from Federal Emergency Management Agency (FEMA) flood insurance studies, because (1) FEMA studies only consider past events, and (2) flood insurance studies only consider the 100-year event, whereas sea level rise affects coastal water elevations at all times.[24]

The third reason is that flood plain regulations allow fills and piling to elevate structures and also allow commercial buildings to be flood proofed in certain areas. While this affords some protection to the structure, it does not protect the marshes and wetlands that need to migrate.

---

[20] State of Washington Department of Ecology, *Shoreline Master Program Handbook Appendix A: Addressing Sea Level Rise in Shoreline Master Programs* pp. 3 – 4 (Publication Number 11-06-010: rev. 12/17).
[21] *Id.* p. 4.
[22] R. A. Feagin, S. M. Lozada-Bernard, T. M. Ravens, I. Möller, K. M. Yeagei, A. H. Baird and David H. Thomas, *Does Vegetation Prevent Wave Erosion of Salt Marsh Edges?* 106 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA pp. 10110-10111 (Jun. 23, 2009) last accessed on April 1, 2022, at: http://www.pnas.org/content/106/25/10109.full and at the Dropbox link in footnote 3 of this letter with the filename: "10109.full.pdf." This journal is peer-reviewed. *Id.* p. 10113.
[23] At the Dropbox link in footnote 3 of this letter with the filenames: "Marsh Skagit Cty MHHW.pdf" and "Marsh Migration Skagit Cty 2 ft Sea Level Rise.pdf." Three maps of the same view are needed to show the three parts of the legend, so that is why there are three pages in the Marsh Migration Skagit Cty 2 ft Sea Level Rise.pdf.
[24] Miller, I.M., Morgan, H., Mauger, G., Newton, T., Weldon, R., Schmidt, D., Welch, M., Grossman, E,. *Projected Sea Level Rise for Washington State – A 2018 Assessment* p. 8 of 24 (A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project: updated 07/2019).

Because of these significant impacts on people, property, and the environment, "[n]early six in ten Americans supported prohibiting development in flood-prone areas (57%)."[25] It is time for Washington state and local governments to follow the lead of the American people and adopt policies and regulations to protect people, property, and the environment from sea level rise. We recommend the addition of the following regulations as part of the shoreline master program periodic update:

> X. New lots shall be designed and located so that the buildable area is outside the area likely to be inundated by sea level rise in 2100 and outside of the area in which wetlands and aquatic vegetation will likely migrate during that time.
>
> X2. Where lots are large enough, new structures and buildings shall be located so that they are outside the area likely to be inundated by sea level rise in 2100 and outside of the area in which wetlands and aquatic vegetation will likely migrate during that time.
>
> X3. New and substantially improved structures shall be elevated above the likely sea level rise elevation in 2100 or for the life of the building, whichever is less.

Also, to avoid flooding, erosion, and other adverse impacts on shoreline resources, we strongly recommend that the County take a comprehensive approach to adapting to sea level rise and its adverse impacts modeled on the process California's coastal counties and cities use. The process includes six steps.[26]

1. Determine the range of sea level rise projections relevant to Skagit County's shorelines subject to tidal influence. The California Coastal Commission recommends analyzing intermediate and long-term projections because "development constructed today is likely to remain in place over the next 75-100 years, or longer."[27]
2. Identify potential physical sea level rise impacts in Skagit County's shorelines subject to tidal influence.
3. Assess potential risks from sea level rise to the resources and development on the shorelines subject to tidal influence.
4. Identify adaptation strategies to minimize risks. The *California Coastal Commission Sea Level Rise Policy Guidance* includes recommended adaptation strategies to consider.[28]
5. Adopt an updated shoreline master program incorporating the selected adaption strategies.

---

[25] Bo MacInnis and Jon A. Krosnick, *Climate Insights 2020: Surveying American Public Opinion on Climate Change and the Environment Report: Natural Disasters* p. 8 (Washington, DC: Resources for the Future, 2020) last accessed on April 1, 2022, at: https://www.rff.org/publications/reports/climateinsights2020-natural-disasters/ and at the Dropbox link in footnote 3 of this letter with the filename: "Climate_Insights_2020_Natural_Disasters.pdf."

