Economic evaluation of sea-level rise adaptation strongly influenced by hydrodynamic feedbacks

Michelle Hummel[1], Robert Griffin[2,3], Anne Guerry[2], Katie Arkema[2,4]

[1]University of Texas at Arlington, [2]Natural Capital Project, Stanford University, [3]University of Massachusetts Dartmouth, [4]Pacific Northwest National Laboratory

SPUR

Oct 5th, 2021
Digital Discourse

UNIVERSITY OF TEXAS ARLINGTON

Stanford University

UMass | Dartmouth

natural capital PROJECT

NSF

NOAA

Overview

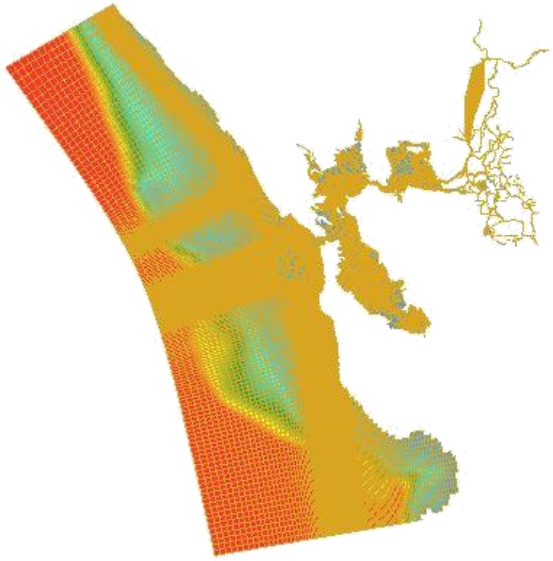
- Human decisions about shoreline adaptation can affect tidal propagation and patterns of inundation in urban estuaries (Pelling et al. 2013; Holleman and Stacey, 2014; Lee et al. 2017; Wang et al. 2018)
- This can lead to externalities (economic/social) for people living in other parts of the system

How do local-scale shoreline modifications affect regional hydrodynamics, shoreline inundation, and economic damages?

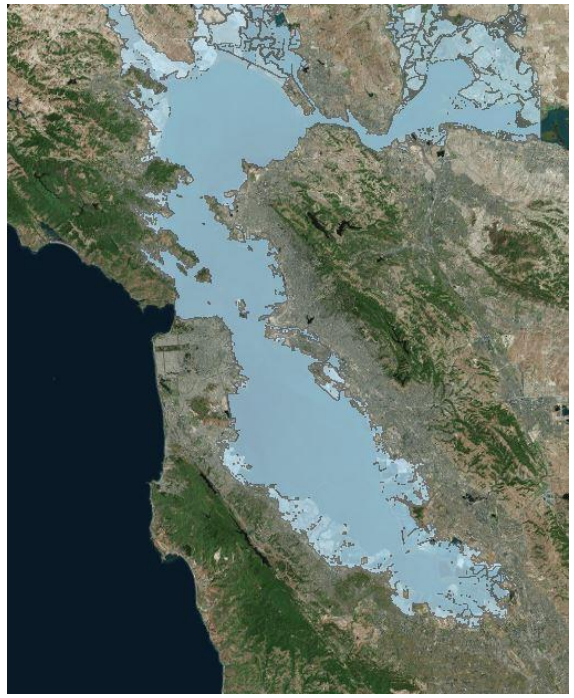
What are the implications for the selection and evaluation of shoreline adaptation strategies?

