



# Sea level rise and estuaries: Past, present and future

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LA 12 ENVIRONMENTAL SCIENCE FOR SUSTAINABLE DEVELOPMENT

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**Sea-level is not constant.** It is influenced locally by forcing factors such as **atmospheric pressure**, **prevailing winds**, etc

There is a **natural variability**, but the impacts of extreme events will be severely aggravated over higher sea-levels

**Sea-Level Rise** refers to the persistent **effects of climate change over average (mean) sea-level**

**Intergovernmental Panel for Climate Change (IPCC) has been compiling the state-of-the-art on Climate Change**

**Mitigation** relates mostly to **preventive actions**, targeting **reduced emissions** of greenhouse gases

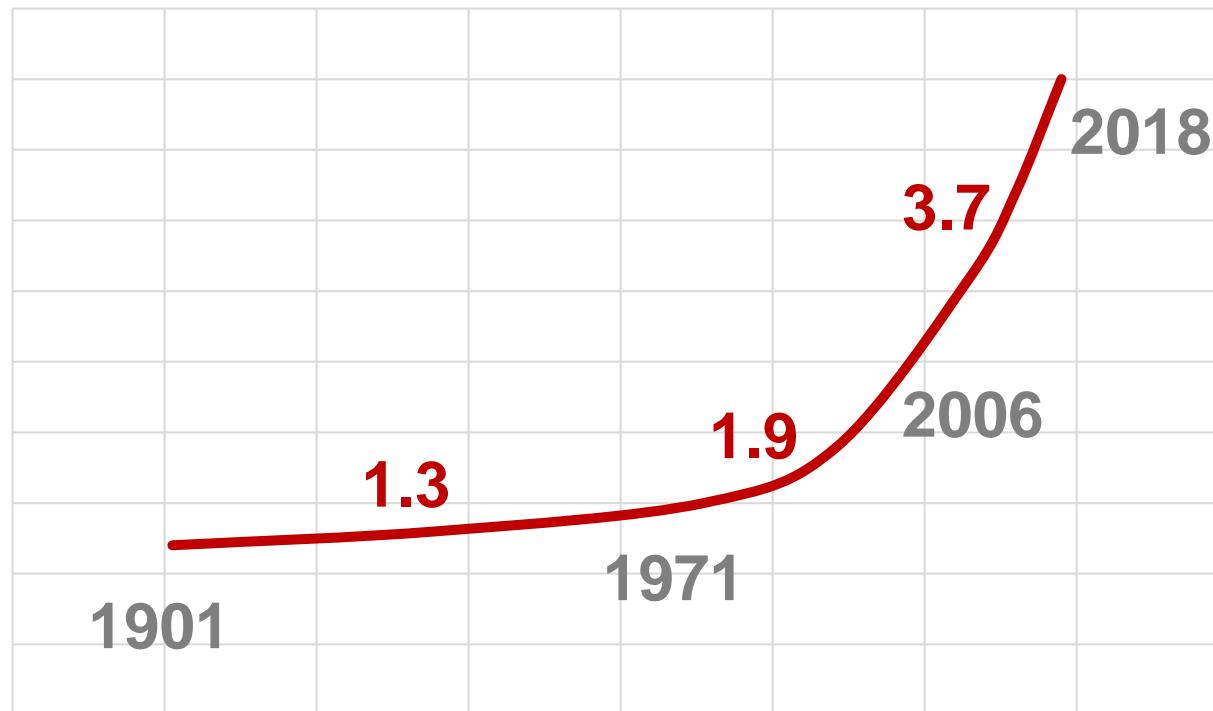
**Adaptation** deals with **adjusting to current and future effects** of climate change

Their latest Assessment Report 6 (2021):

**Heating of the climate system has caused global mean sea level rise through ice loss on land and thermal expansion from ocean warming.**

**The rate of ice sheet loss increased by a factor of four between 1992–1999 and 2010–2019.**

**Sea-level rise has accelerated for over a century.**  
**Mean Sea-Level increased by **0.20 m (.65 ft)** between**  
**1901 and 2018.**



Yearly rate of sea-level rise (mm/year)  
IPCC/AR6

# **Global mean sea level will continue to rise over the 21st century.**

Relative to 1995-2014, the table displays the likely global mean sea level rise by 2050 and 2100

<b>GHG Emissions Scenario</b>	<b>~2005-2050</b>	<b>~2005-2100</b>
Very Low	0.28-0.55m	0.37-0.86m
Low	0.32-0.62 m	0.46-0.99m
Intermediate	0.44-0.76m	0.66-1.33m
Very High	0.63-1.01m	0.98-1.98m

**At least 1m or 3.3 ft by 2100**

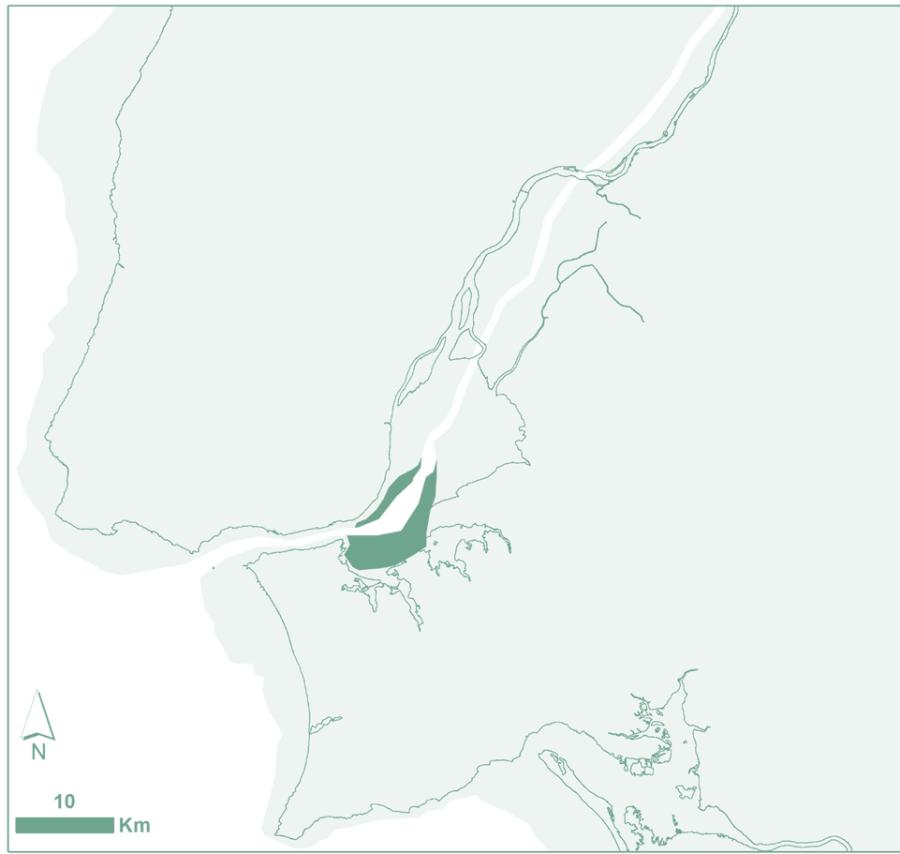
**SLR above the likely range – approaching 2 m (6.6 ft) by 2100 and 5 m (16.4 ft) by 2150 under a very high GHG emissions scenario**

We are already **committed to several feet of SLR over the coming centuries.**

**Mitigation** strategies can help avoid more catastrophic scenarios

**Projections of multi-millennial global mean sea level rise are consistent with reconstructed levels during past warm climate periods**

**Past**



**Tagus Estuary, Lisbon, Portugal**

**12,000 YBP**

Pinto, P. J., & Kondolf, G. M. (2016). Evolution of two urbanized estuaries: Environmental change, legal framework, and implications for sea-level rise vulnerability. *Water*, 8(11), 535.

**San Francisco Bay, California**





**Tagus Estuary, Lisbon, Portugal**

**4,000 YBP**

Pinto, P. J., & Kondolf, G. M. (2016). Evolution of two urbanized estuaries: Environmental change, legal framework, and implications for sea-level rise vulnerability. *Water*, 8(11), 535.