[26] *California Coastal Commission Sea Level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits* pp. 69 – 95 (Nov. 7, 2018) last accessed on April 1, 2022, at: https://www.coastal.ca.gov/climate/slrguidance.html and at the Dropbox link in footnote 3 of this letter with the filename: "0_Full_2018AdoptedSLRGuidanceUpdate.pdf."

[27] *Id.* p. 74.

[28] *Id.* pp. 121 – 162.

6. Implement the updated shoreline master program and monitor and revise as needed. Because the scientific data on sea level rise is evolving, the California Coastal Commission recommends modifying "the current and future hazard areas on a five-to-ten-year basis or as necessary to allow for the incorporation of new sea level rise science, monitoring results, and information on coastal conditions."[29]

Based on this proven model, we recommend that the following proposed policy be adopted as part of the shoreline master program periodic update.

> Policy X. Skagit County shall monitor the impacts of climate change on Skagit County's shorelands, the shoreline master program's ability to adapt to sea level rise and other aspects of climate change at least every periodic update and revise the shoreline master program as needed. Skagit County shall periodically assess the best available sea level rise projections and other science related to climate change within shoreline jurisdiction and incorporate them into future shoreline master program updates as needed.

While Futurewise lost an appeal of the Grays Harbor County Shoreline Master Program arguing that the SMA and SMP guidelines require addressing sea level rise, that Shoreline Hearings Board decision is on appeal to the Court of Appeals.[30] Futurewise continues to believe that addressing sea level rise is both legally required and the right thing to do.

The County staff respond that Skagit County will apply for a competitive grant to address climate change and sea level rise. But as was documented above, sea level rise is happening now and accelerating. This update was due on December 1, 2012.[31] We need effective policies and regulations to address sea level rise now, not in five or ten years. Since the program is a competitive grant program there is no guarantee the County's application will even be funded.

Adopt up-to-date riparian buffers in Table 14.26.310-1 Dimensional Standards on pages 60 and 61 to protect Chinook habitat and other aquatic habitats.

As has been reported in media and scientific reports, the southern resident orcas, or killer whales, are threatened by (1) an inadequate availability of prey, the Chinook salmon, "(2) legacy and new toxic contaminants, and (3) disturbance from noise and vessel traffic."[32] "Recent scientific studies

[29] *Id.* p. 94.
[30] *Friends Of Grays Harbor and Futurewise v. State of Washington, Department of Ecology; and Grays Harbor County*, State of Washington, Shorelines Hearings Board (SHB) Case No. 20-006; *Friends Of Grays Harbor and Futurewise v. State of Washington et al.*, Court of Appeals Case No. 57100-5-II.
[31] RCW 90.58.080(2)(a)(iv).
[32] State of Washington Office of the Governor, Executive Order 18-02 Southern Resident Killer Whale Recovery and Task Force p. 1 (March 14, 2018) last accessed on April 1, 2022, at: https://www.governor.wa.gov/sites/default/files/exe_order/eo_18-02_1.pdf and at the Dropbox link in footnote 3 of this letter with the filename: "eo_18-02_1.pdf."

indicate that reduced Chinook salmon runs undermine the potential for the southern resident population to successfully reproduce and recover."[33] The shoreline master program update is an opportunity to take steps to help recover the southern resident orcas, the Chinook salmon, and the species and habitats on which they depend.

The Shoreline Master Program (SMP) Guidelines, in WAC 173-26-221(3)(c), provides in part that "[i]n establishing vegetation conservation regulations, local governments must use available scientific and technical information, as described in WAC 173-26-201(2)(a). At a minimum, local governments should consult shoreline management assistance materials provided by the department and *Management Recommendations for Washington's Priority Habitats*, prepared by the Washington state department of fish and wildlife where applicable."