Modeling approach

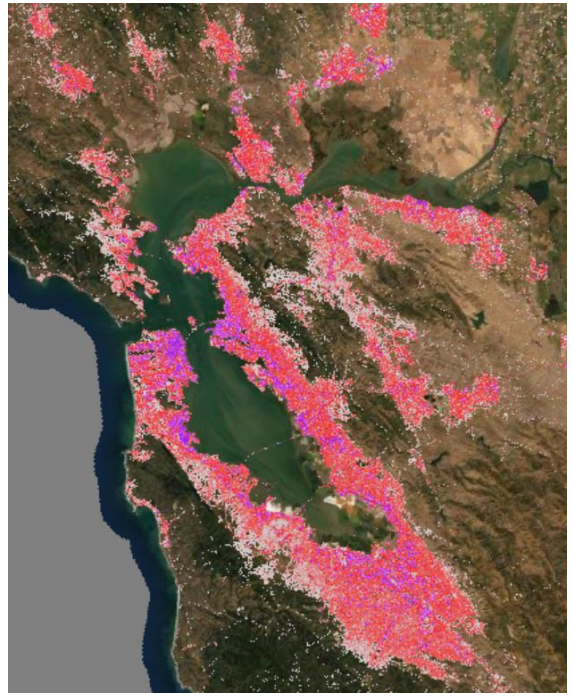
Hydrodynamic model

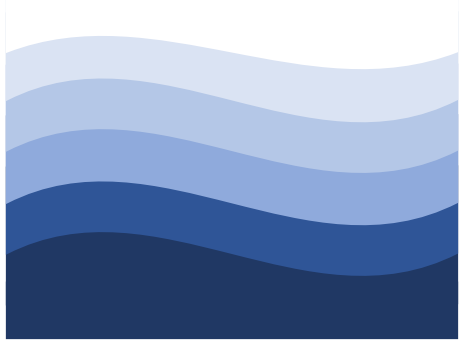


Flooding

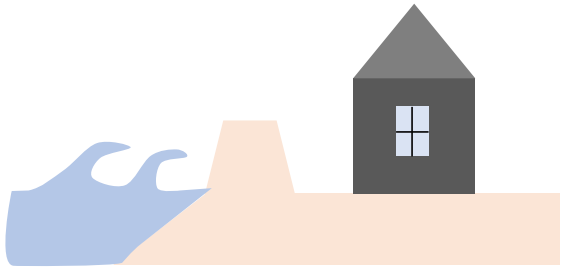


Damages



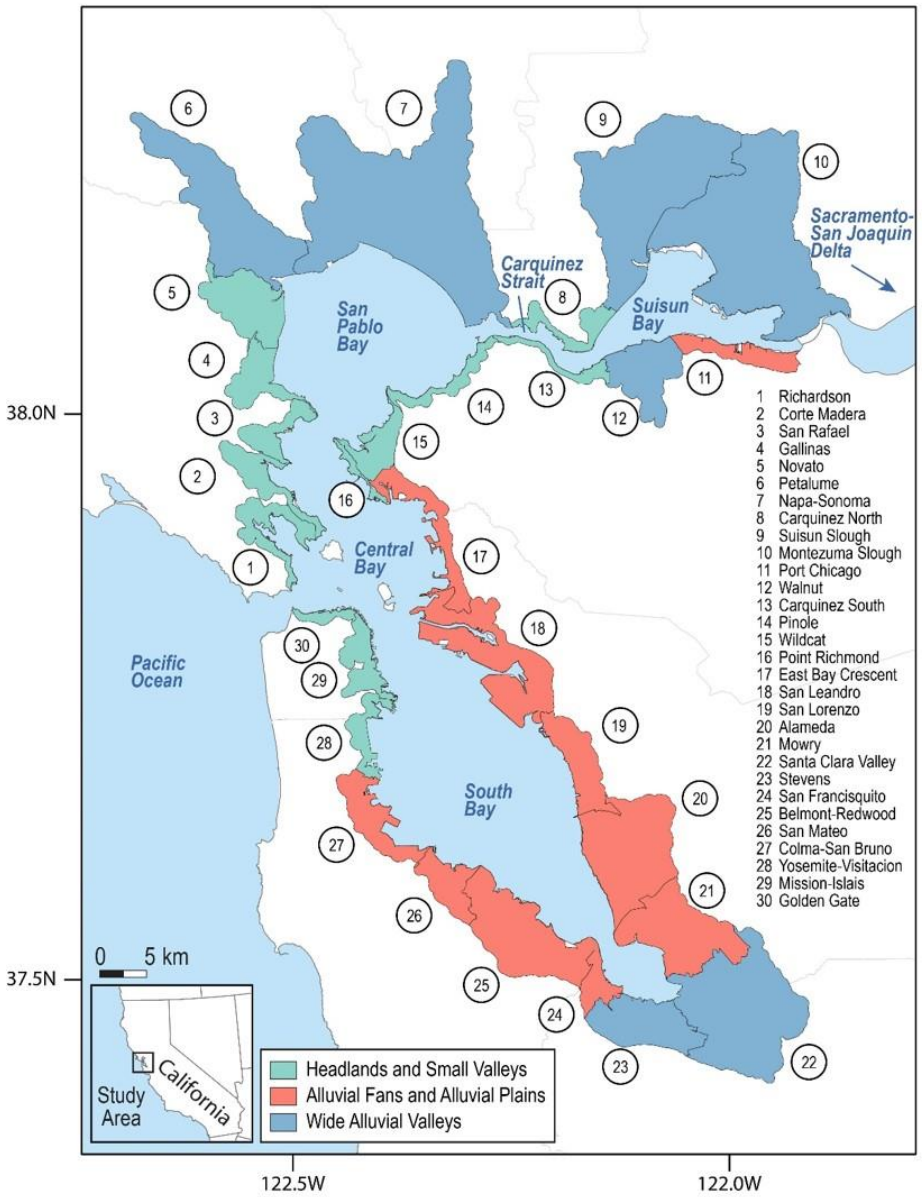


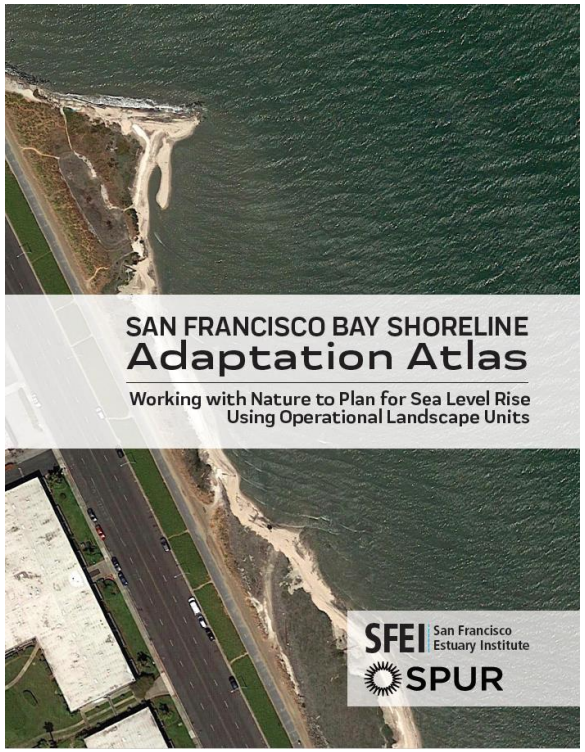
Sea-level rise



Shoreline protection

Shoreline segments

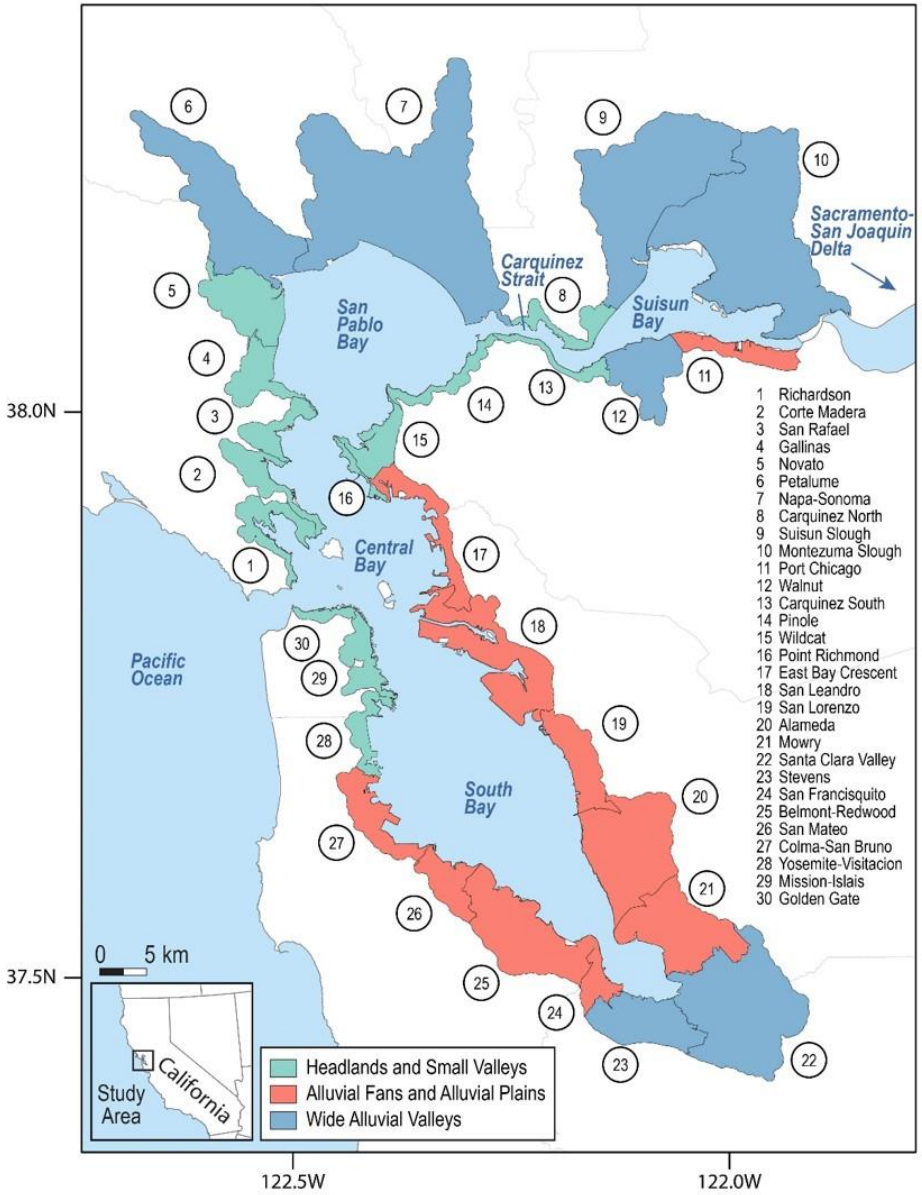


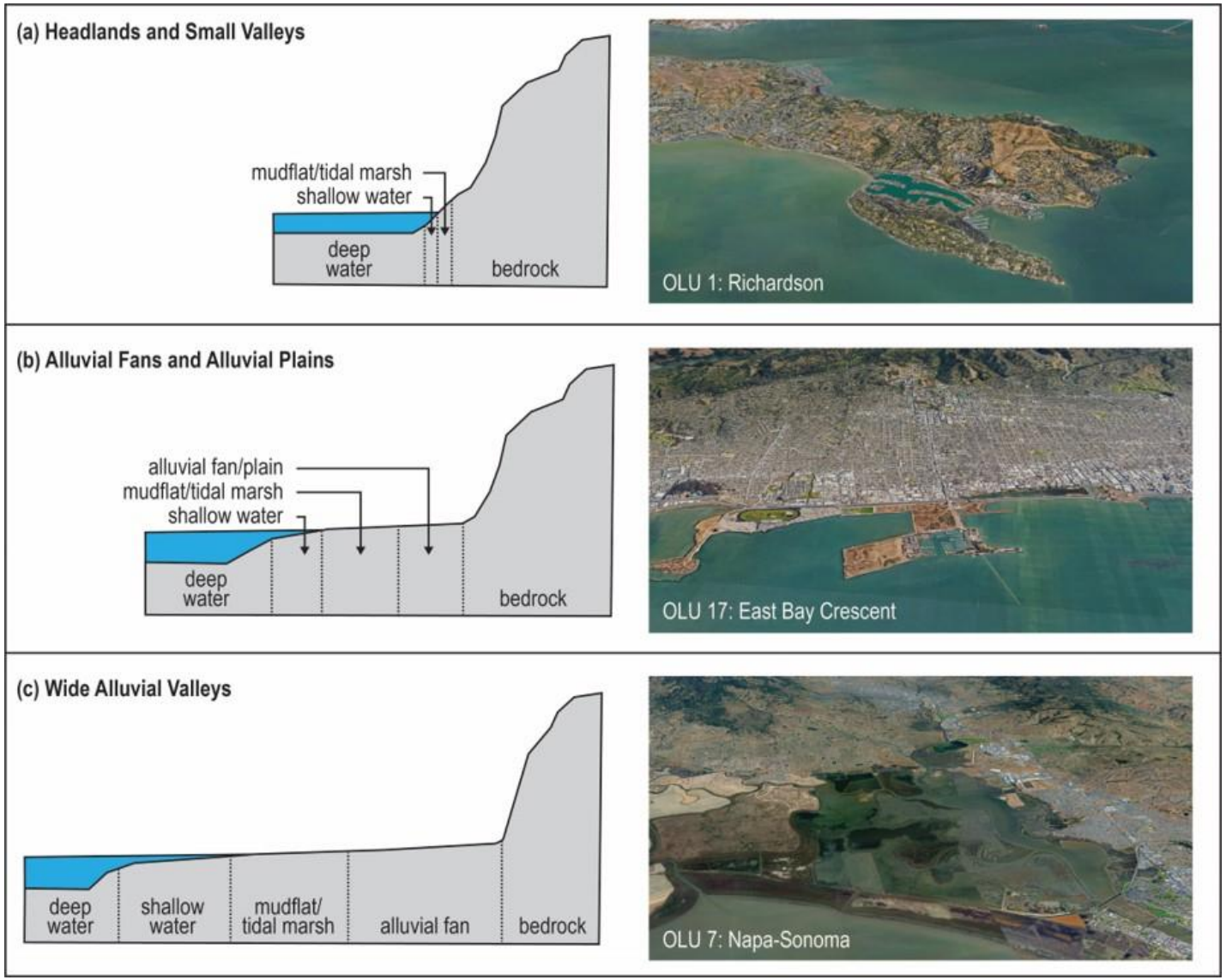


SFEI divided the bayshore into shoreline segments called Operational Landscape Units (OLUs)

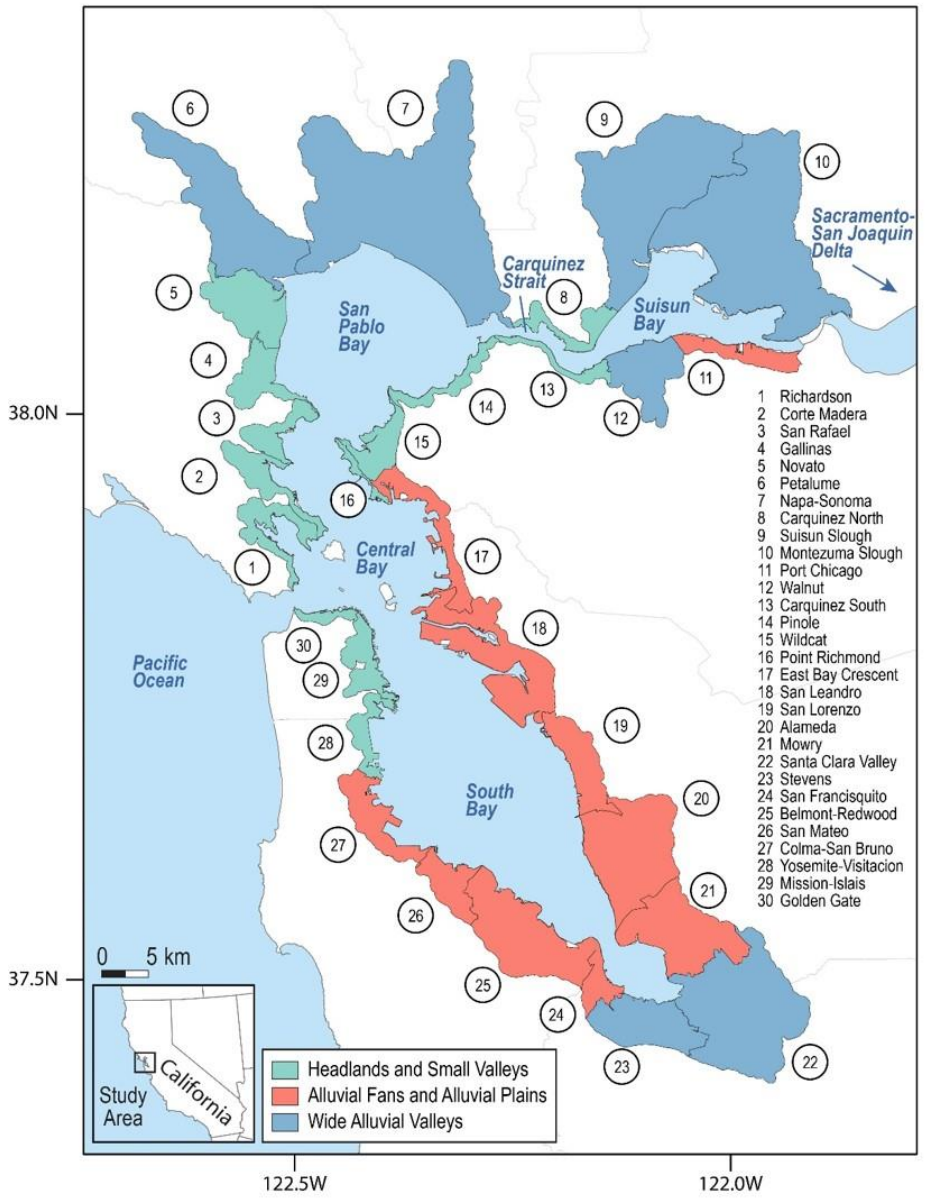
OLUs were delineated based on geomorphic features, topography, watershed boundaries, and nearshore hydrodynamic processes (SFEI and SPUR 2019)