**San Francisco Bay, California**





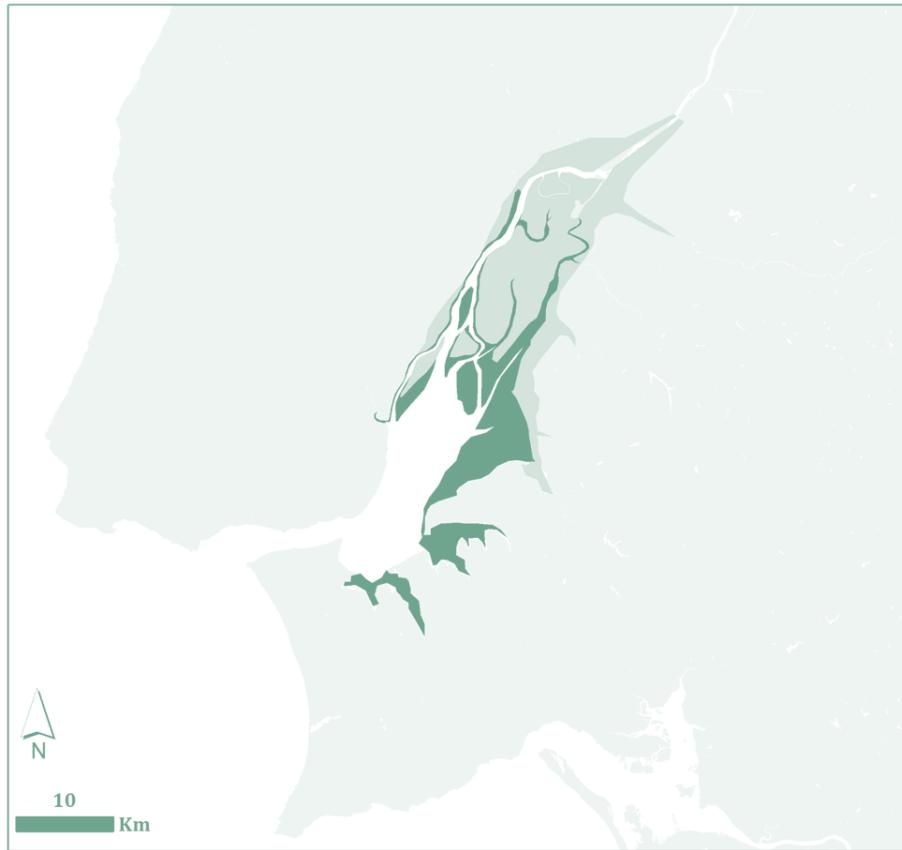
**Tagus Estuary, Lisbon, Portugal**

**Year 1000ce**

Pinto, P. J., & Kondolf, G. M. (2016). Evolution of two urbanized estuaries: Environmental change, legal framework, and implications for sea-level rise vulnerability. *Water*, 8(11), 535.

**San Francisco Bay, California**





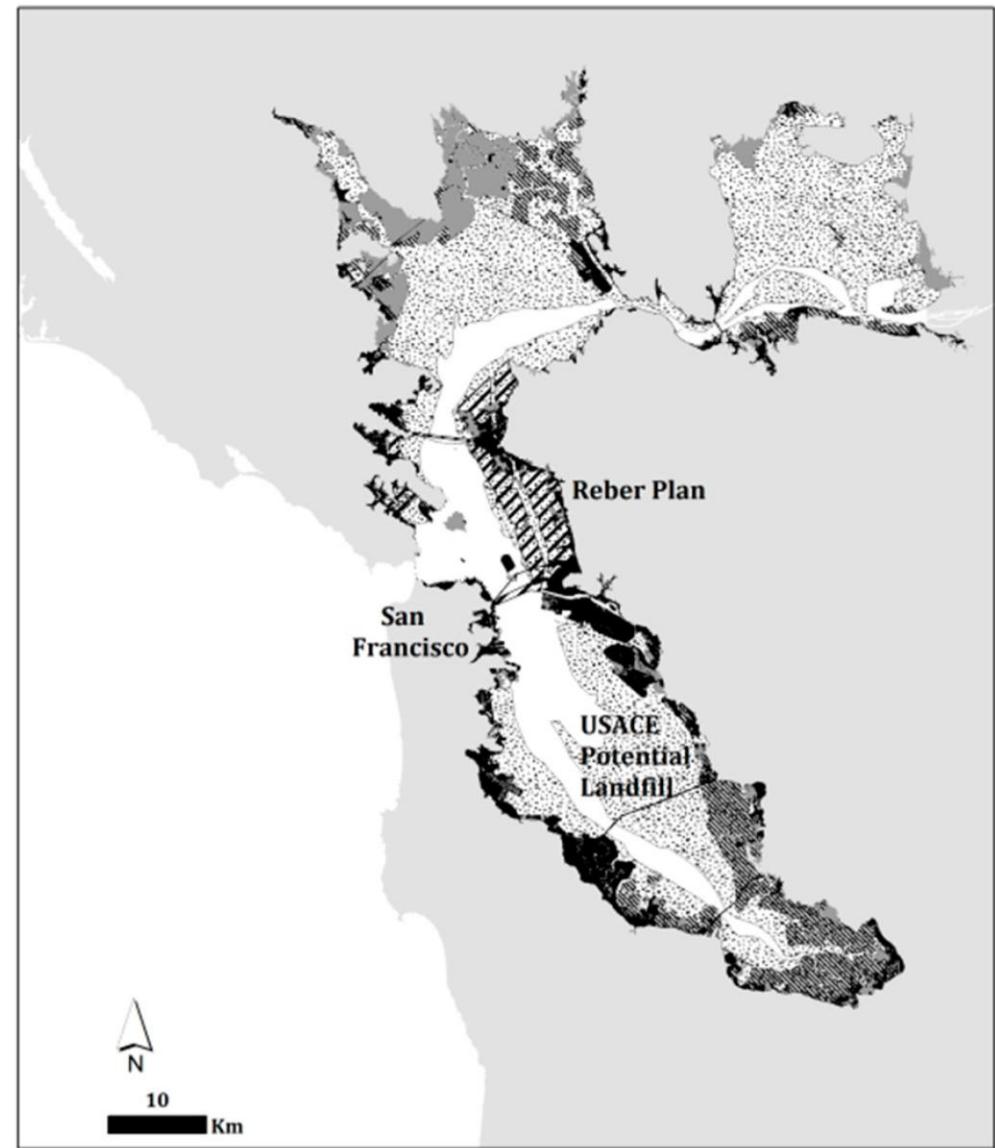
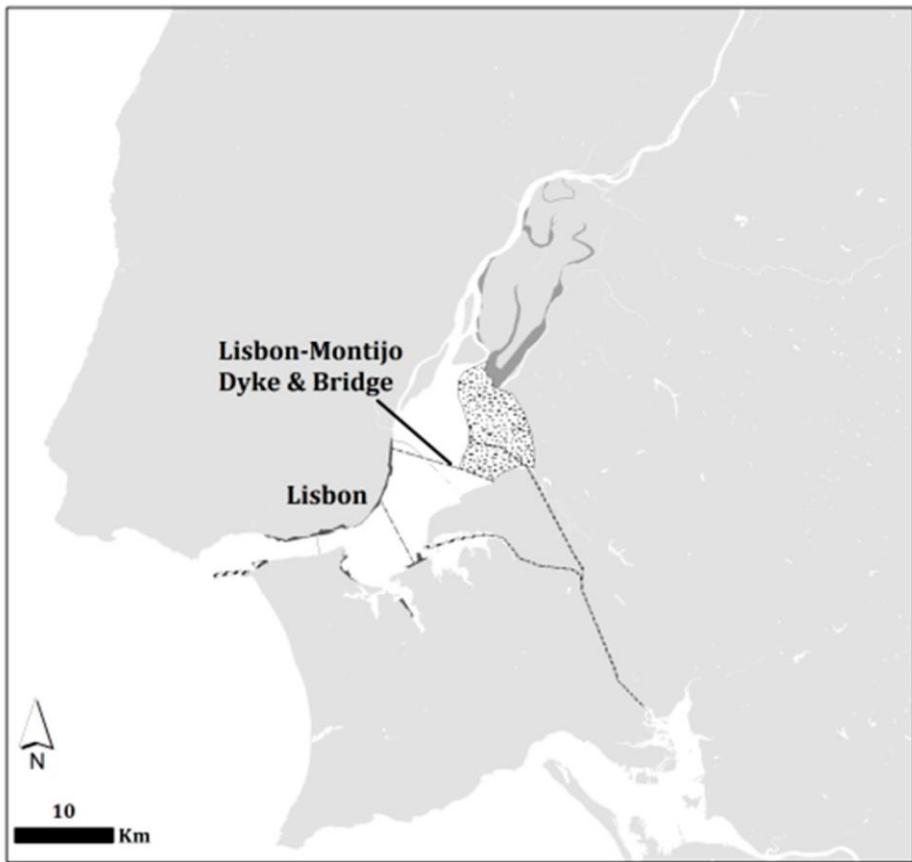
**Tagus Estuary, Lisbon, Portugal**

**Year 1800ce**

Pinto, P. J., & Kondolf, G. M. (2016). Evolution of two urbanized estuaries: Environmental change, legal framework, and implications for sea-level rise vulnerability. *Water*, 8(11), 535.