The State of Washington Department of Fish and Wildlife has recently updated the Priority Habitat and Species recommendations for riparian areas. The updated management recommendations document that fish and wildlife depend on protecting riparian vegetation and the functions this vegetation performs such as maintaining a complex food web that supports salmon and maintaining temperature regimes to name just a few of the functions.[34]

The updated *Riparian Ecosystems, Volume 1: Science synthesis and management implications* scientific report concludes that the "[p]rotection and restoration of riparian ecosystems continues to be critically important because: a) they are disproportionately important, relative to area, for aquatic species, e.g., salmon, and terrestrial wildlife, b) they provide ecosystem services such as water purification and fisheries (Naiman and Bilby 2001; NRC 2002; Richardson et al. 2012), and c) by interacting with watershed-scale processes, they contribute to the creation and maintenance of aquatic habitats."[35] The report states that "[t]he width of the riparian ecosystem is estimated by one 200-year site-potential tree height (SPTH) measured from the edge of the active channel or active floodplain. Protecting functions within at least one 200-year SPTH is a scientifically supported approach if the goal is to protect and maintain full function of the riparian ecosystem."[36] These recommendations are explained further in *Riparian Ecosystems, Volume 2: Management Recommendations A Priority Habitats and Species Document of The Washington Department of Fish and Wildlife.*[37]

Based on these new scientific documents, we recommend that shoreline jurisdiction should include the 100-year flood plain[38] and that the buffers for rivers and streams in shoreline jurisdiction be

---

[33] *Id.*
[34] Timothy Quinn, George F. Wilhere, and Kirk L. Krueger, technical editors, *Riparian Ecosystems, Volume 1: Science Synthesis and Management Implications* pp. 265 – 68 & p. 270 (A Priority Habitat and Species Document of the Washington Department of Fish and Wildlife, Olympia, WA: Updated July 2020) last accessed on April 1, 2022, at: https://wdfw.wa.gov/publications/01987/ and at the Dropbox link in footnote 3 of this letter with the filename: "wdfw01987.pdf." This report was peer-reviewed. *Id.* pp. 11 – 12.
[35] *Id.* p. 270.
[36] *Id.* p. 271.
[37] Amy Windrope, Terra Rentz, Keith Folkerts, and Jeff Azerrad, *Riparian Ecosystems, Volume 2: Management Recommendations A Priority Habitats and Species Document of The Washington Department of Fish and Wildlife* (Dec. 2020) last accessed on April 1, 2022, at: https://wdfw.wa.gov/publications/01988 and at the Dropbox link in footnote 3 of this letter with the filename: "wdfw01988.pdf."
[38] Authorized by RCW 90.58.030(2)(d)(i).

increased to use the newly recommended 200-year SPTH and that this width should be measured from the edge of the channel, channel migration zone, or active floodplain whichever is wider. New development, except water dependent uses should not be allowed within this area.[39] This will help maintain shoreline functions and Chinook salmon habitat.

Adopt better impervious surface limits and lot width requirements for areas outside the urban growth area in Table 14.26.310-1 Dimensional Standards on pages 60 and 61.

The Shoreline Master Program Guidelines, in WAC 173-26-211(5)(b)(ii)(D), provide that "[s]cientific studies support density or lot coverage limitation standards that assure that development will be limited to a maximum of ten percent total impervious surface area within the lot or parcel, will maintain the existing hydrologic character of the shoreline." We recommend that the hard surface limits for the Rural Conservancy and Urban Conservancy shoreline environments be limited to ten percent.

This is important because impervious surfaces are continuing to increase in the Skagit basin and without policy changes they will continue to increase.[40] As the *2020 State of Our Watersheds State of Our Watersheds: A Report by the Treaty Tribes in Western Washington* documents:

> As impervious surface increases in a watershed, stream temperatures and sediment transport are likely to increase, along with a decrease in stream biodiversity by reducing the number of insect and fish species. It will also contribute to pollutants in stormwater runoff, which can contaminate local aquatic systems. Contaminated runoff poses significant threats to freshwater, estuarine and marine species, including the Pacific Northwest's salmon and steelhead runs. The addition of impervious surface reduces water infiltration and increases runoff, causing higher peak flows during wet times and lower dry weather flows due to lack of groundwater recharge.[41]

WAC 173-26-186(8)(b) provides that "[l]ocal master programs shall include policies and regulations designed to achieve no net loss of those ecological functions." Impervious surface requirements are needed to maintain no net loss of shoreline ecological functions. We appreciate that Table 14.26.310-1 now provides that "[l]ots in Rural Conservancy created after the adoption of the SMP have a hard surface limit of 10 percent for residential development." But what is existing lots are large enough to meet the ten percent requirement? The requirement should apply to all Rural Conservancy and Urban Conservancy lots for the important reasons documented above.