Shoreline segments

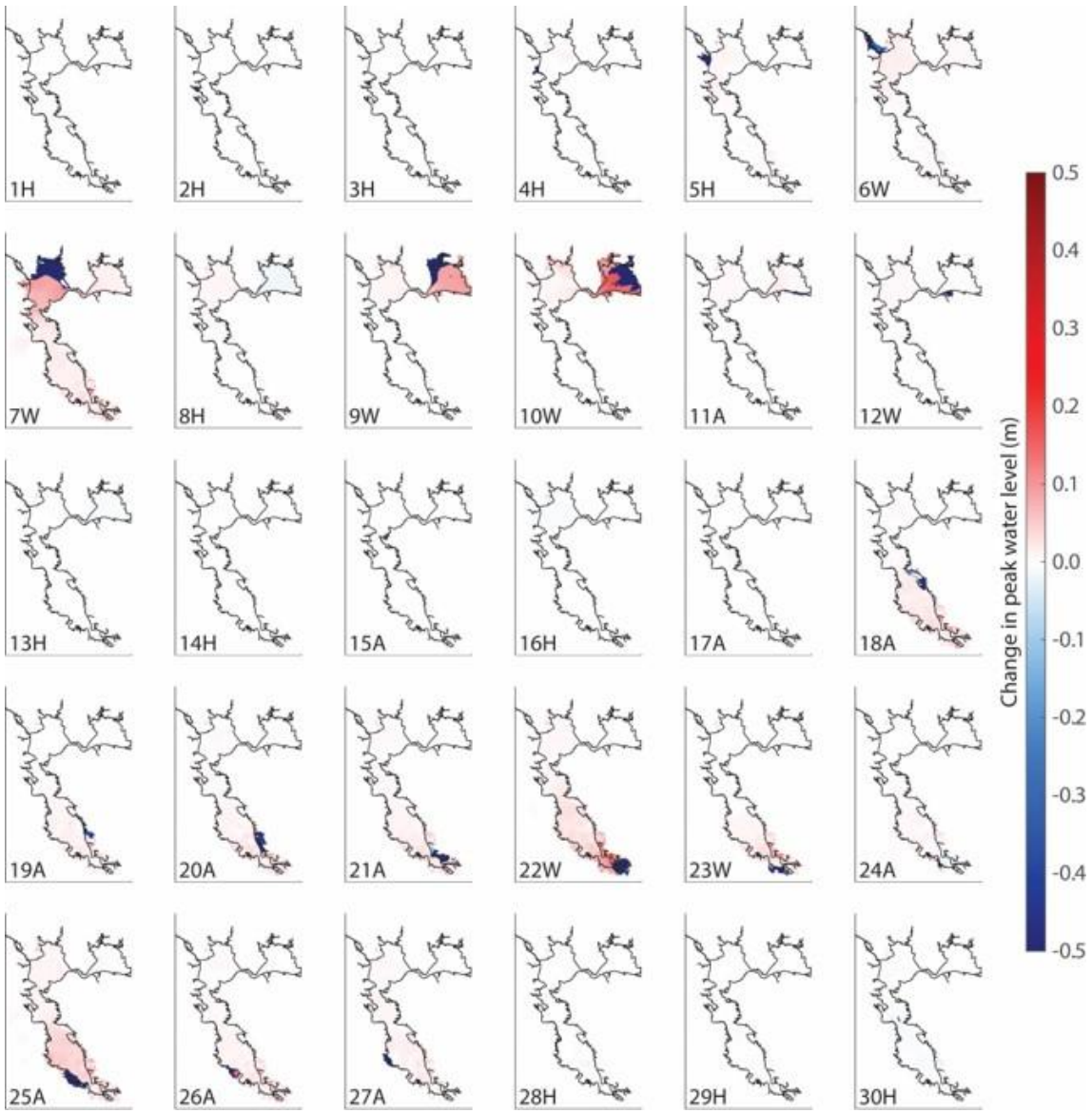




Effects of shoreline protection on hydrodynamics

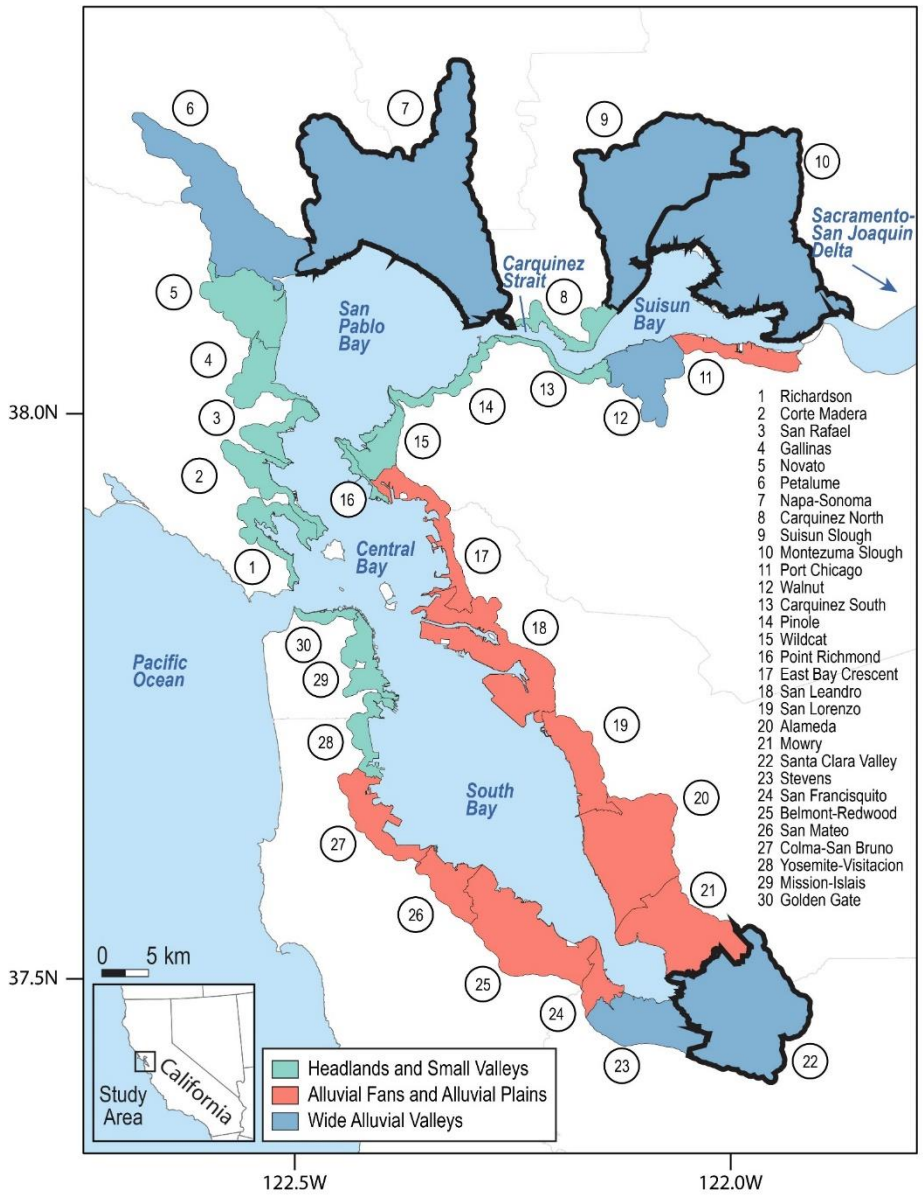


150 cm SLR

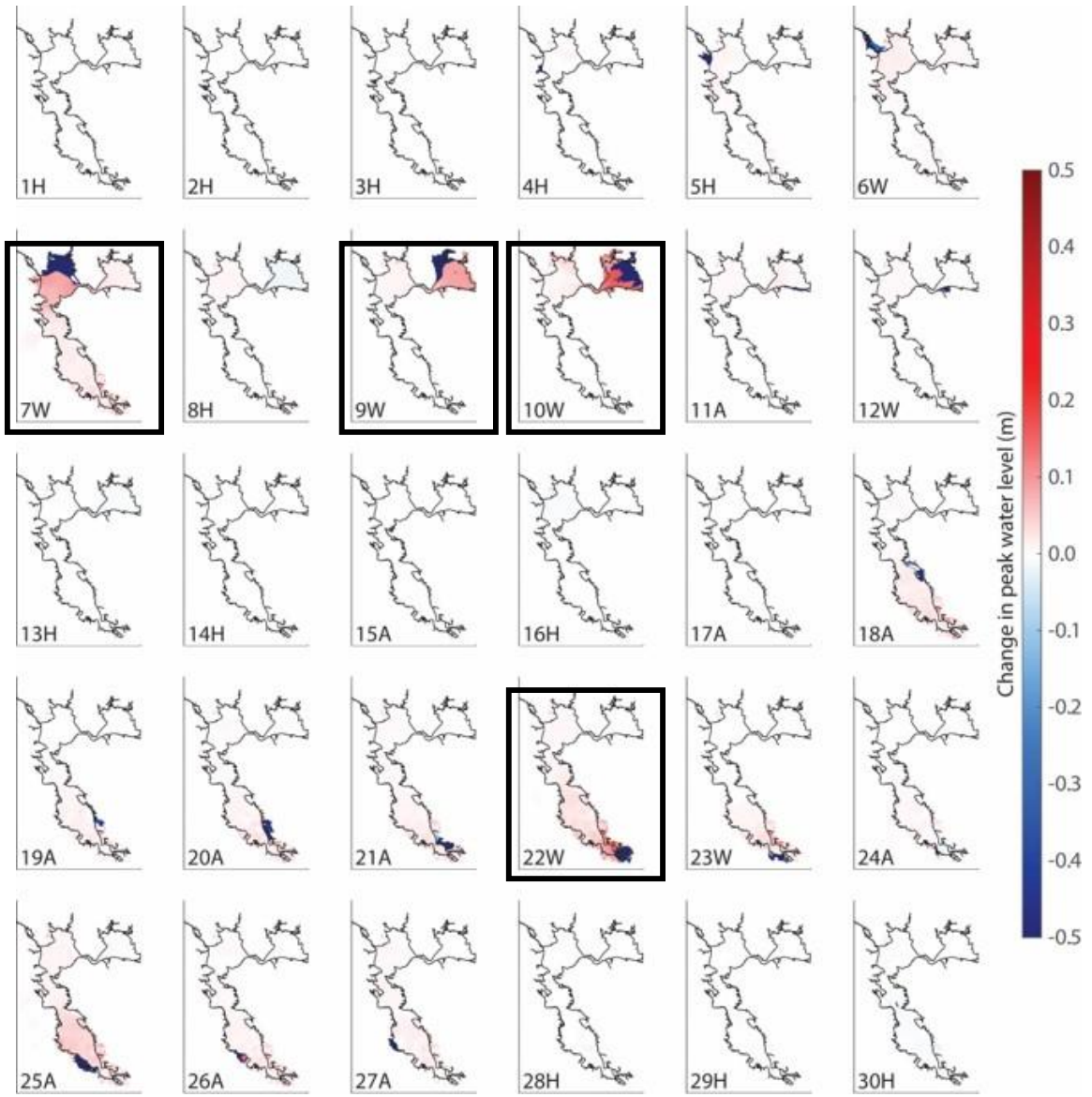


Hummel and Stacey (2020)