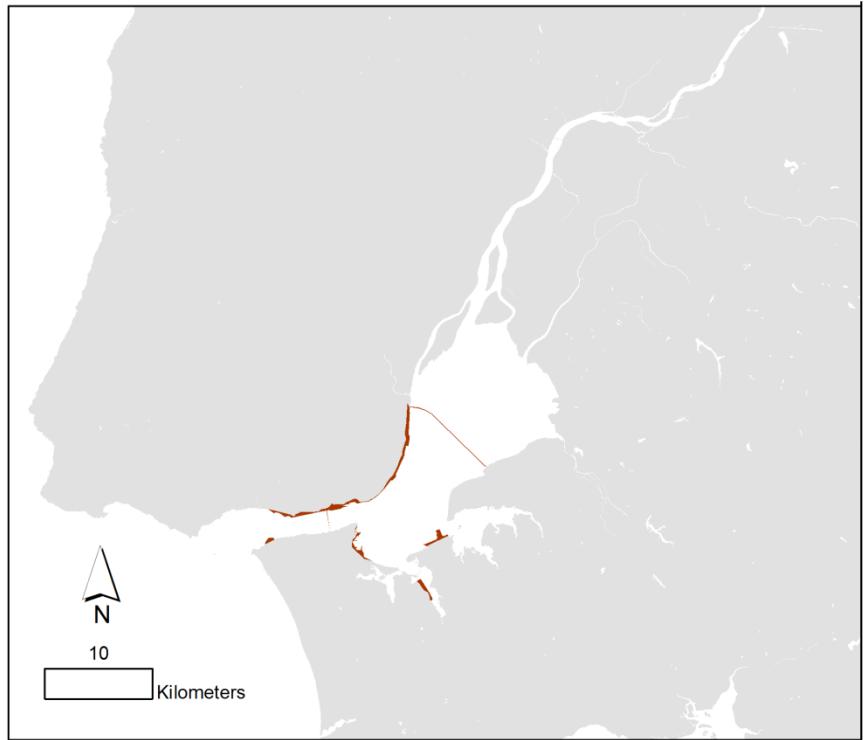
**San Francisco Bay, California**





Pinto, P. J., & Kondolf, G. M. (2016). Evolution of two urbanized estuaries: Environmental change, legal framework, and implications for sea-level rise vulnerability. *Water*, 8(11), 535.