---

[39] Timothy Quinn, George F. Wilhere, and Kirk L. Krueger, technical editors, *Riparian Ecosystems, Volume 1: Science Synthesis and Management Implications* pp. 270 – 71 (A Priority Habitat and Species Document of the Washington Department of Fish and Wildlife, Olympia, WA: Updated July 2020).

[40] Northwest Indian Fisheries Commission and Member Tribes, *2020 State of Our Watersheds State of Our Watersheds: A Report by the Treaty Tribes in Western Washington* p. 35 last accessed on April 1, 2022, at: https://nwifc.org/publications/state-of-our-watersheds/ and at the Dropbox link in footnote 3 of this letter with the filename: "state-of-our-watersheds-sow-2020-final-web.pdf."

[41] *Id.* footnotes omitted.

We also recommend that Table 14.26.310-1 include minimum lot widths for lots outside urban growth areas. In shoreline areas there is a strong incentive to have narrow lots along the shoreline since waterfront lots are highly valued. This can lead to narrow lots and buildings that are built cheek-by-jowl along the water – which is the historic practice of cramming as many water-access lots in as possible – cutting the wildlife in the uplands off from the water areas and vise-versa. *Riparian Ecosystems, Volume 1: Science Synthesis and Management Implications* documents that "[c]onnectivity in riparian areas occurs not only parallel to the stream (previous section), but also orthogonally to the channel in a lateral dimension — from the stream through the riparian area into uplands—and the vertical dimension in the hyporheic zone."[42] These movements include surface and ground water, sediment, large wood, other organic debris,[43] and animals that may spend part of their day or year in upland areas and part of the day or year along the water body. While modern rural lot area requirements reduce this likelihood, reasonable lot width requirements prevent long narrow lots that can meet area requirements and still place houses close together. Minimum lot widths need to allow wildlife to pass through residential areas to use upland areas and to use shorelines. A simple lot length to width ratio of 3:1 can address this problem. Another alternative would be to establish 300' lot widths for the Conservancy and Natural shoreline environments.

Skagit County Code (SCC) 14.26.340, Archaeological, Historic, and Scientific Resources, needs to require predevelopment investigations for areas where archaeological resources are likely to be located. See pages 66 – 68.

We appreciate and support the archaeological, historic, and scientific resources policies and regulations. Many historical and cultural sites are located in shoreline jurisdiction due to the availability of water, food sources, and transportation routes. The Washington State Department of Archaeology and Historic Preservation has developed an archaeological predictive model that can predict where archaeological resources are likely to be located and where the department recommends archaeological surveys should be completed before earth disturbing activities and other uses and activities that can damage archaeological sites are undertaken.[44] The results of the predictive model are available for Skagit County to use in planning and project reviews from the Washington State Department of Archaeology and Historic Preservation's WISAARD (Washington Information System for Architectural & Archaeological Records Data) online mapping tool. You can access WISAARD here: https://dahp.wa.gov/project-review/wisaard-system Many shoreline areas in Skagit County, and Washington State, are rated "survey recommended moderate risk", "survey highly advised high risk," and "survey highly advised very high risk." See the WISAARD website.

---

[42] *Id.* p. 256.
[43] *Id.*
[44] Russell Holter, Washington State Department of Archaeology and Historic Preservation, *Protecting the Past Using Tools of the Future: Archaeology Predictive Modeling* p. 5 (Presentation: 10/2/2014) last accessed on April 1, 2022, at: http://www.infrafunding.wa.gov/downloads/2014_Conference_Presentations/S53.pdf.

Addressing archaeological resources upfront before projects begin can save money. For example, the Jefferson County Public Utility District's (PUD) contractor building a community septic system at Becket Point in Jefferson County encountered human bones and Native American artifacts.[45] The contractor had to stop construction. An archaeologist was called in and conducted an investigation that allowed the project to be redesigned and to be completed. However, PUD staff "estimated the delays and additional engineering incurred because of the artifacts added about $90,000 to the project's cost."[46] Much of that money could have been saved by an upfront archeological investigation. So, to both protect archaeological resources and to forestall project stoppages, we recommend that SCC 14.26.340(3) and (5) be modified to read as follows with our additions underlined and our deletions struck through.