Effects of shoreline protection on hydrodynamics

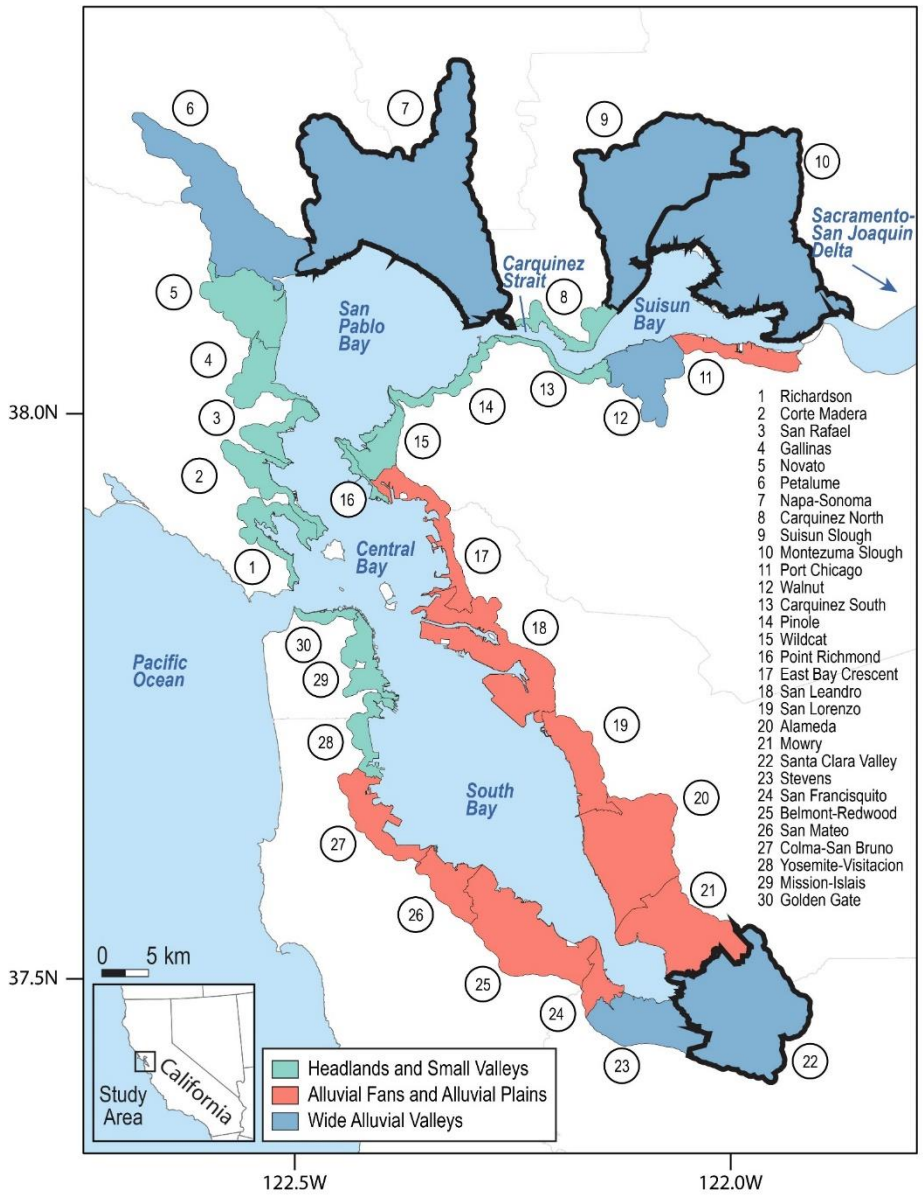


150 cm SLR

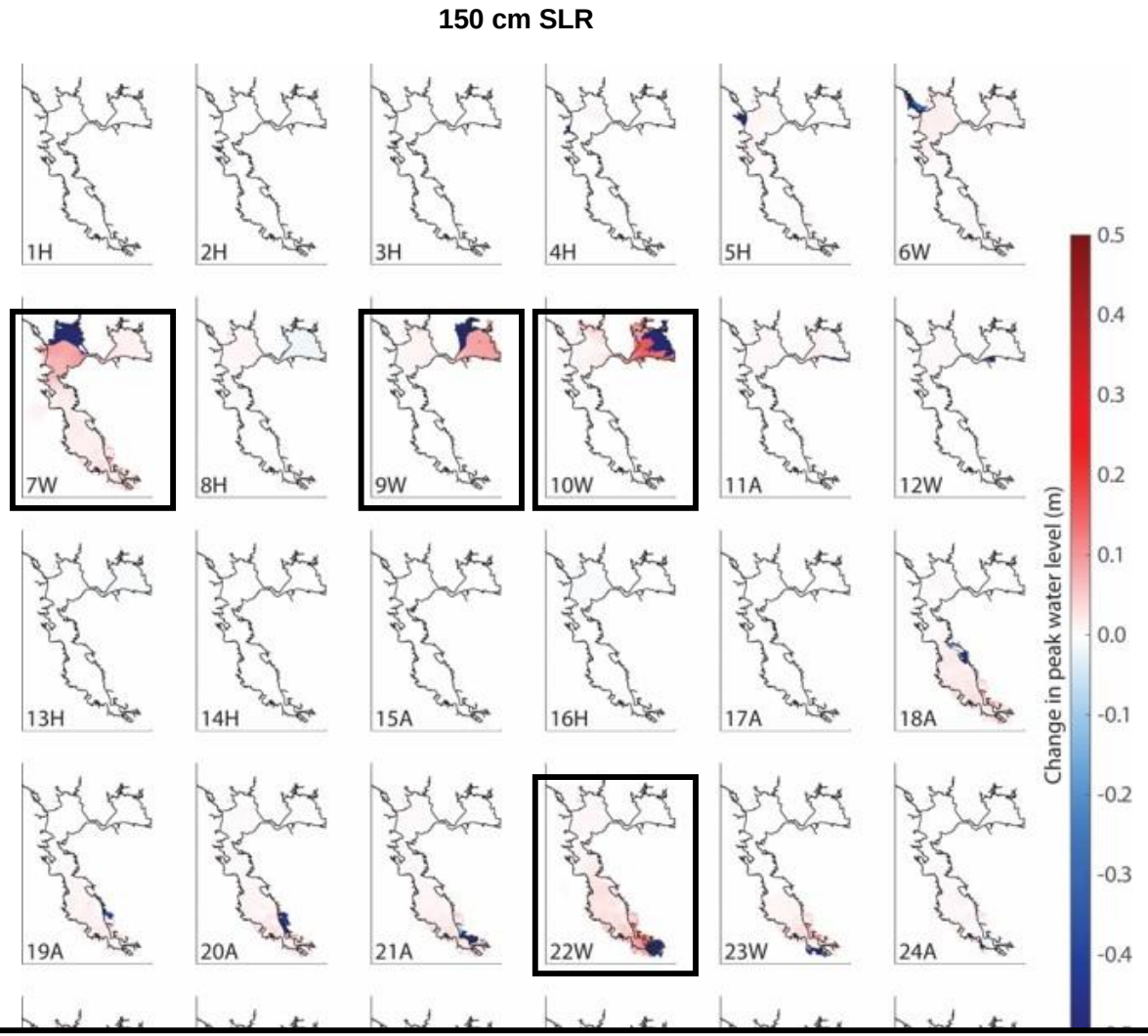


Hummel and Stacey (2020)

Effects of shoreline protection on hydrodynamics

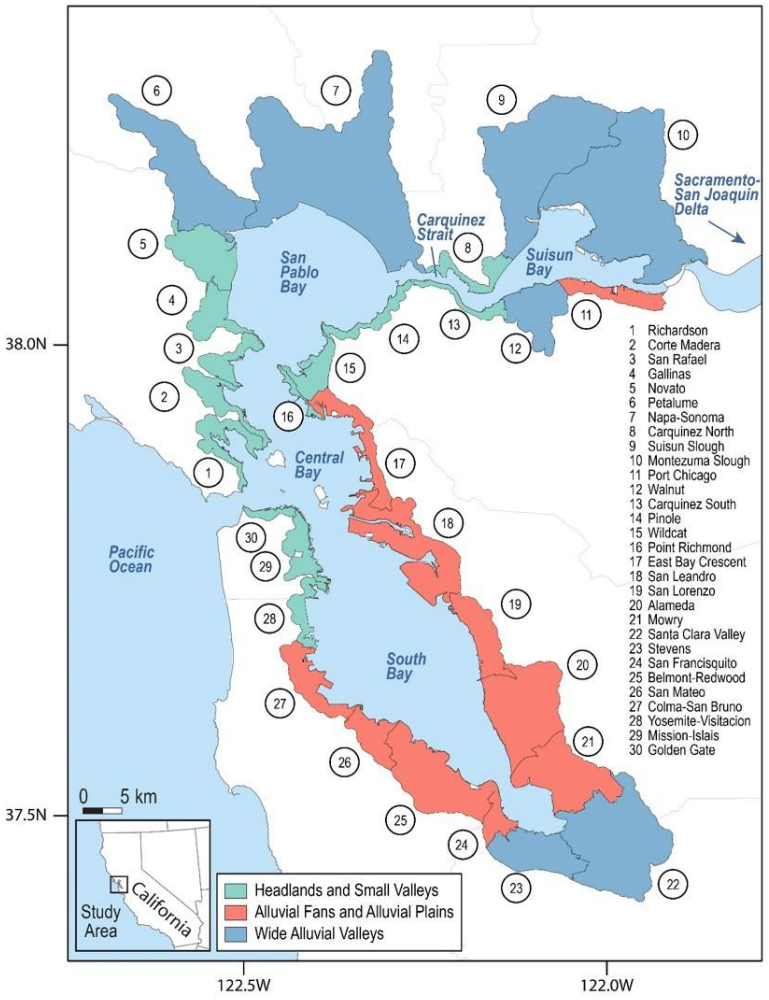


Hummel and Stacey (2020)

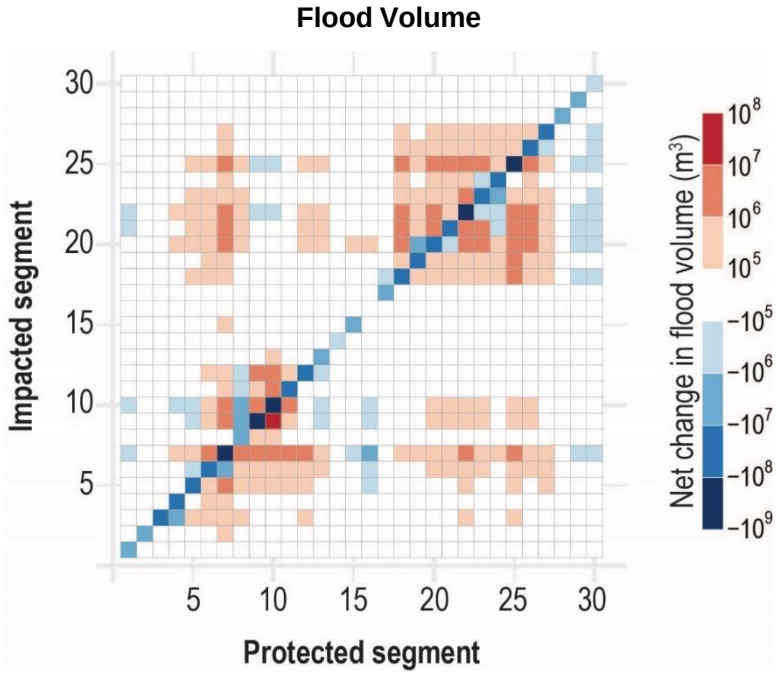


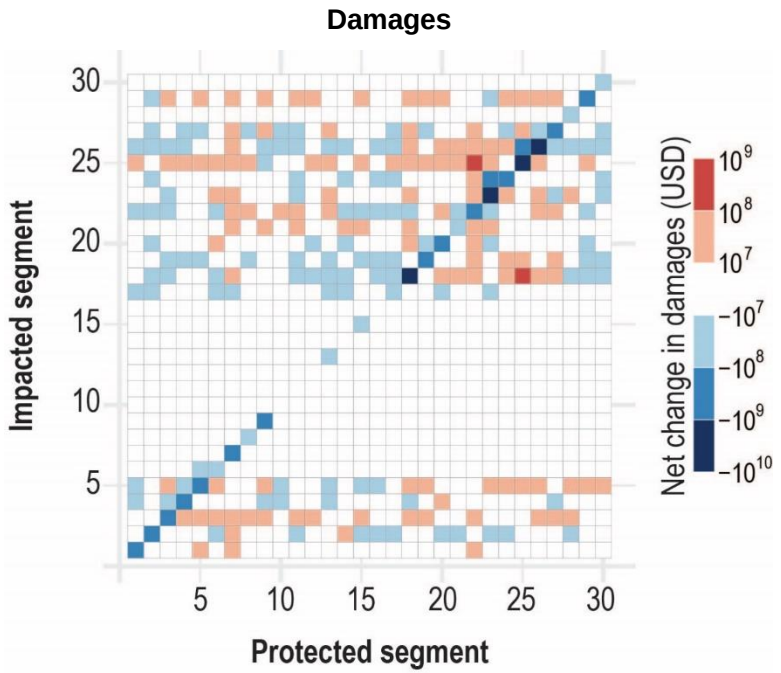
Shoreline protection in Wide Alluvial Valleys causes the largest increase in water levels across the Bay.