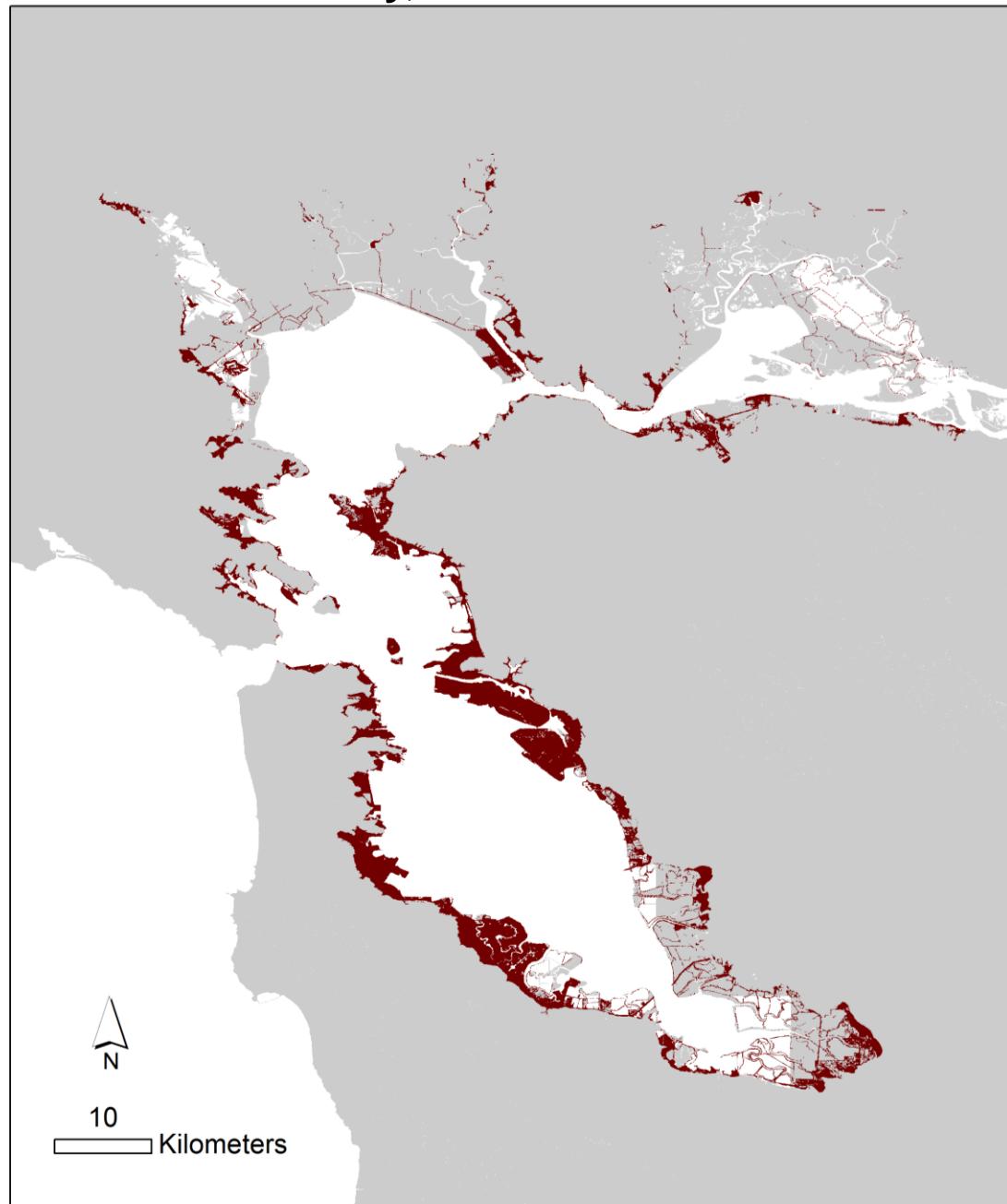
# Unrealized mid-20th century projects



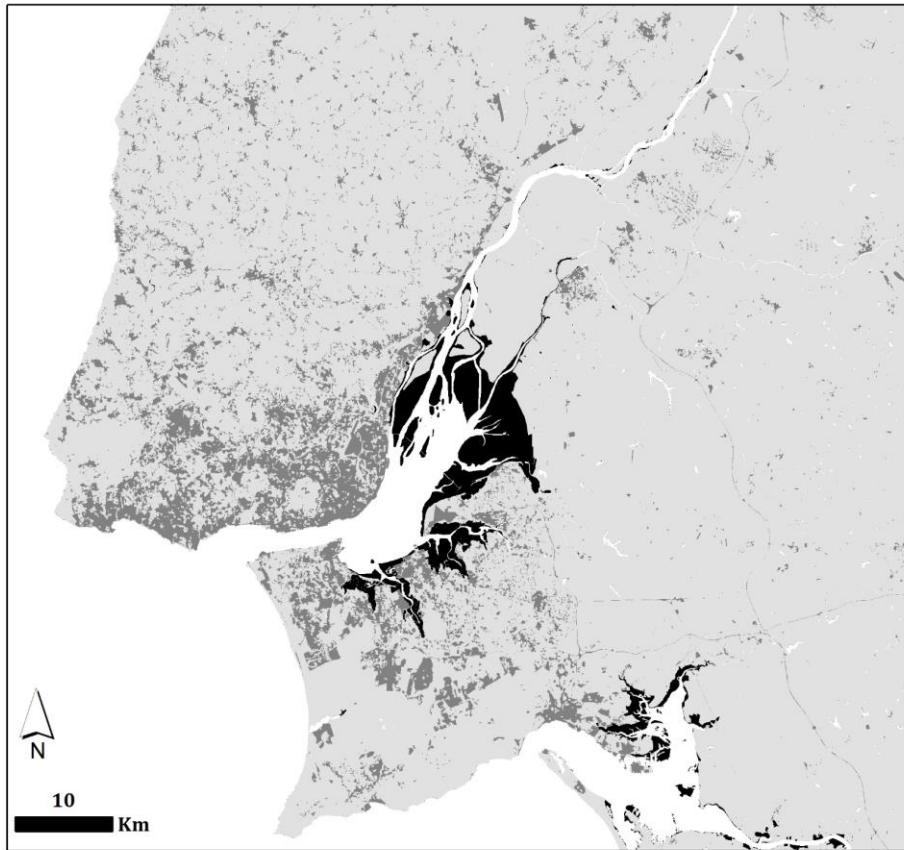
**Tagus Estuary, Lisbon, Portugal**

**Urban and  
infrastructure  
development over  
landfill**

**San Francisco Bay, California**



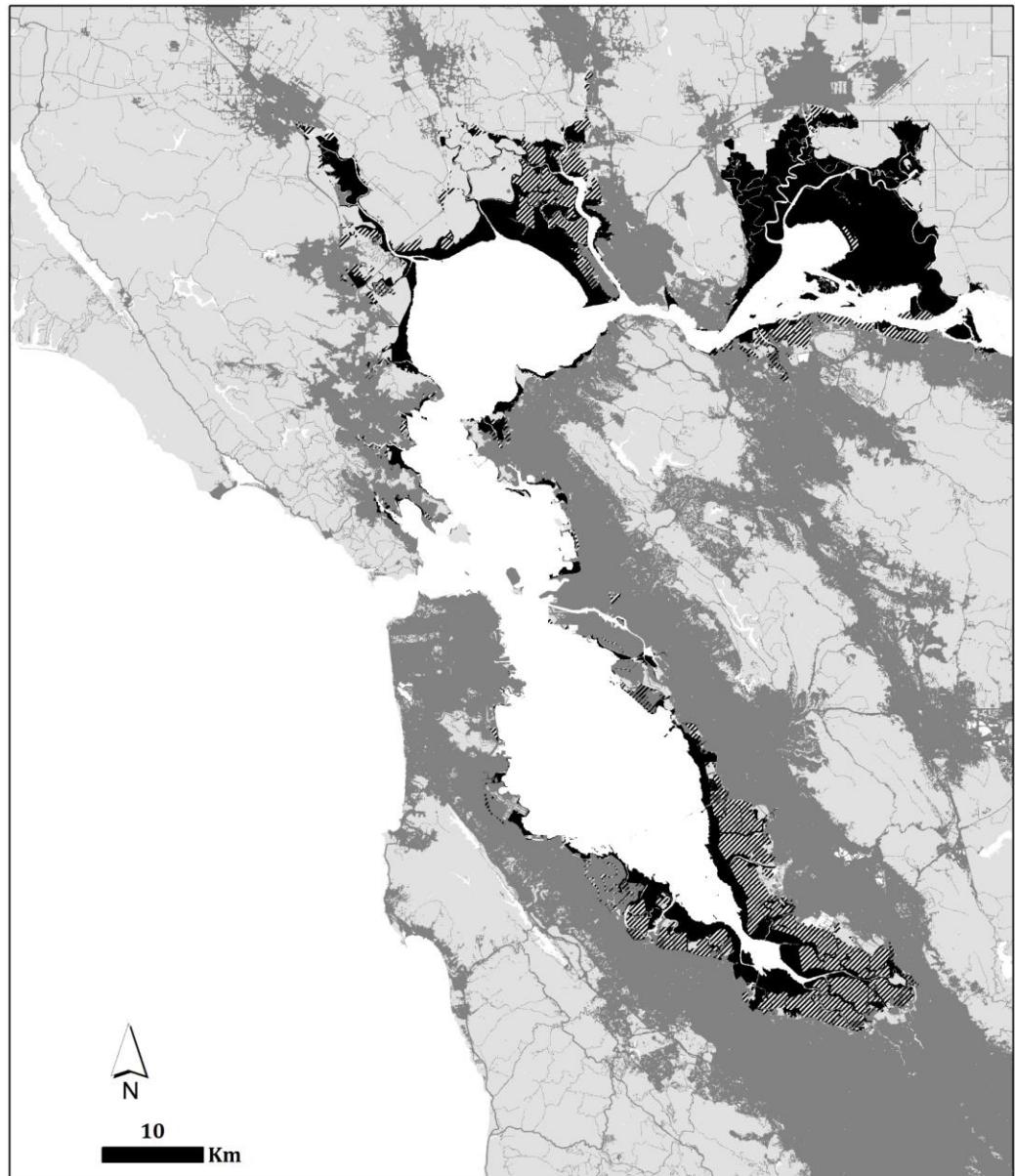
# **Present**

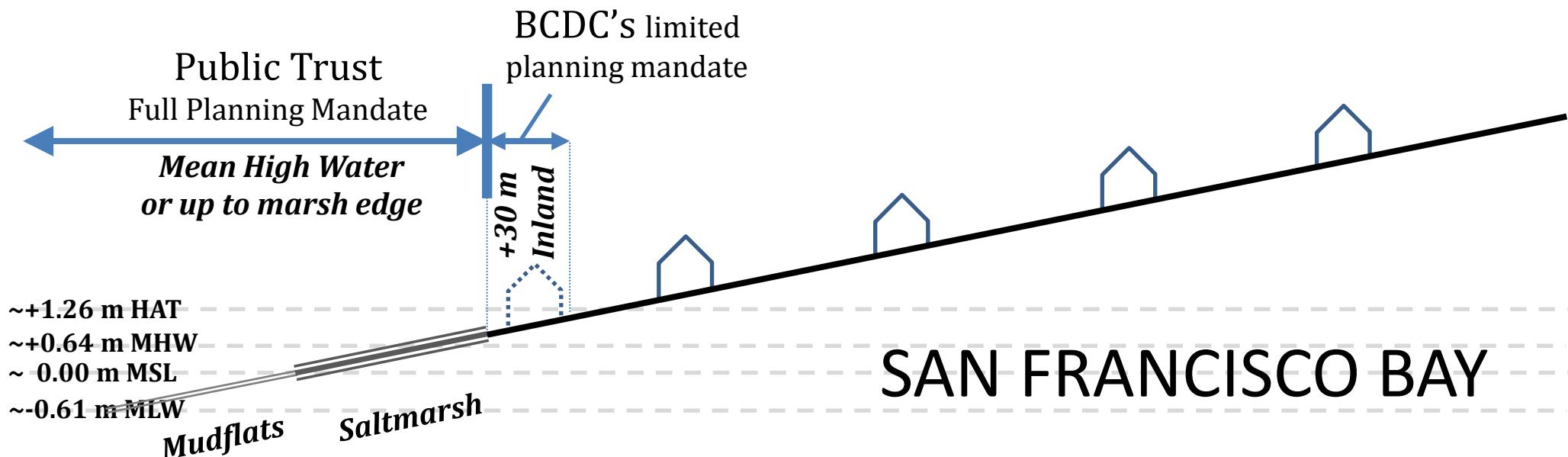
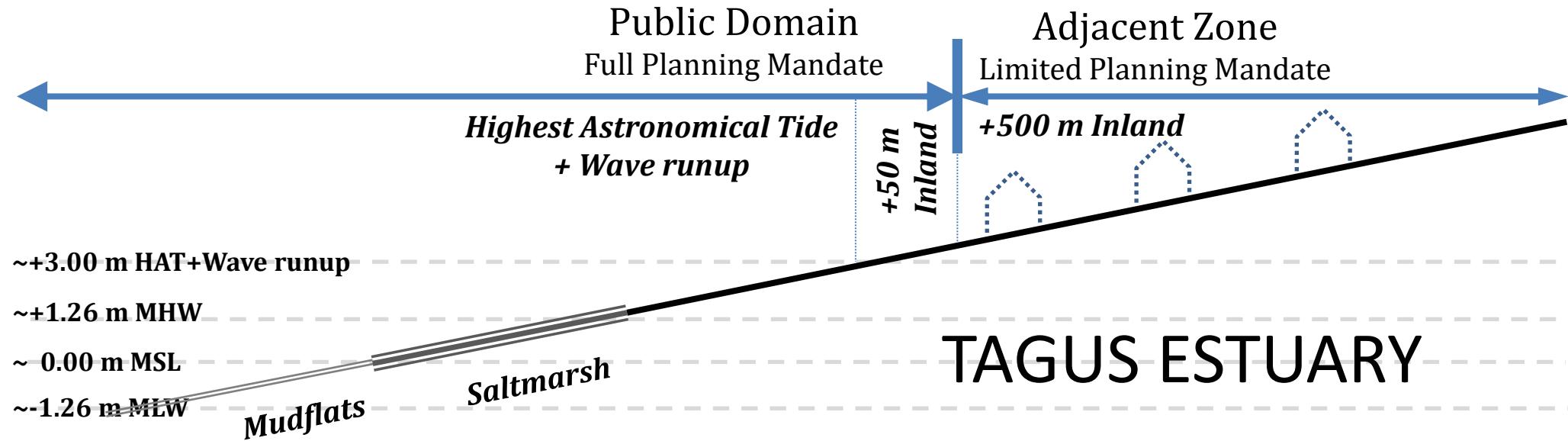