(3) Site inspection and evaluation. Proposals for shoreline development or use in or on areas <u>within 200 feet of a site rated as rated "survey recommended moderate risk," "survey highly advised high risk," and "survey highly advised very high risk" by the current version of the Washington State Department of Archaeology and Historic Preservation's archaeological predictive model or</u> documented to contain archaeological, historic, or scientific resources require site inspection and evaluation by qualified personnel prior to any development activity in or on the site. In areas <u>within 200 feet of a site rated as rated "survey recommended moderate risk," "survey highly advised high risk," and "survey highly advised very high risk" by the current version of the Washington State Department of Archaeology and Historic Preservation's archaeological predictive model or</u> documented to contain archaeological resources, site inspection and evaluation must be performed by a professional archaeologist in coordination with affected Indian tribes.

(5) Adjacent and nearby development. Proposals for shoreline development or use adjacent to or nearby areas <u>rated as rated "survey recommended moderate risk," "survey highly advised high risk," and "survey highly advised very high risk" by the current version of the Washington State Department of Archaeology and Historic Preservation's archaeological predictive model or</u> documented to contain archaeological, historic, or scientific resources must be located, designed, and operated to not adversely affect the purpose, character, or value of such resources.

---

[45] Jeff Chew, *Jefferson PUD sticks with Beckett Point* <u>Connections</u> p. 8 (Washington Public Utility Districts Association [WPUDA]: Winter 2008) last accessed on April 1, 2022, at: https://www.yumpu.com/en/document/view/46547248/connections-washington-public-utility-district-association/11.
[46] *Id.* at p. 9.

Buffer reductions of more than 25 percent must require a standard variance, not an administrative variance. See proposed 14.26.735(2)(a) on page 221.

Allowing buffer reductions of more than 25 percent is inconsistent with best available science and should not be allowed except through a standard variance.[47] The administrative variance should be limited to a 25 percent reduction.

Amend SCC 14.26.460, Mining, so that it is consistent with amendments to state law and to protect the shoreline environment. See pages 126 through 130.

SCC 14.26.460(1)(b)(ii) exempts from the SMP "mining that complies with the Washington Department of Fish and Wildlife's Gold and Fish Pamphlet." In 2020, the legislature adopted RCW 90.48.615(2) which prohibits "[m]otorized or gravity siphon aquatic mining or discharge of effluent from such activity to any waters of the state that has been designated under the endangered species act as critical habitat, or would impact critical habitat for salmon, steelhead, or bull trout. This includes all fresh waters with designated uses of: Salmonid spawning, rearing, and migration." We recommend that the SMP Update prohibit motorized or gravity siphon aquatic mining and discharging effluent from this type of mining in shorelines that are the critical habitat for salmon, steelhead, or bull trout and that salmonids use for spawning, rearing, and migration.

Gravel mining in flood plains, floodways, channel migration zones, and river bars, active channels, has the potential to adversely impact rivers and streams. As the Washington State Department of Natural Resources geology staff have written:

> Seeking the lowest cost material, gravel miners commonly choose to excavate large, deep ponds adjacent to active river channels … Wherever a channel shifts into a gravel pit or multiple pits that are large relative to the scale of the flood plain and the river's sediment transport regime, natural recovery of original flood plain environment and similar channel morphology could take millennia (Collins, 1997). The time for recovery is highly dependent on the availability of sediment, particle size, gradient, and the size of excavations to be filled. Regardless of the best planning and intentions, impacts of flood-plain mining may simply be delayed until the river is captured by the gravel pit. While capture may not occur in the next 100-year flood event, it is likely to occur in the future as development and consequent flood magnitude increase. In the long term, stream capture by gravel pits is a near certainty.

---

[47] T. Granger, T. Hruby, A. McMillan, D. Peters, J. Rubey, D. Sheldon, S. Stanley, E. Stockdale, *Wetlands in Washington State - Volume 2: Guidance for Protecting and Managing Wetlands* (Washington State Department of Ecology, Olympia, WA: April 2005, Publication #05-06-008) Appendix 8-C Guidance on Widths of Buffers and Ratios for Compensatory Mitigation for Use with the Western Washington Wetland Rating System p. 14 (July 2018 Modified Habitat Score Ranges) last accessed on April 1, 2022, at: https://fortress.wa.gov/ecy/publications/summarypages/0506008.html and at the Dropbox link in footnote 3 of this letter with the filename: "0506008part3.pdf."