Effects of shoreline protection on flooding and economic damages



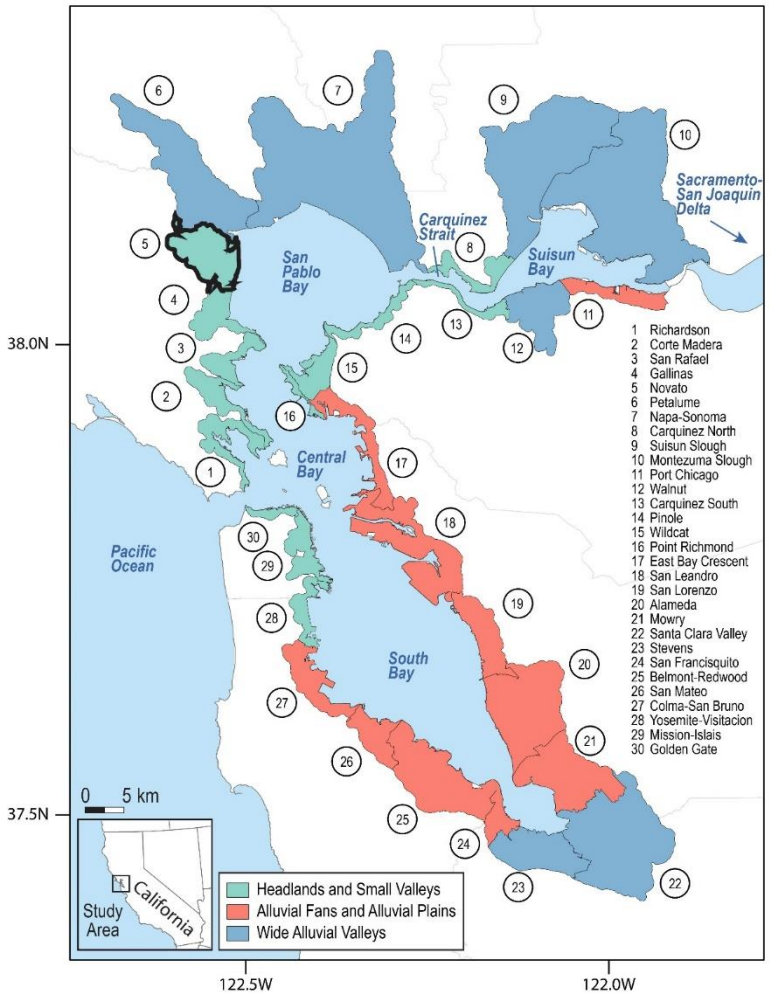
150 cm SLR

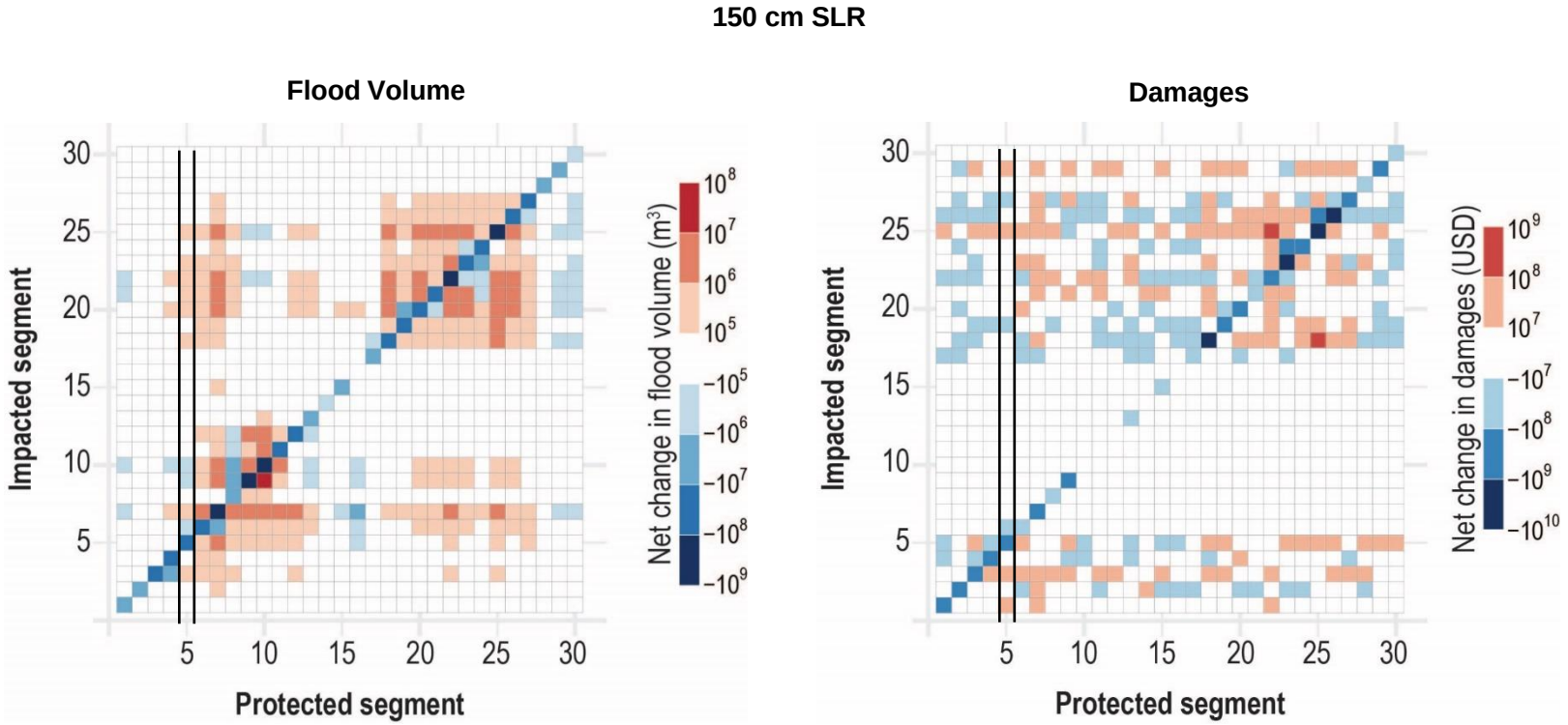




Shoreline protection provides substantial internal flood reduction and damage reduction benefits along most shoreline segments

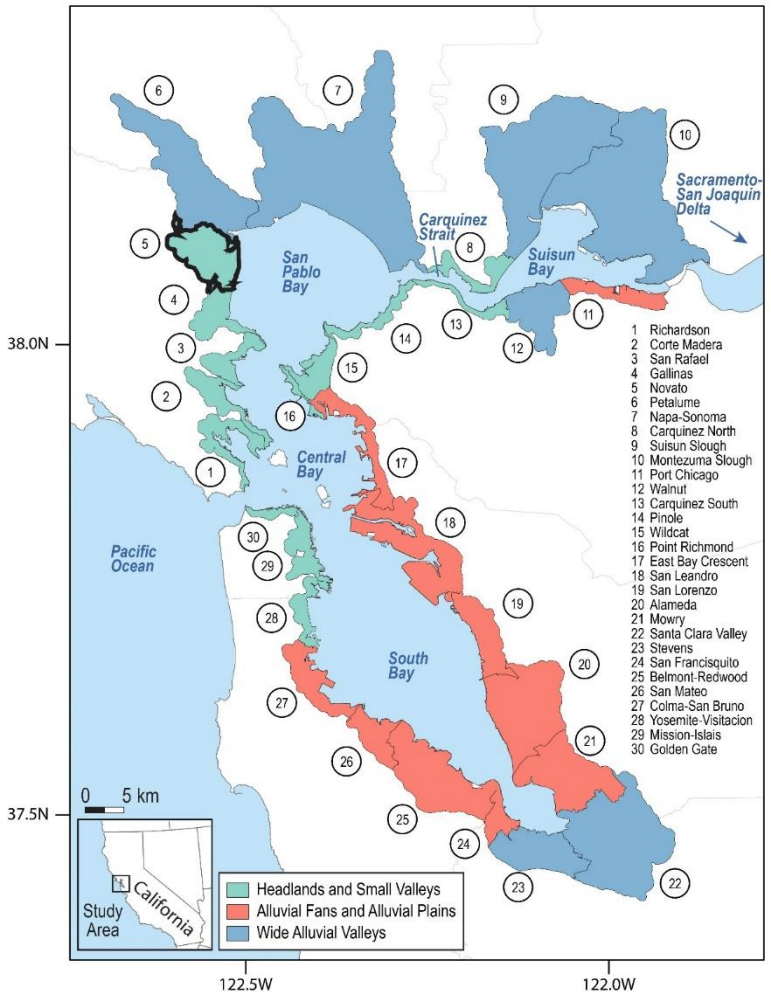
Effects of shoreline protection on flooding and economic damages

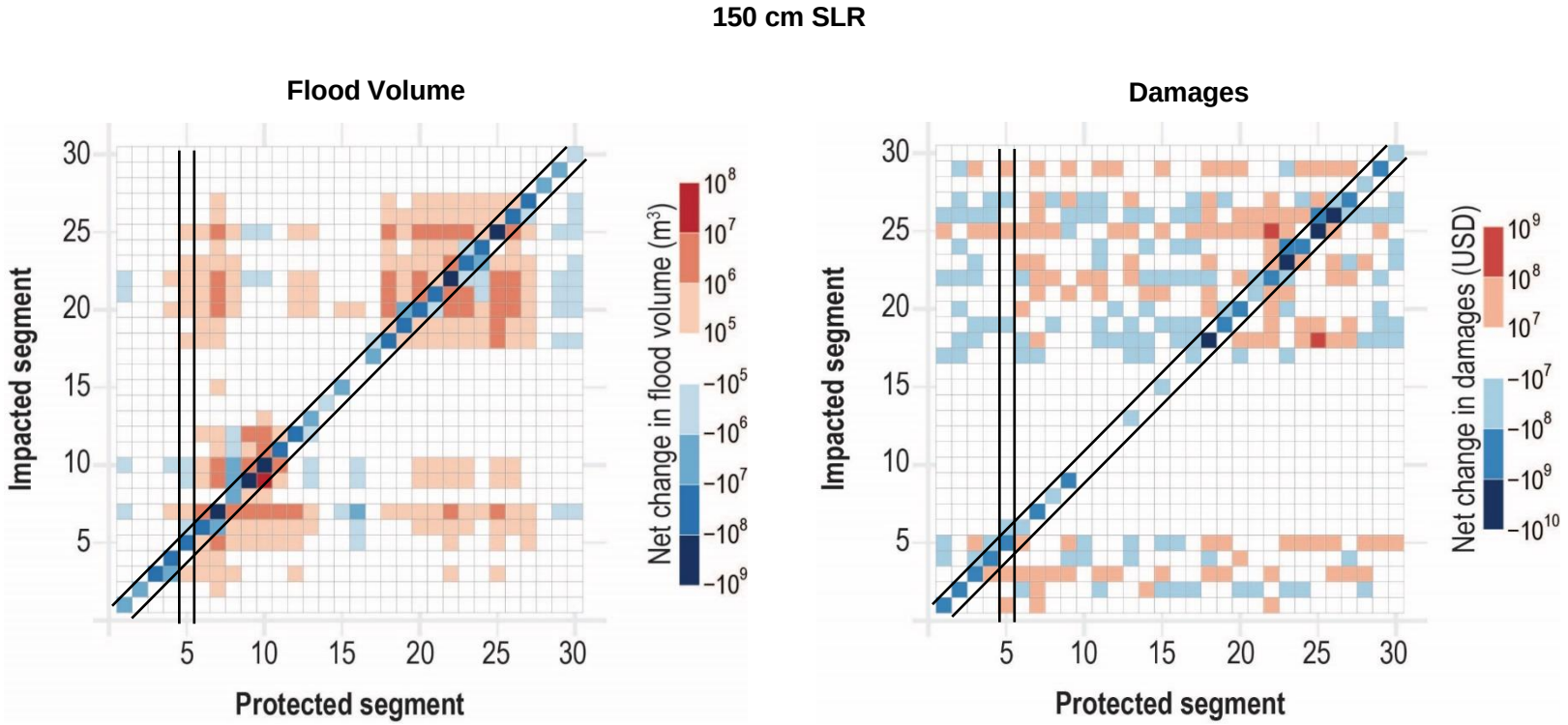




Shoreline protection provides substantial internal flood reduction and damage reduction benefits along most shoreline segments

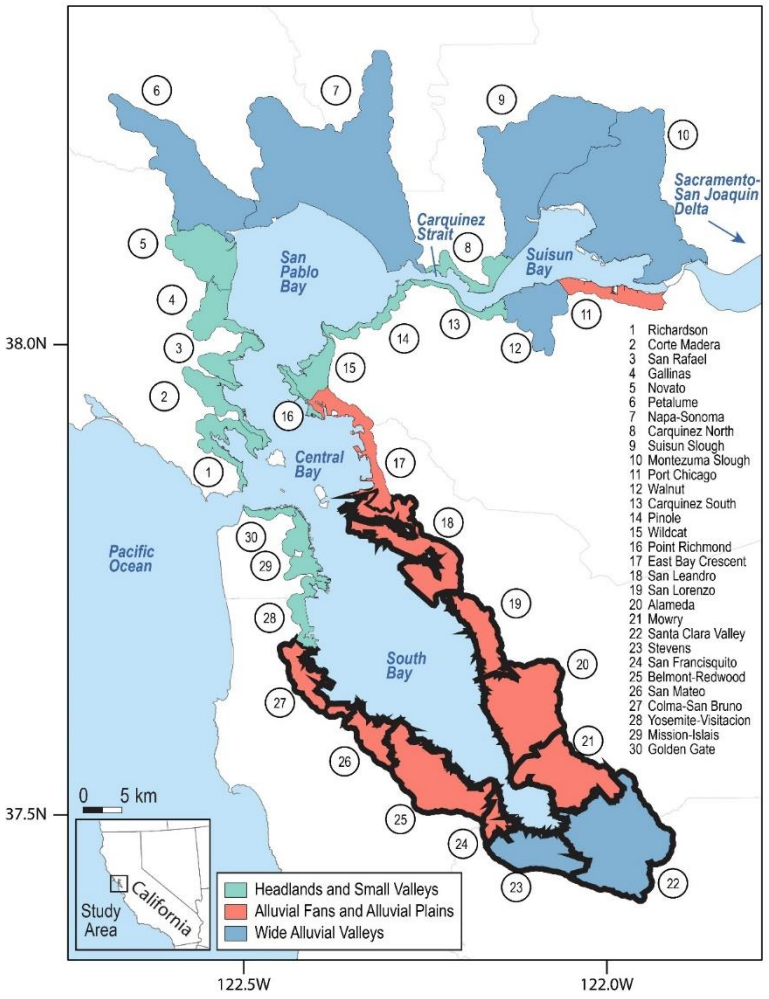
Effects of shoreline protection on flooding and economic damages