**Tagus Estuary, Lisbon, Portugal**

**Today**

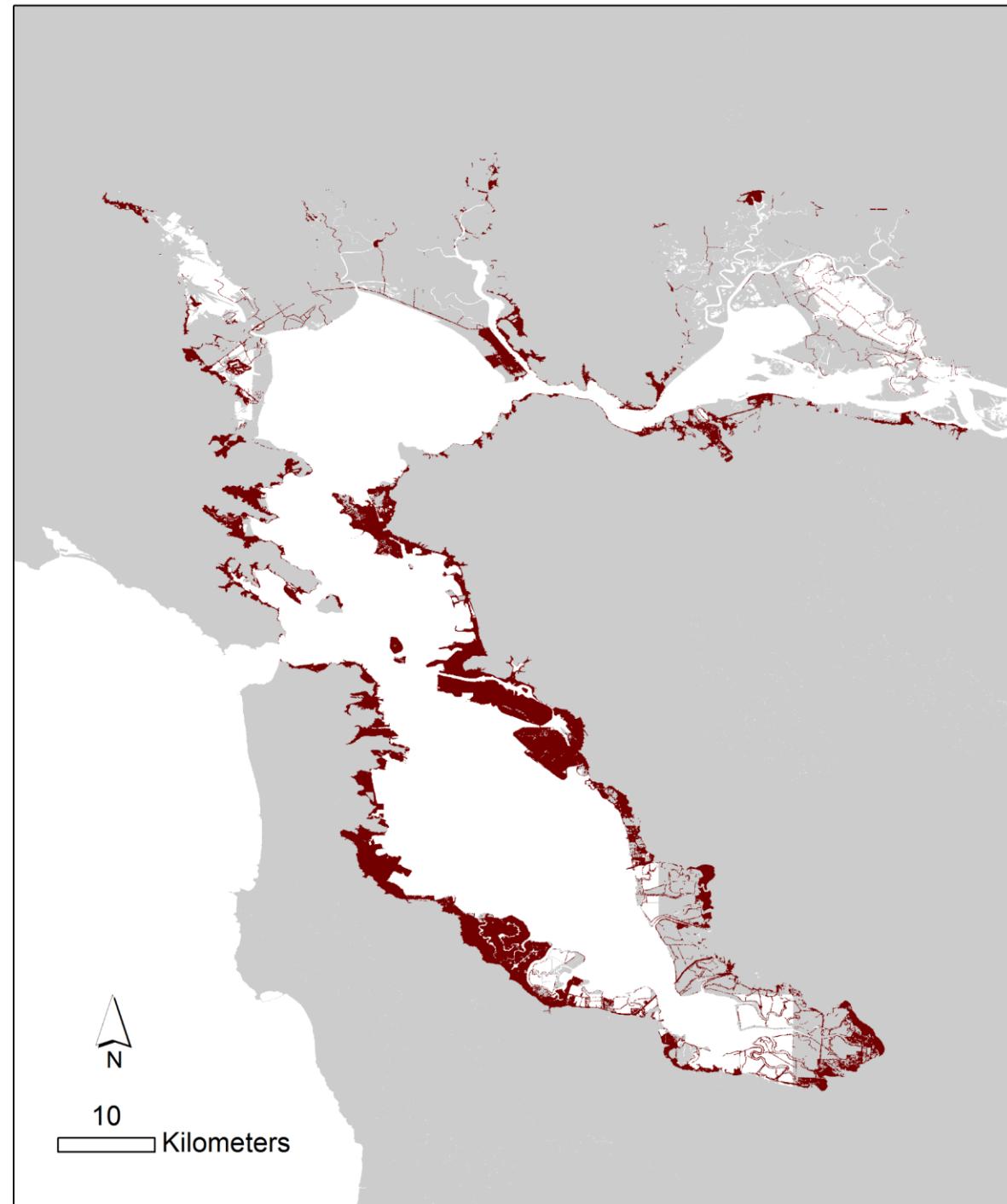
**San Francisco Bay, California**



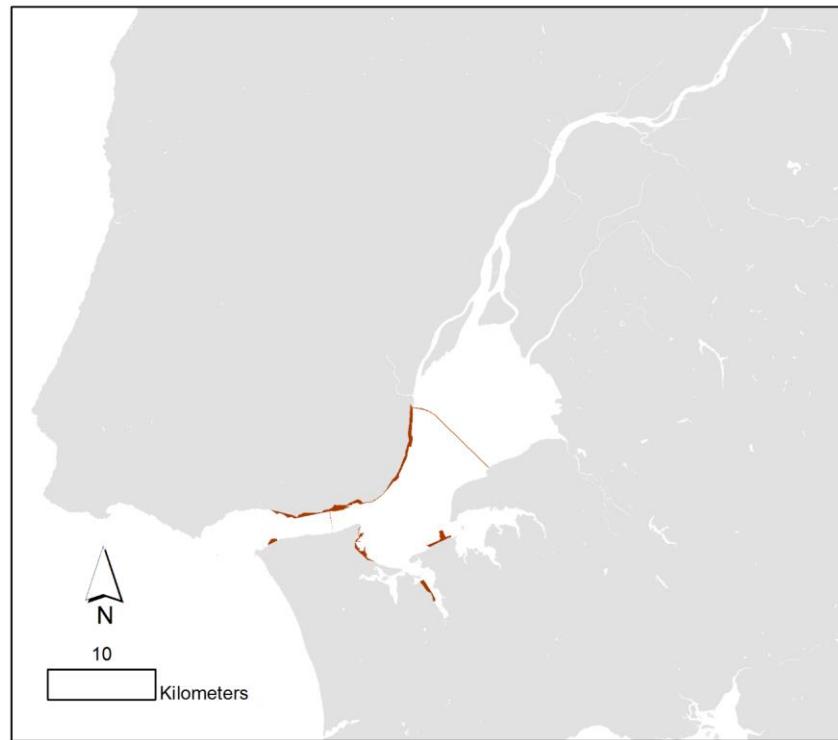


**San Francisco Bay, California**

**Landfill**