> Because the gravel pits have a lower base elevation, there is risk of rapid channel change into the pits during high flows, a process termed avulsion. The flooded pits "capture" the stream. The effects of avulsion are similar to those of in-stream mining discussed in Evoy and Holland (1989), Collins and Dunne (1990), Netsch and others (1981), Kondolf and Graham Matthews (1993), Kondolf (1993, 1994), and Williamson and others (1995a,b). They may include:
>
> - lowering the river bed upstream and downstream of mining operations, causing river bed erosion and (or) channel incision and bank erosion and collapse,
> - eroding of footings for bridges or utility rights-of-way,
> - changing aquatic habitat,
> - unnaturally simplifying the complex natural stream system,
> - increasing suspended sediment, and
> - abandoning reaches of spawning gravels or damaging these gravels by channel erosion or deposition of silts in spawning and rearing reaches.[48]

If mining is going to be allowed in flood plains, floodways, and channel migration zones, which the County is proposing, then additional standards are needed. First, mines should be located outside the channel migration zone so that they do not increase the rate of channel migration. Second, mines should be no deeper than the bottom of the nearby streams and rivers so when the river moves into the mine, which is a certainty, the impacts will be reduced. Third the mine reclamation plan should have a design so that when the river or stream moves into the mine, the mine workings are not so wide that the captured sediments destabilize the river or stream or increase erosion risks on upstream properties.

We recommend that the following new regulation be added on page 129 under "(e)".

(vi) Mines should be located outside the channel migration zone unless there is no feasible alternative site and no feasible source of sand and gravel.

(vii) Mines in the 100-year flood plain, floodway, or channel migration zones shall be no deeper than the bottom of the nearby streams and rivers.

(vii) In the 100-year flood plain, floodway, or channel migration zones, the mine reclamation plan shall have a design so that when the river or stream moves into the mine it is not so wide or deep that the captured sediments destabilize the river or stream or increase erosion risks to upstream properties.

---

[48] David K. Norman, C. Jeff Cederholm, and William S. Lingley, Jr, "Flood Plains, Salmon Habitat, and Sand and Gravel Mining" *Washington Geology*, vol. 26, no. 2/3, pp. 4 – 5 (Sept. 1998) accessed on April 1, 2022, at: http://file.dnr.wa.gov/publications/ger_washington_geology_1998_v26_no2-3.pdf and at the Dropbox link in footnote 3 of this letter with the file name: "ger_washington_geology_1998_v26_no2-3.pdf."

Require analysis of all geological hazards which can adversely impact a proposed development and require case-by-case determinations of landslide buffers including landslide runout areas based on the risk to the proposed development. Please see SCC 14.26.562 and SCC 14.26.563 on pages 195 – 199.

The March 22, 2014, Oso landslide "claimed the lives of 43 people, making it the deadliest landslide event in United States history. Of the approximately 10 individuals who were struck by the landslide and survived, several sustained serious injuries."[49] Several years before, a family of four was killed by shallow debris flow that initiated above Rolling Bay Walk on Bainbridge Island crushing their home.[50] So properly identifying geologically hazardous areas and protecting people from geological hazards is important.

Homeowner's insurance does not cover the damage from landslides. "Insurance coverage for landslides is uncommon. It is almost never a standard coverage and is difficult to purchase inexpensively as a policy endorsement."[51]

None of the Oso victims' homes were covered by insurance for landslide hazards.[52] And that is common when homes are damaged by landslides.[53] For example, on March 14, 2011, a landslide damaged the home of Rich and Pat Lord.[54] This damage required the homeowners to abandon their home on Norma Beach Road near Edmonds, Washington. Because their homeowner's insurance

---

[49] Jeffrey R. Keaton, Joseph Wartman, Scott Anderson, Jean Benoît, John deLaChapelle, Robert Gilbert, David R. Montgomery, *The 22 March 2014 Oso Landslide, Snohomish County, Washington* p. 1 (Geotechnical Extreme Events Reconnaissance (GEER): July 22, 2014) last accessed on April 1, 2022 at: http://www.geerassociation.org/index.php/component/geer_reports/?view=geerreports&layout=build&id=30. If the American territories are included, then the Oso landslide is the second deadliest landslide in American history. R.M. Iverson, D.L. George, K. Allstadt, *Landslide mobility and hazards: implications of the Oso disaster* 412 EARTH AND PLANETARY SCIENCE LETTERS 197, 198 (2015). The Geological Society of America gave an award to *The 22 March 2014 Oso Landslide, Snohomish County, Washington.* Hannah Hickey, Joseph Wartman, David Montgomery honored for Oso landslide report p. 1 (July 15, 2016).