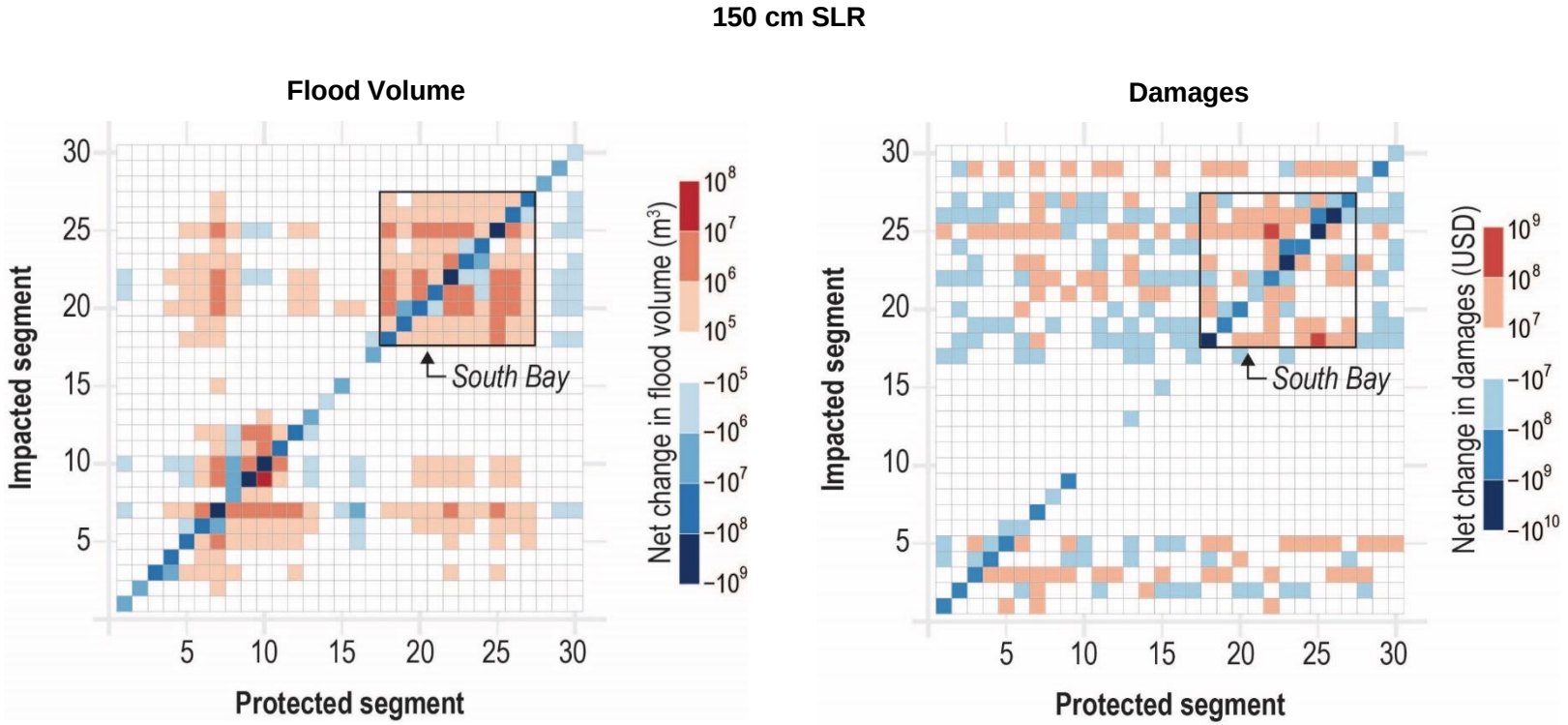




Shoreline protection provides substantial internal flood reduction and damage reduction benefits along most shoreline segments

Effects of shoreline protection on flooding and economic damages

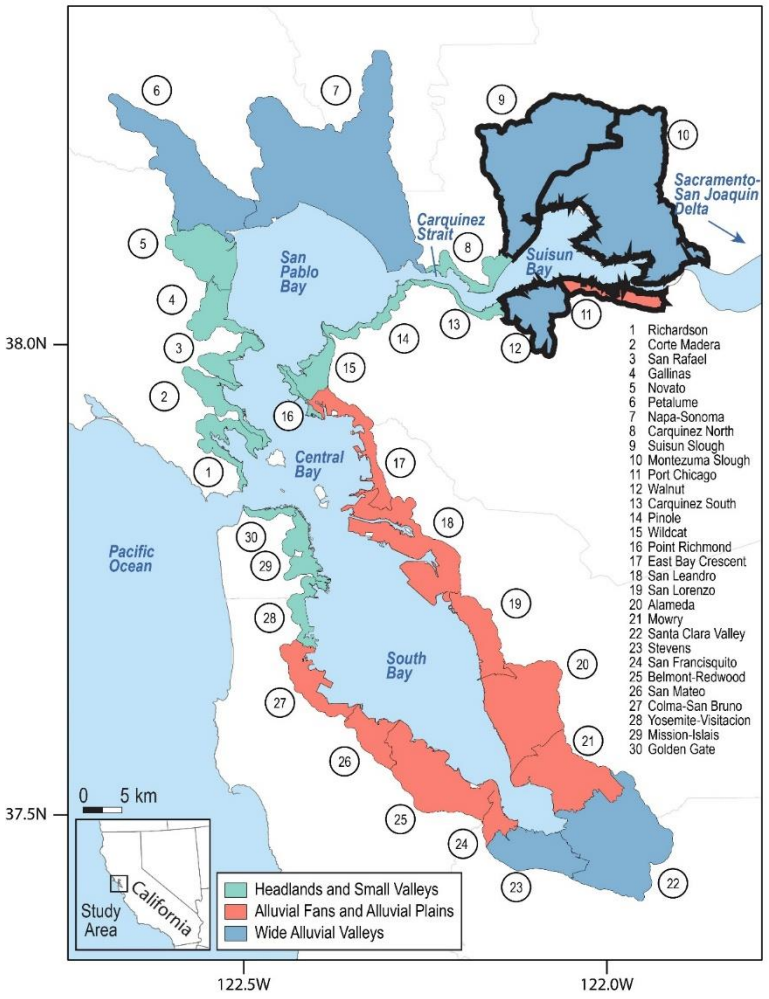


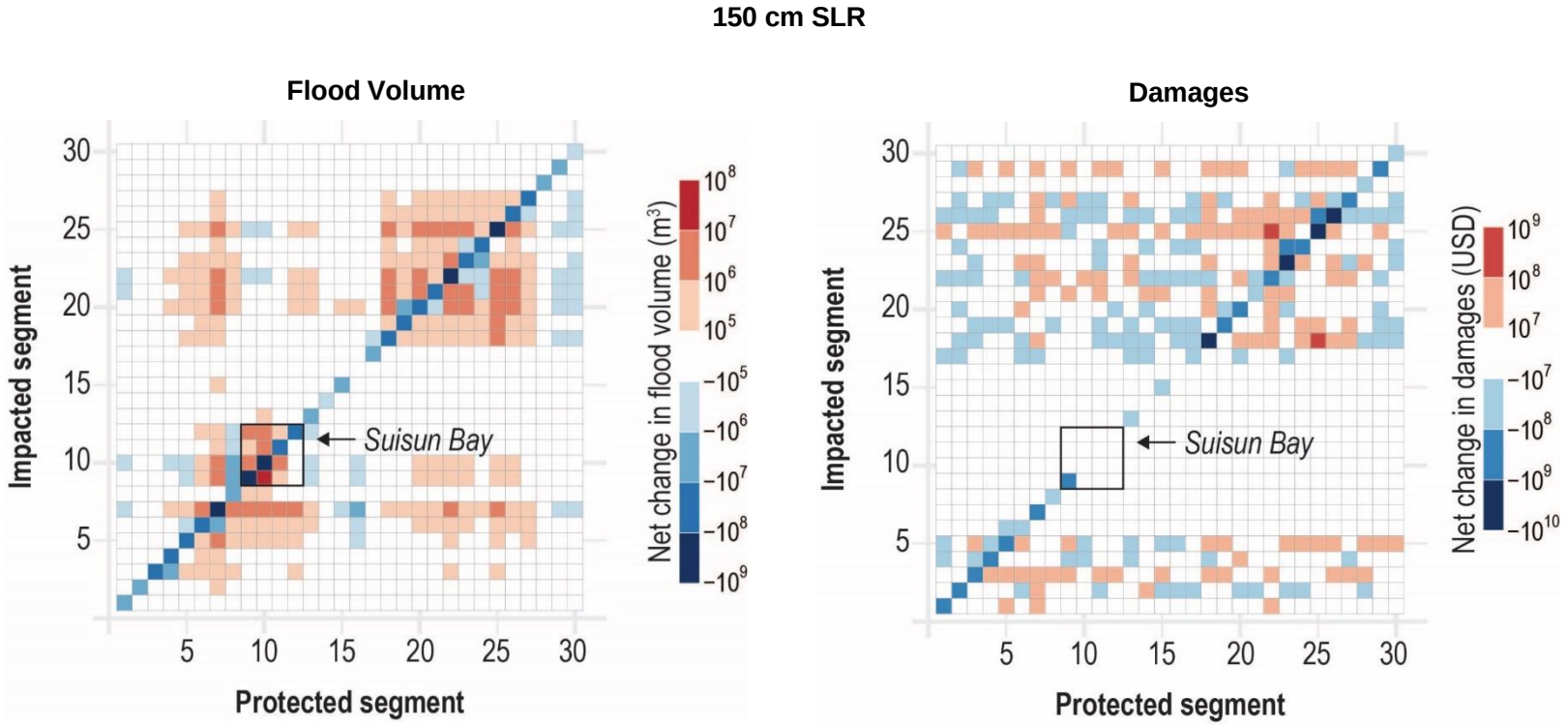


Local shoreline actions produce strong flood interactions within the same sub-embayments

Flood interactions drive economic damage externalities, particularly along highly developed shoreline segments

Effects of shoreline protection on flooding and economic damages

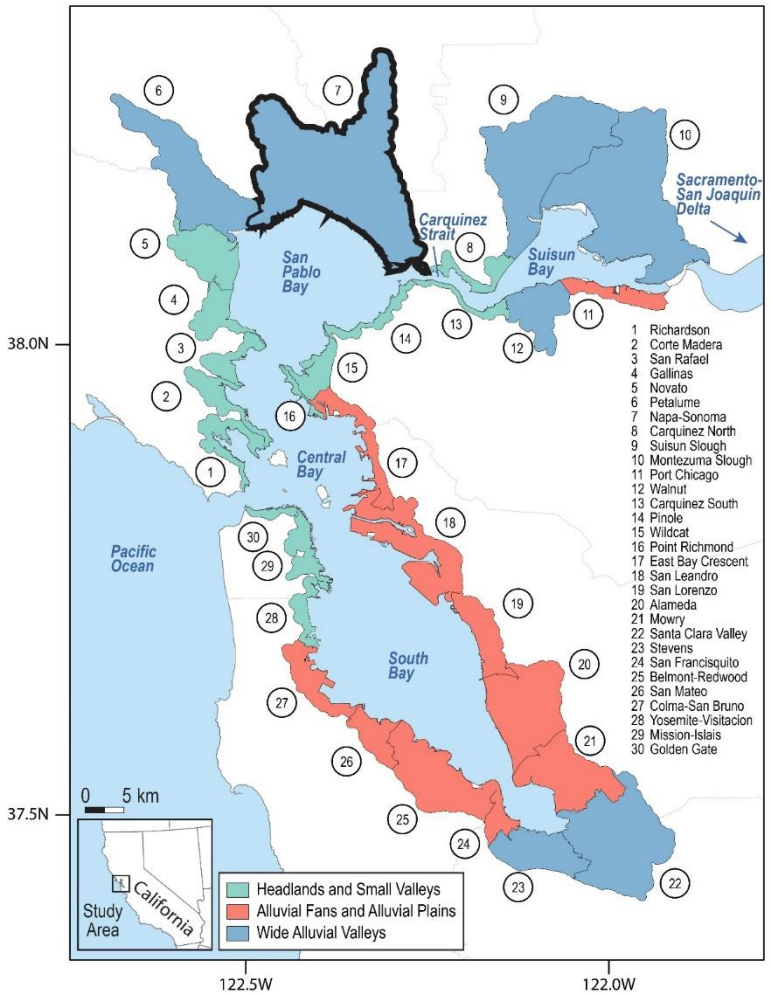




Local shoreline actions produce strong flood interactions within the same sub-embayments

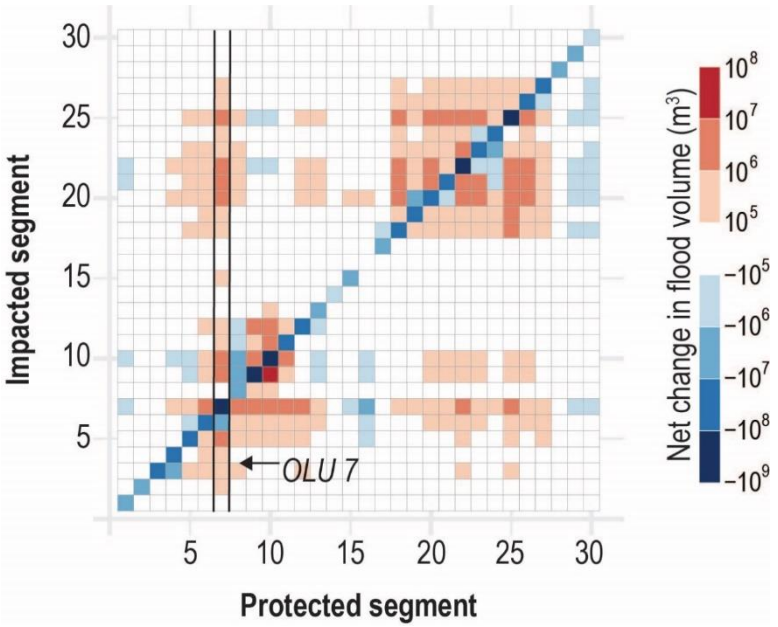
Flood interactions drive economic damage externalities, particularly along highly developed shoreline segments