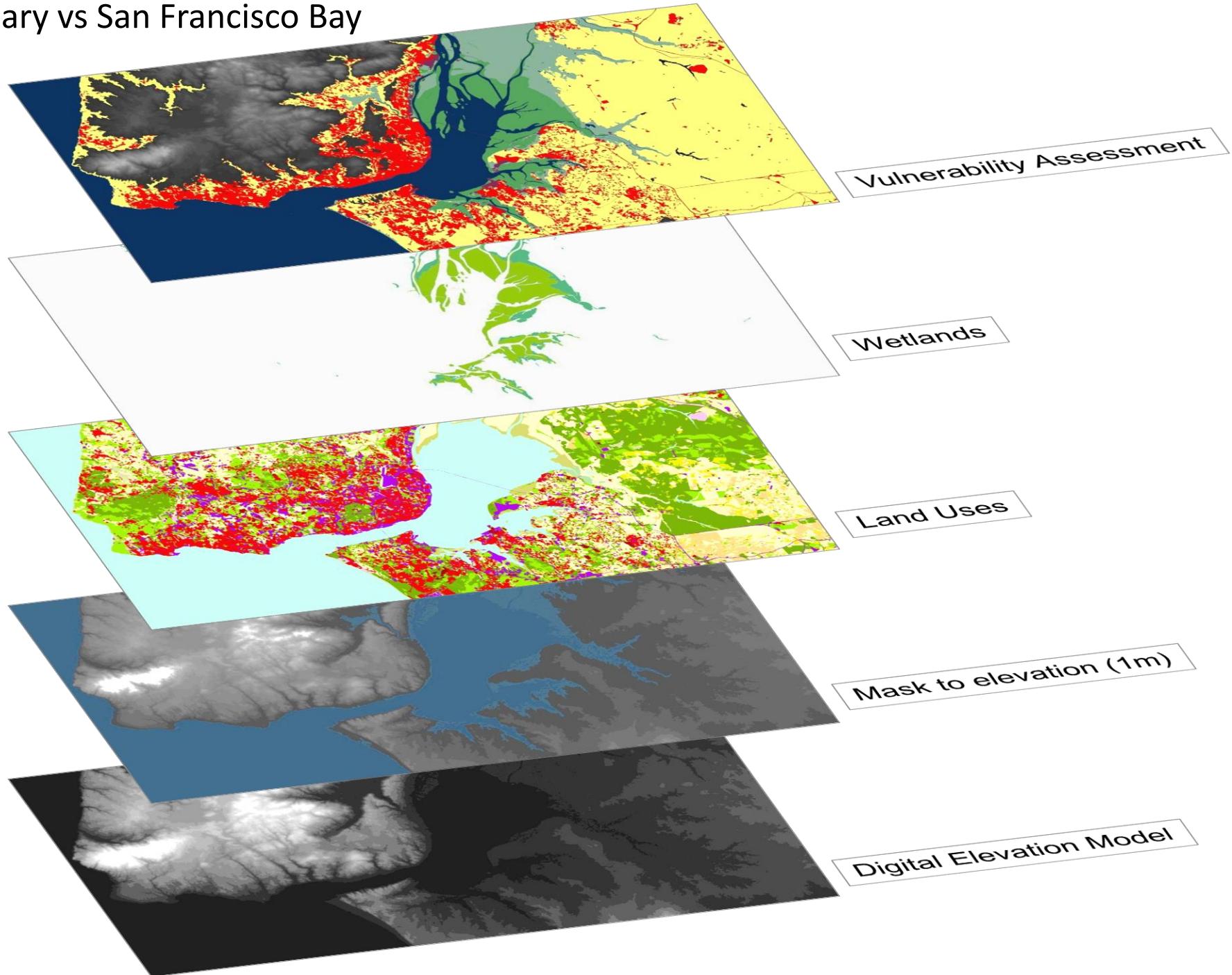
**Tagus Estuary, Lisbon, Portugal**



# **Future**

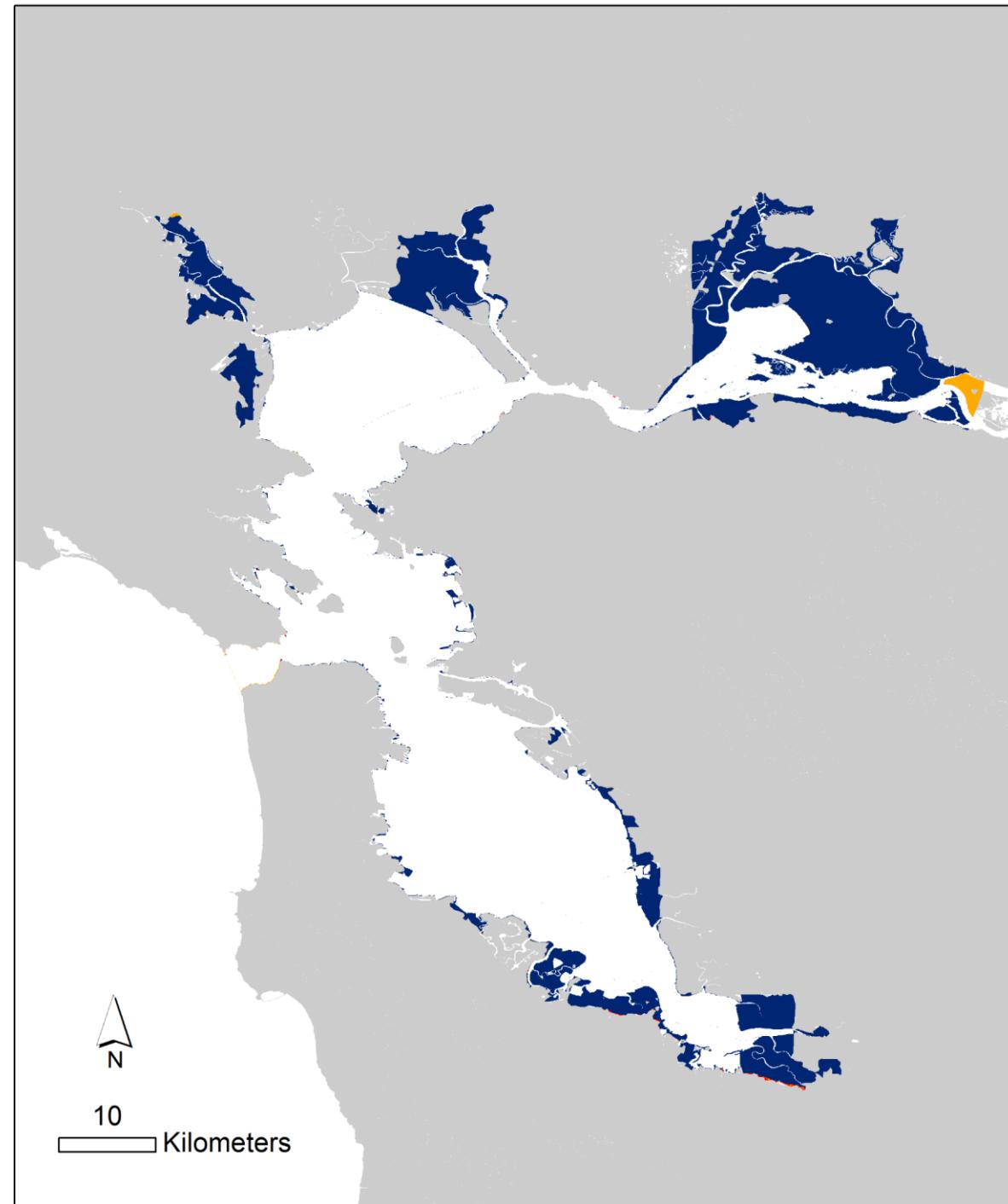
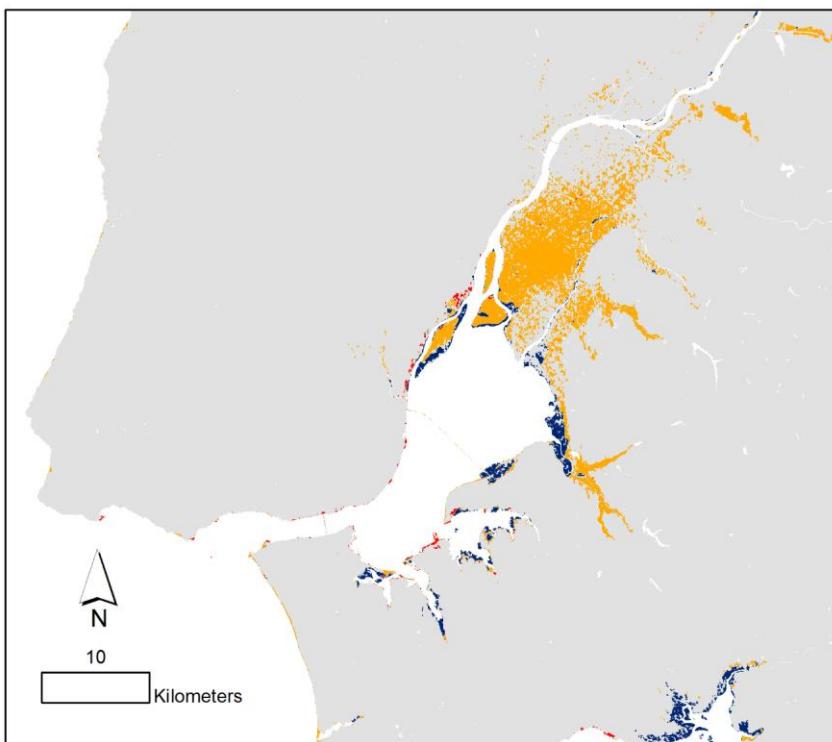
# Rapid assessment of vulnerability to SLR