[50] Edwin L. Harp, John A. Michael, and William T. Laprade, *Shallow-Landslide Hazard Map of Seattle, Washington* p. 2 (U.S. Geological Survey Open-File Report 2006–1139: 2006) last accessed on April 1, 2022, at: http://pubs.usgs.gov/of/2006/1139/ and at the Dropbox link in footnote 3 of this letter with the filename: "of06-1139_508.pdf."

[51] Robert L. Schuster & Lynn M. Highland, *The Third Hans Cloos Lecture: Urban landslides: socioeconomic impacts and overview of mitigative strategies* 66 BULLETIN OF ENGINEERING GEOLOGY AND THE ENVIRONMENT 1, p. 22 (2007) last accessed on April 1, 2022, at: https://www.researchgate.net/publication/225794820_The_Third_Hans_Cloos_Lecture_Urban_landslides_socioeconomic_impacts_and_overview_of_mitigative_strategies.

[52] Sanjay Bhatt, *Slide erased their homes, but maybe not their loans* The Seattle Times (April 2, 2014) last accessed on April 1, 2022 at: http://old.seattletimes.com/html/latestnews/2023278858_mudslidefinancialxml.html.

[53] *Id.*

[54] Ian Terry, *Abandoned and trashed after mudslide, Edmonds house now for sale* The Herald (Feb. 11, 2015). The house is for sale after the bank who held the Lords' mortgage took ownership of the home. *Id.* Last accessed on April 1, 2022, at: http://www.heraldnet.com/article/20150211/NEWS01/150219829.

did not cover landslides, they lost their home.[55] This loss of what may be a family's largest financial asset is common when homes are damaged or destroyed by landslides or other geological hazards.

Landslide buyouts are rare and when they occur the property owner often only recovers pennies on the dollar. The property owners bought out after the Aldercrest-Banyon landslide in Kelso, Washington destroyed their homes received 30 cents on the dollar.[56] This underlines why preventing development in geologically hazardous areas is just plain ordinary consumer protection.

Landslides in Western Washington can run out long distances. The 1949 Tacoma Narrows Landslide, in Tacoma "failed catastrophically along steep" 300 feet high bluffs and ran out 1,500 feet into Puget Sound.[57] This is five times the buff height. The 2014 Oso slide ran out for over a mile (5,500 feet) even through the slope height was 600 feet.[58] This was nine times the slope height. Recent research shows that long runout landslides are more common than had been realized.[59] This research documents that over the past 2000 years, the average landslide frequency of long runout landsides in the area near the Oso landslide is one landslide every 140 years.[60] The landslides ran out from 656 feet to the 6,561 feet of the 2014 landside.[61] The 2013 Ledgewood-Bonair Landslide on Whidbey Island extended approximately 300 feet into Puget Sound.[62] In a study of shallow landslides along Puget Sound from Seattle to Everett, the average runout length was 197.5 feet (60.2