Effects of shoreline protection on flooding and economic damages

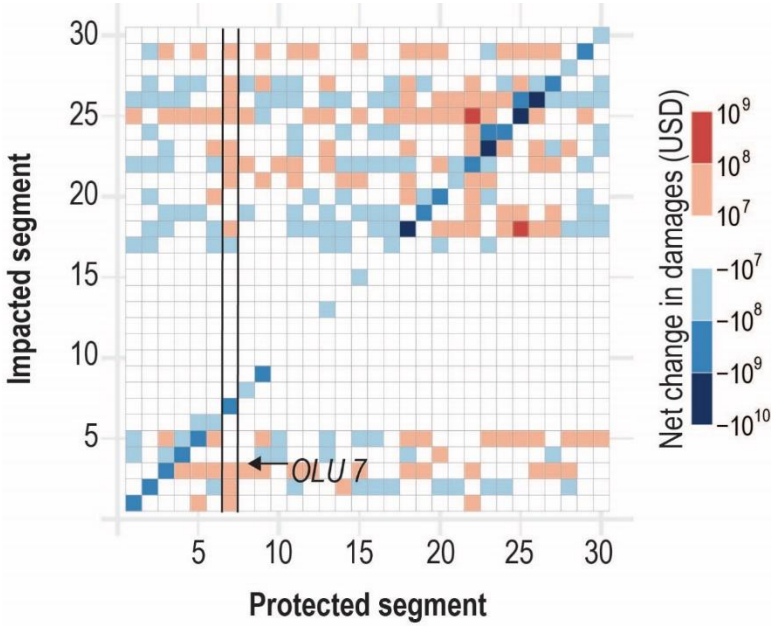


150 cm SLR

Flood Volume

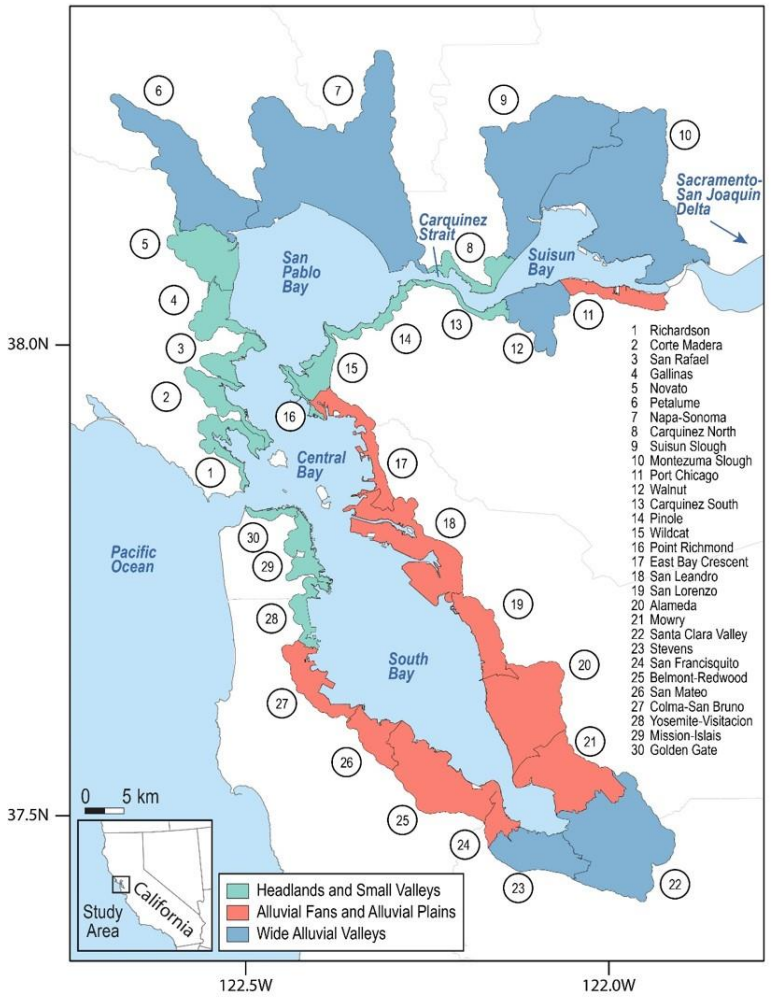


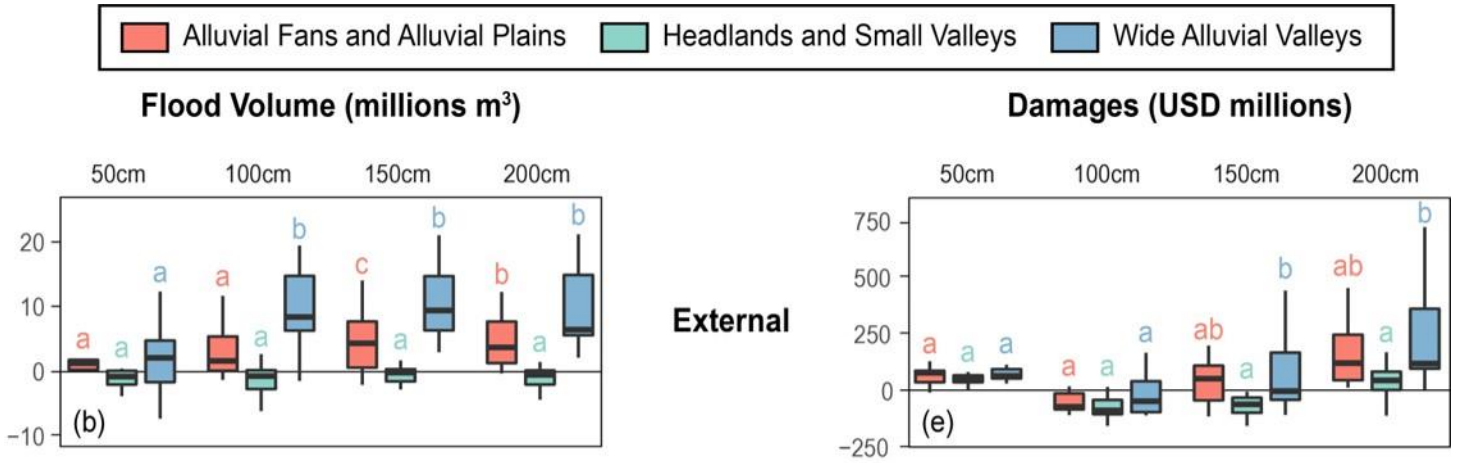
Damages



Local shoreline actions can cause flood externalities for more distant shorelines as well

Externalities by geomorphic type





Geomorphic characteristics influence the magnitude of flood and damage externalities that result from protection of individual shoreline segments

Evaluating local adaptation strategies

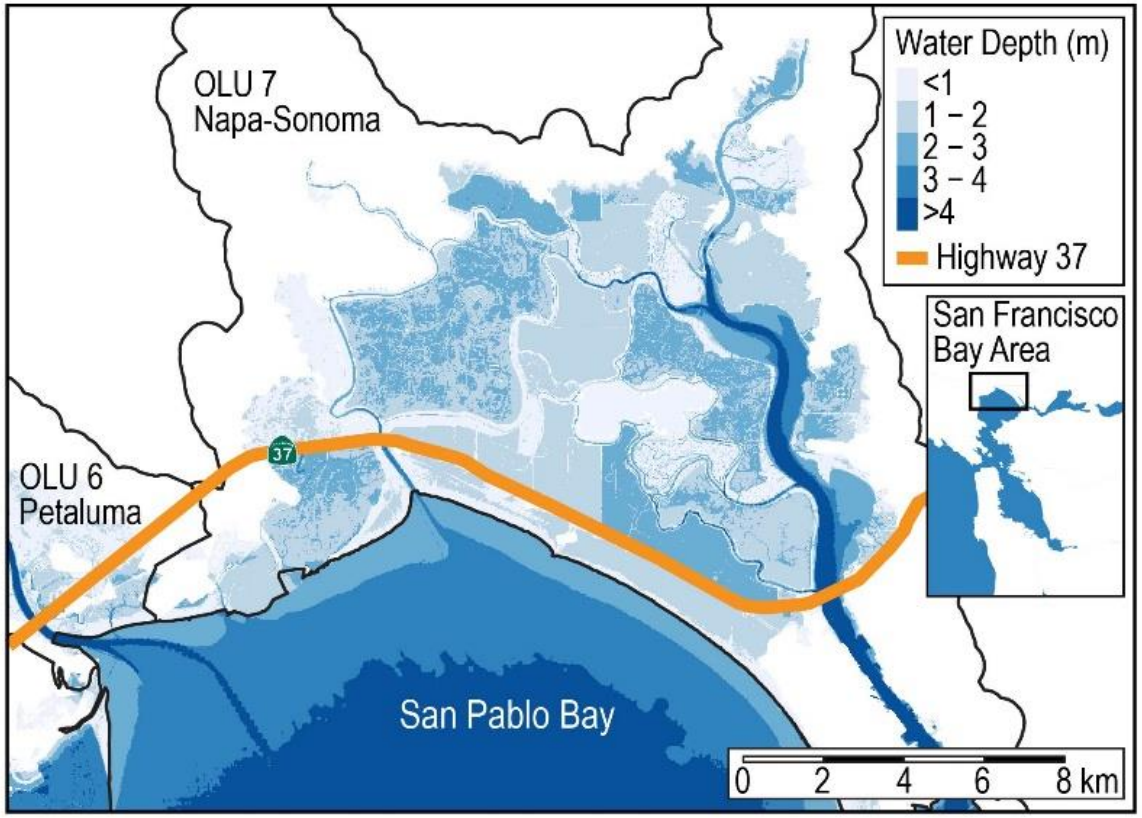
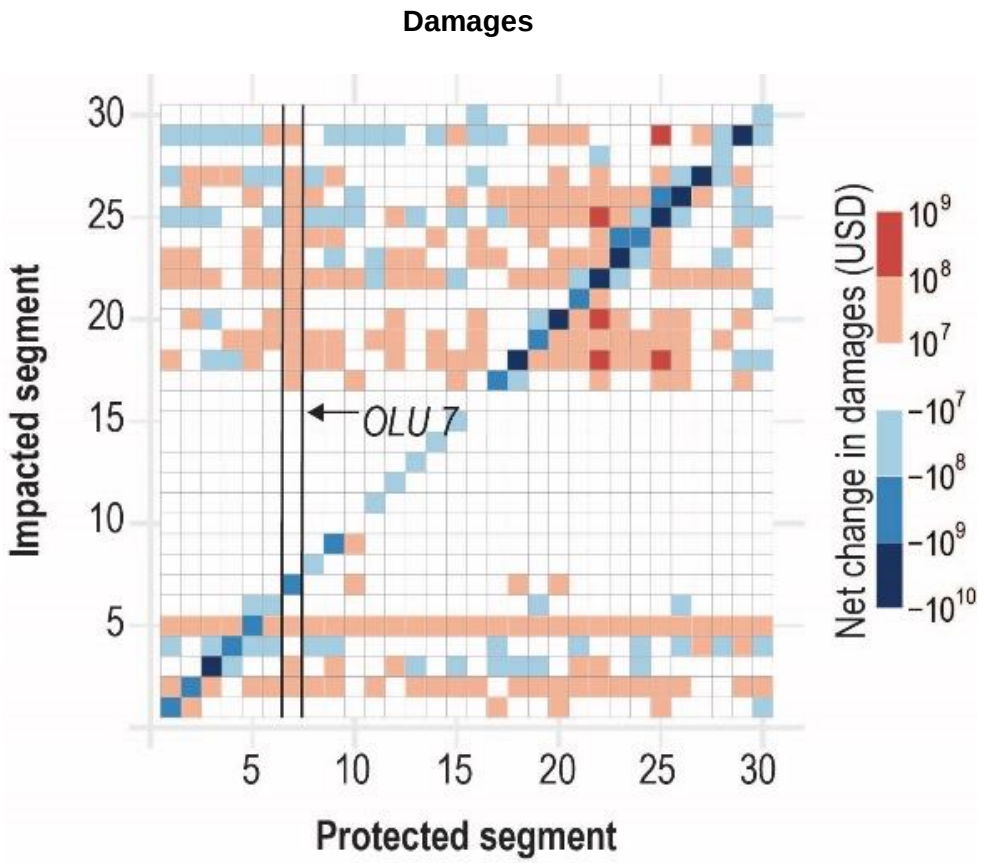