## Tagus Estuary vs San Francisco Bay



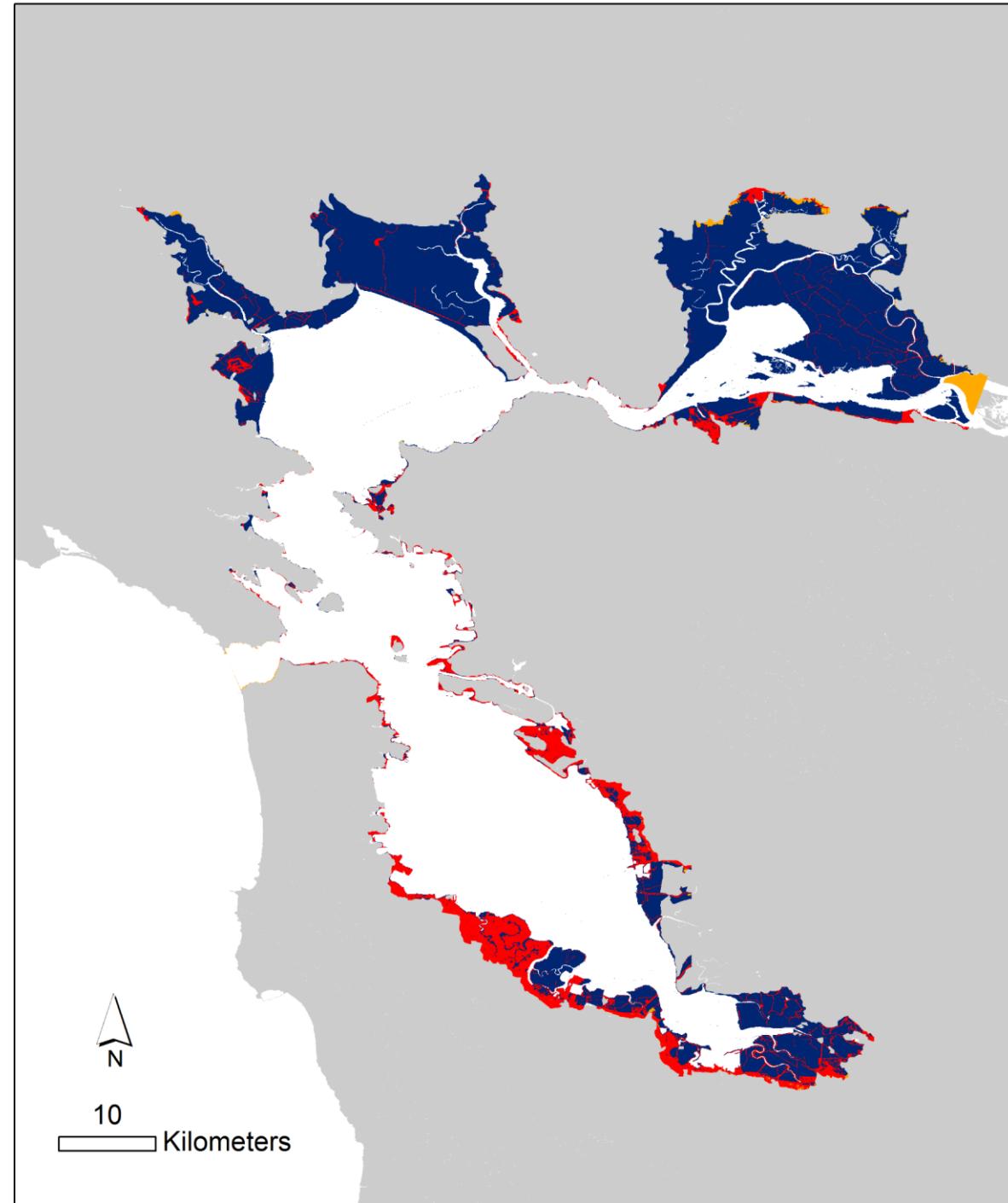
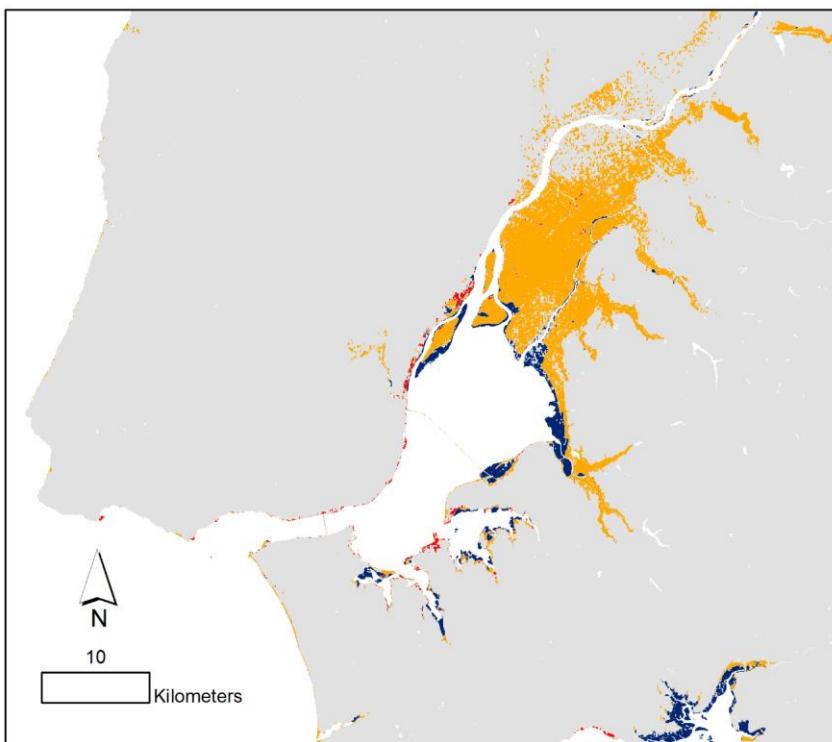
**+1m/3.3ft above  
current sea-level**

- Built-up areas
- Farmland
- Wetlands



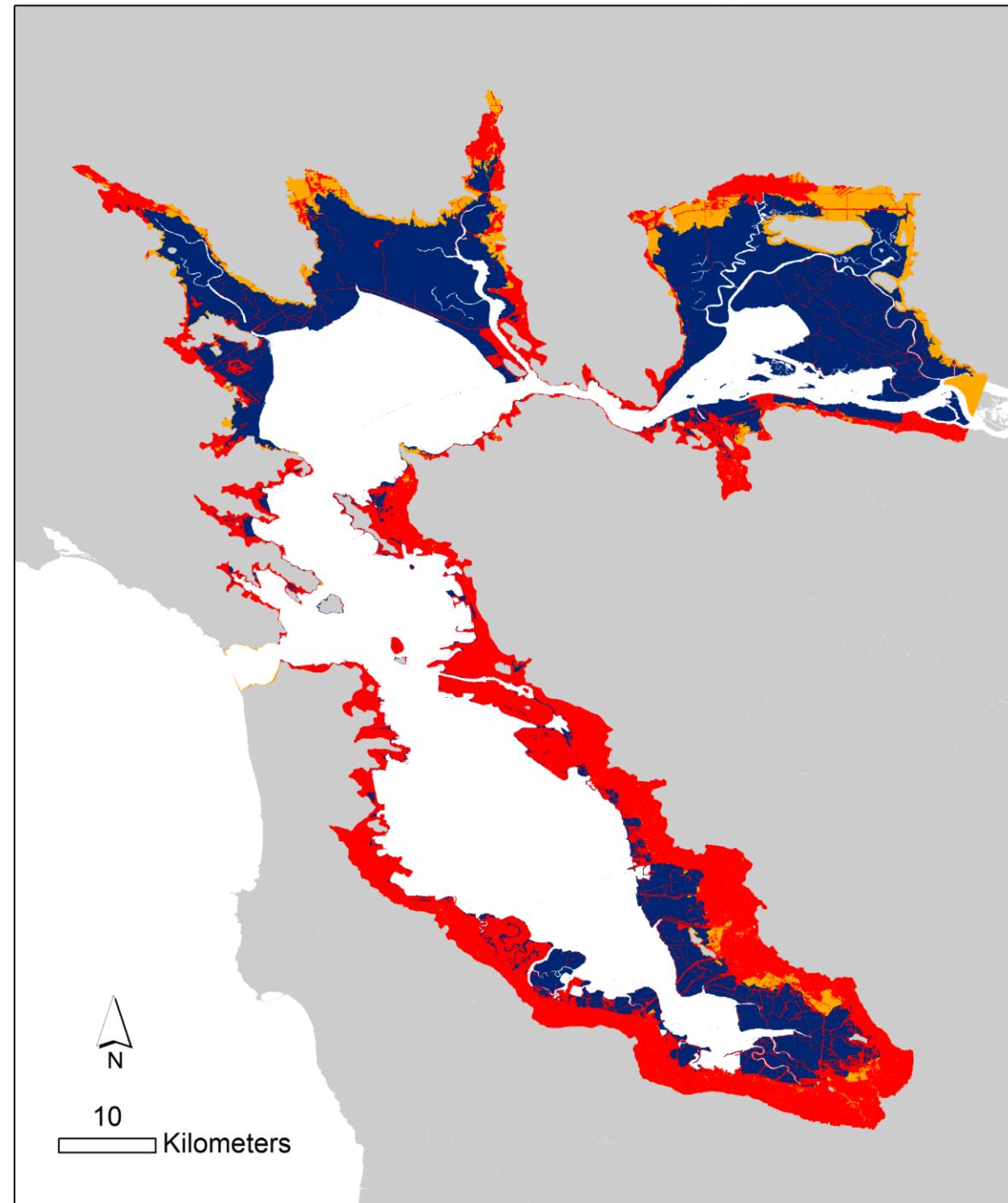
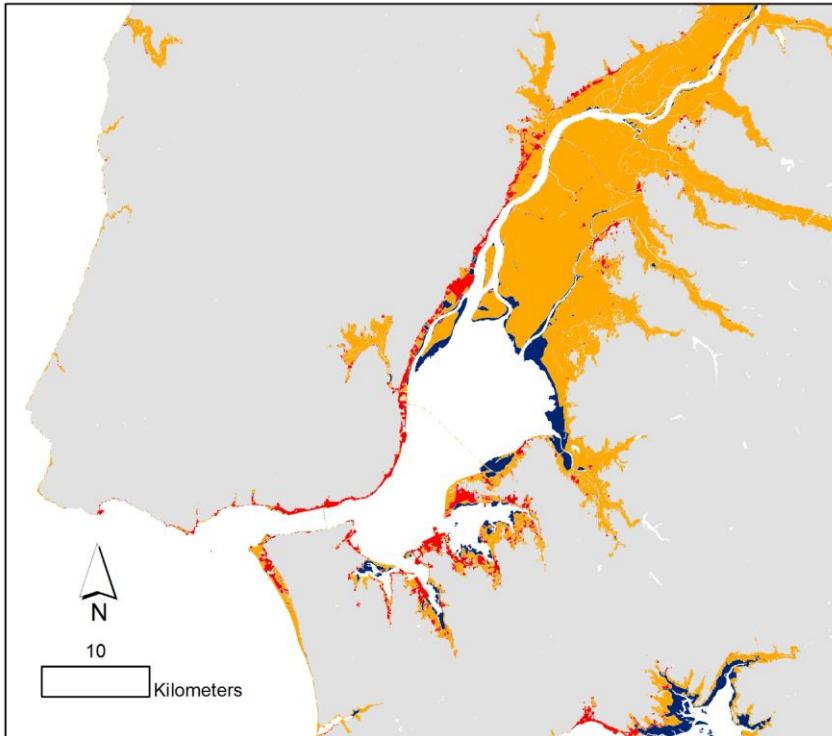
# +2m/6.6ft above current sea-level