[55] *Id.* p. *6.
[56] Isabelle Sarikhan, *Sliding Thought Blog, Washington's Landslide Blog* Landslide of the Week – Aldercrest Banyon Landslide July 29, 2009 last accessed on April 1, 2022 at: https://slidingthought.wordpress.com/2009/07/29/landslide-of-the-week-aldercrest-banyon-landslide/.
[57] Alan F. Chleborad, *Modeling and Analysis of the 1949 Narrows Landslide, Tacoma, Washington* xxxi ENVIRONMENTAL AND ENGINEERING GEOSCIENCE 305 p. 305 (1994) last accessed on April 1, 2022, at: https://pubs.geoscienceworld.org/aeg/eeg/article-abstract/xxxi/3/305/137520/modeling-and-analysis-of-the-1949-narrows?redirectedFrom=fulltext. Environmental & Engineering Geoscience is a peer-reviewed journal. Environmental & Engineering Geoscience Complete Author Instructions p. 1 of 6 (May 8, 2012).
[58] Jeffrey R. Keaton, Joseph Wartman, Scott Anderson, Jean Benoît, John deLaChapelle, Robert Gilbert, David R. Montgomery, *The 22 March 2014 Oso Landslide, Snohomish County, Washington* p. 56 & p. 144 (Geotechnical Extreme Events Reconnaissance (GEER): July 22, 2014).
[59] Sean R. LaHusen, Alison R. Duvall, Adam M. Booth, and David R. Montgomery, *Surface roughness dating of long-runout landslides near Oso, Washington (USA), reveals persistent postglacial hillslope instability* GEOLOGY pp. *2 – 3, published online on 22 December 2015 as doi:10.1130/G37267.1; Geological Society of America (GSA) Data Repository 2016029, *Data repository for: Surface roughness dating of long-runout landslides near Oso, WA reveals persistent postglacial hillslope instability* p. 4. Geology is a peer-reviewed scientific journal. Geology – Prep webpage last accessed on April 11, 2022 at: http://www.geosociety.org/GSA/Publications/Journals/Geology/GSA/Pubs/geology/home.aspx#overview.
[60] Sean R. LaHusen, Alison R. Duvall, Adam M. Booth, and David R. Montgomery, *Surface roughness dating of long-runout landslides near Oso, Washington (USA), reveals persistent postglacial hillslope instability* GEOLOGY p. *2, published online on 22 December 2015 as doi:10.1130/G37267.1 at the Dropbox link in footnote 3 of this letter with the filename: "G37267.1.full.pdf."
[61] Geological Society of America (GSA) Data Repository 2016029, *Data repository for: Surface roughness dating of long-runout landslides near Oso, WA reveals persistent postglacial hillslope instability* p. 4 at the Dropbox link in footnote 3 of this letter with the filename: "2016029.pdf."
[62] Stephen Slaughter, Isabelle Sarikhan, Michael Polenz, and Tim Walsh, *Quick Report for the Ledgewood-Bonair Landslide, Whidbey Island, Island County, Washington* pp. 3 – 4 (Washington State Department of Natural Resources, Division of Geology and Earth Resources: March 28, 2013) last accessed on April 1, 2022 at: http://www.dnr.wa.gov/publications/ger_qr_whidbey_island_landslide_2013.pdf.

m) and the maximum runout length was 771 feet (235 m).[63] So only requiring development that is within 300 feet of a geological hazard as SCC 14.26.562(1) does will not adequately protect people and property. So, we recommend that all construction, development, earth movement, clearing, drainage facilities, water diversions, or other site disturbance which may be adversely impacted by a geological hazard require a geological report and if necessary a geotechnical report.

The Joint SR 530 Landslide Commission recommends identifying "[c]ritical area buffer widths based on site specific geotechnical studies" as an "innovative development regulation[]" that counties and cities should adopt.[64] So we recommend that all properties that may be adversely impacted by a geological hazard should have their buffers based on a critical areas report for that site. Construction should not be allowed in buffer areas. These standards are necessary to protect Skagit County families and their largest investment, their homes.

Thank you for considering our comments. If you require more information, please contact me at telephone 206-343-0681 Ext. 102 and email: tim@futurewise.org.

Very Truly Yours,

Tim Trohimovich, AICP
Director of Planning and Law

Enclosures via this Dropbox link:
https://www.dropbox.com/sh/hr5kxb0sitoxfk8/AAC_br6R66ByUaVpKScKOC8Ra?dl=0

[63] Edwin L. Harp, John A. Michael, and William T. Laprade, *Shallow-Landslide Hazard Map of Seattle, Washington* p. 17 (U.S. Geological Survey Open-File Report 2006–1139: 2006).
[64] The SR 530 Landslide Commission, *Final Report* p. 31 (Dec. 15, 2014) last accessed on April 1, 2022 at: http://www.governor.wa.gov/sites/default/files/documents/SR530LC_Final_Report.pdf and at the Dropbox link in footnote 3 of this letter with the filename: "SR530LC_Final_Report.pdf."