Table 1. Cost estimates for each engineered concept by reach

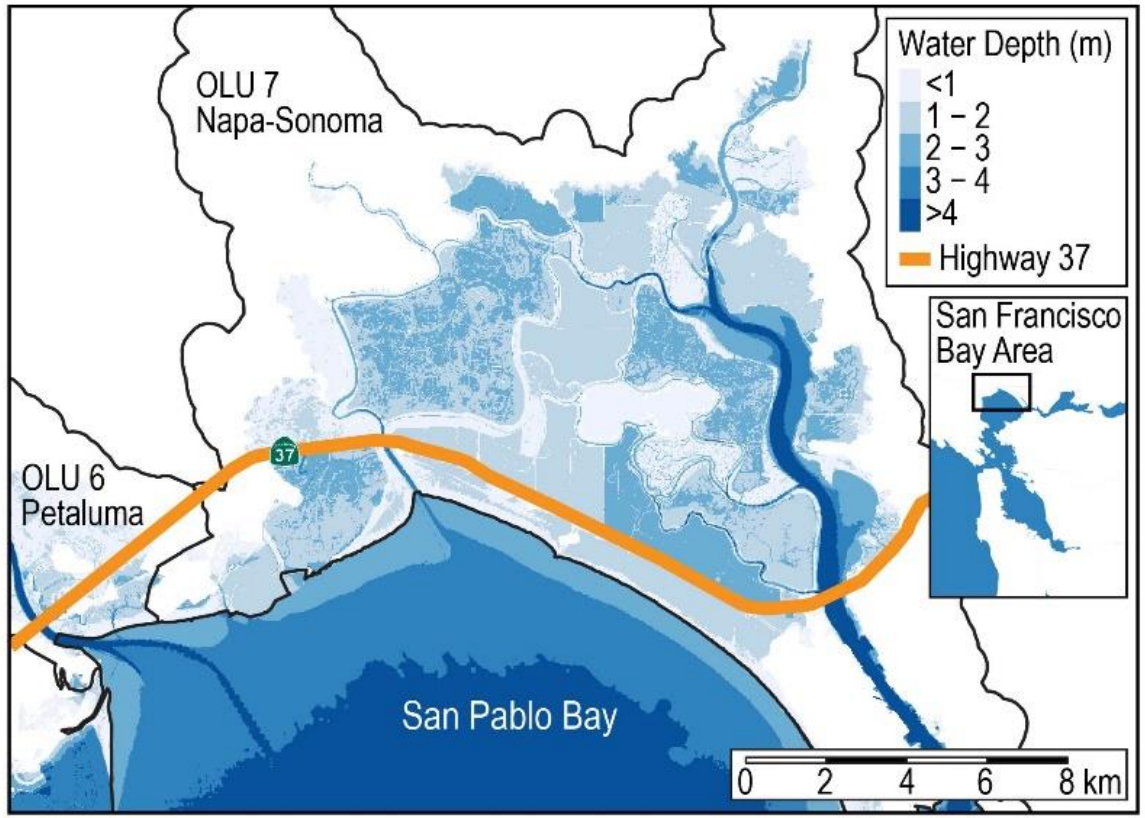
Segment	Scenario Costs (in $M)		
	1 – Levee/ Embankment	2 – Box Girder Causeway	3 – Slab Bridge Causeway
A	$460	$1,400	$1,300
B	$650	$2,500	$2,200
C	$150	$400	$340
Total	**$1,260**	**$4,300**	**$3,840**

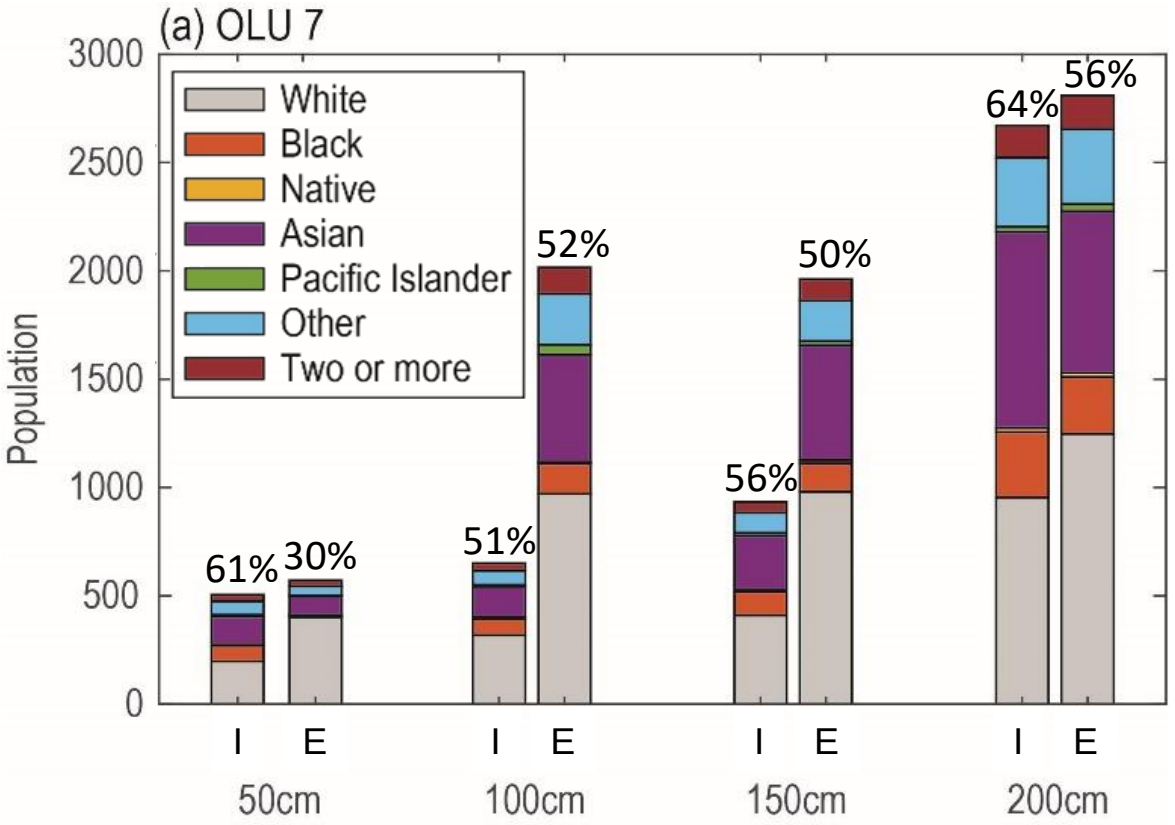
Villafranca et al. (2015)



Net external damages: $293 million

Evaluating local adaptation strategies





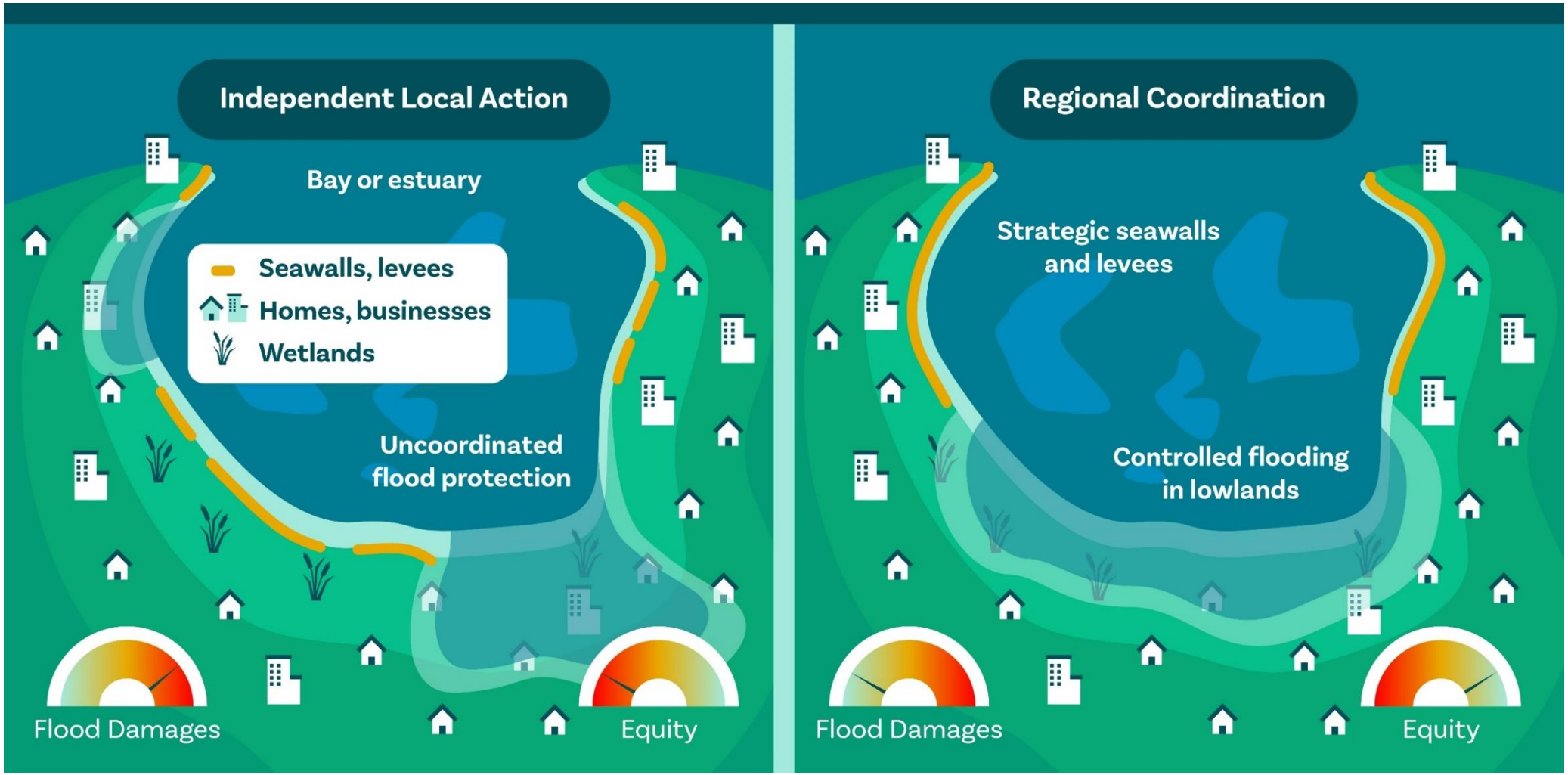
Incorporating demographic data into project evaluation and cost-benefit analysis can promote more equitable risk reduction

Conclusions

- Local shoreline actions produce flood and economic damage externalities along other parts of the coastline
- Geomorphic characteristics of the shoreline play a critical role in determining how shoreline protection influences regional water levels and flooding
- Ignoring regional interactions could lead to significant underestimation of externalities associated with shoreline adaptation projects

Conclusions

- Strategic and coordinated planning approaches could provide opportunities to avoid or mitigate externalities



References

- Holleman RC, MT Stacey (2014) Coupling of Sea Level Rise, Tidal Amplification, and Inundation. *Journal of Physical Oceanography*, 44.
- Hummel MA, Stacey MT (2020) Assessing the influence of shoreline adaptation on tidal hydrodynamics: The role of shoreline typologies. *Journal of Geophysical Research: Oceans*, 126(2).
- Hummel MA, Griffin R, Guerry AD, Arkema K. Economic evaluation of sea-level rise adaptation strongly influenced by hydrodynamic feedbacks. *Proceedings of the National Academy of Sciences*, 118 (29).
- Lee SB, Li M, Zhang F (2017) Impact of sea level rise on tidal range in Chesapeake and Delaware Bays. *Journal of Geophysical Research: Oc*eans, 122.
- Pelling HE, Green JAM, Ward SL (2013) Modelling tides and sea-level rise: To flood or not to flood. *Ocean Modelling*, 63.
- SFEI, SPUR (2019) *San Francisco Bay Shoreline Adaptation Atlas: Working with Nature to Plan for Sea Level Rise Using Operational Landscape Units*. Publication #915, San Francisco Estuary Institute, Richmond, CA.
- Villafranca J, May K, Vandever J (2015). *State Route 37 Integrated Traffic, Infrastructure and Sea Level-Rise Analysis: Final Report*. University of California Davis Road Ecology Center, Davis, CA.
- Wang RQ, Stacey MT, Herdman LMM, Barnard PL, Erikson L (2018) The Influence of Sea Level Rise on the Regional Interdependence of Coastal Infrastructure. *Earth's Future*, 6.

Evaluating local adaptation strategies