- Built-up areas
- Farmland
- Wetlands

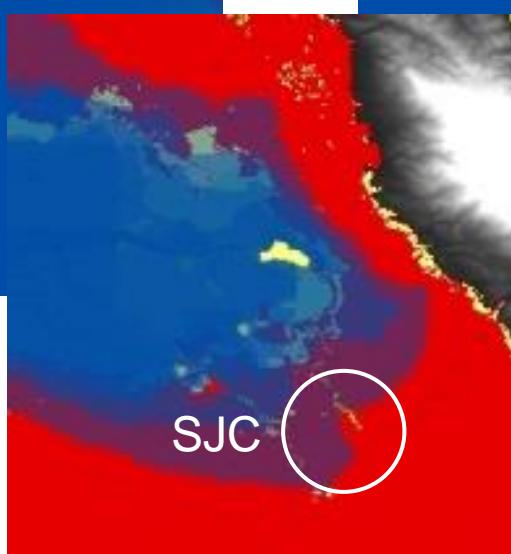
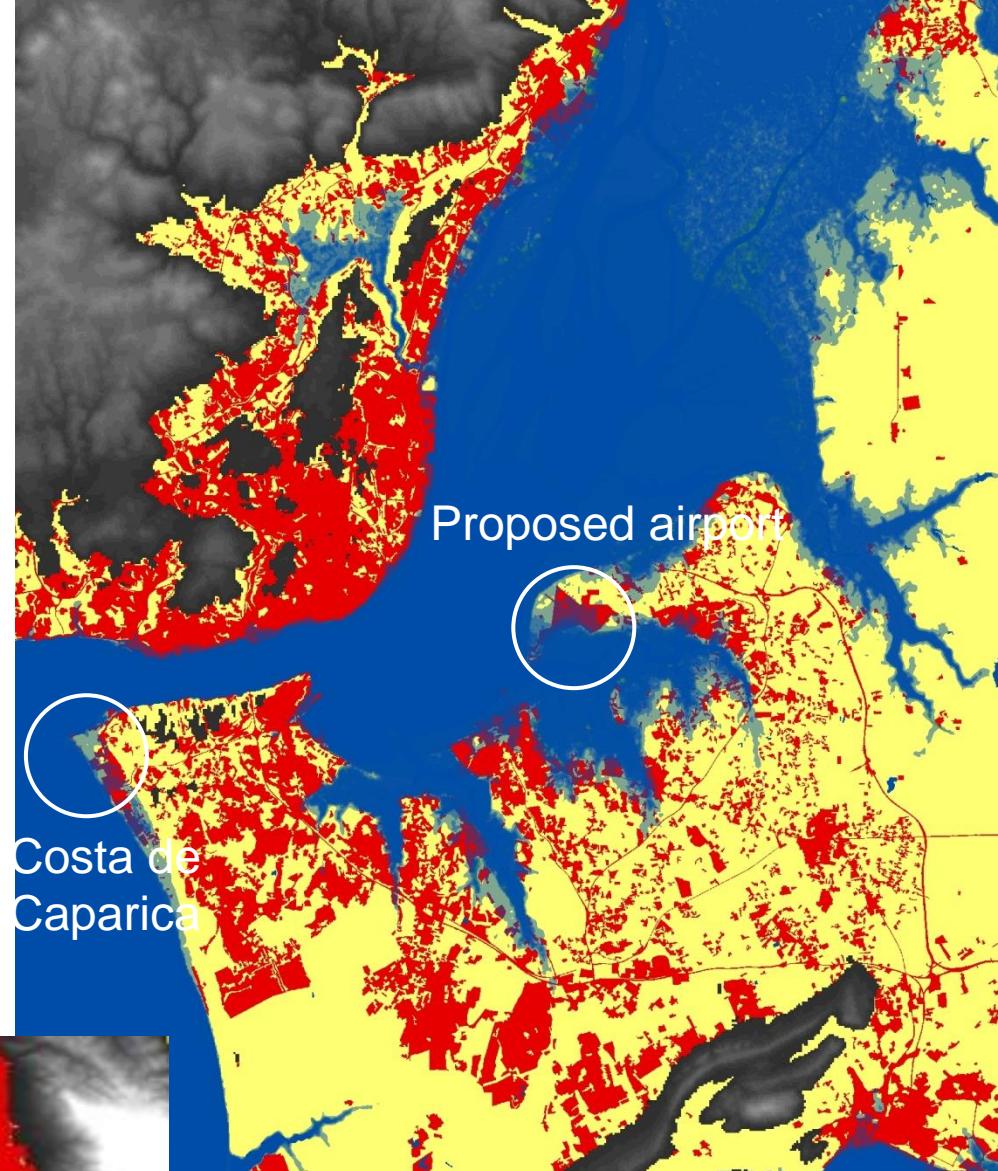
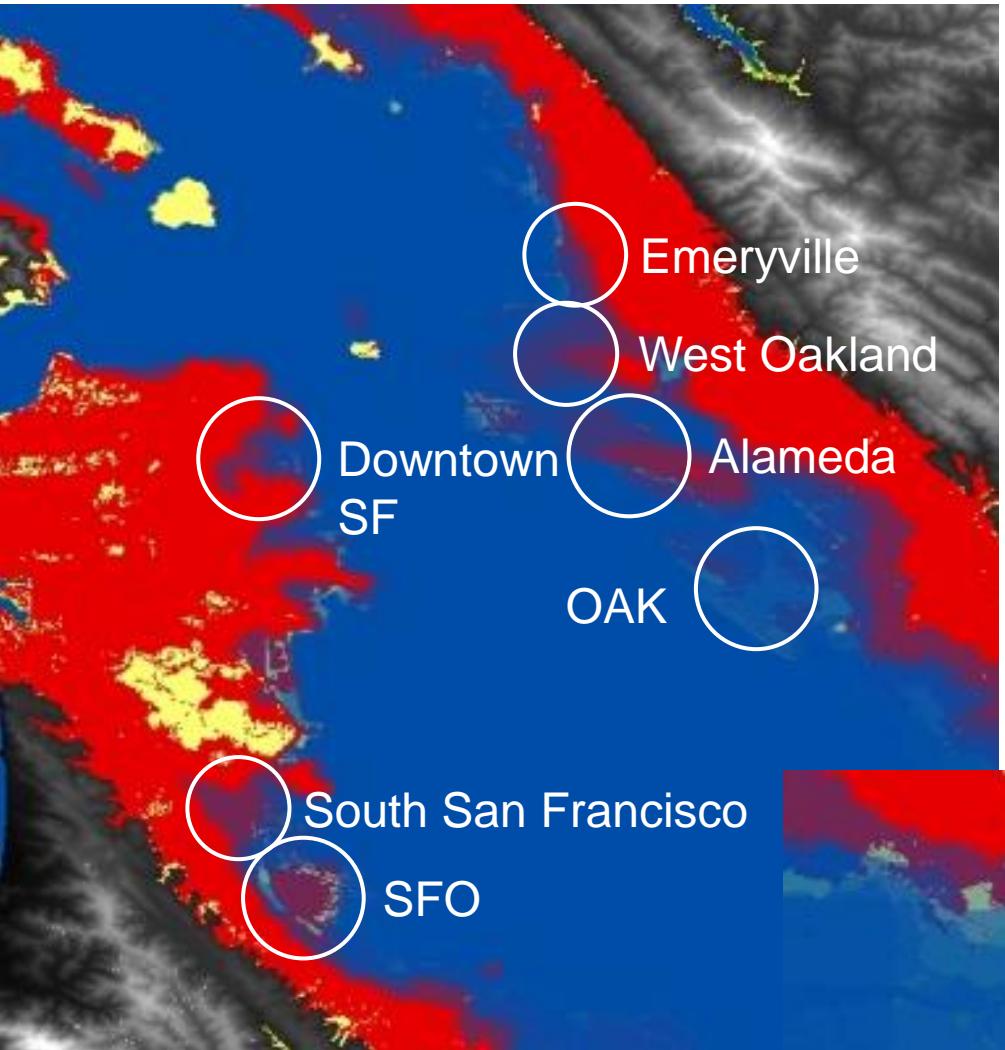


**+10m/33ft above  
current sea-level**

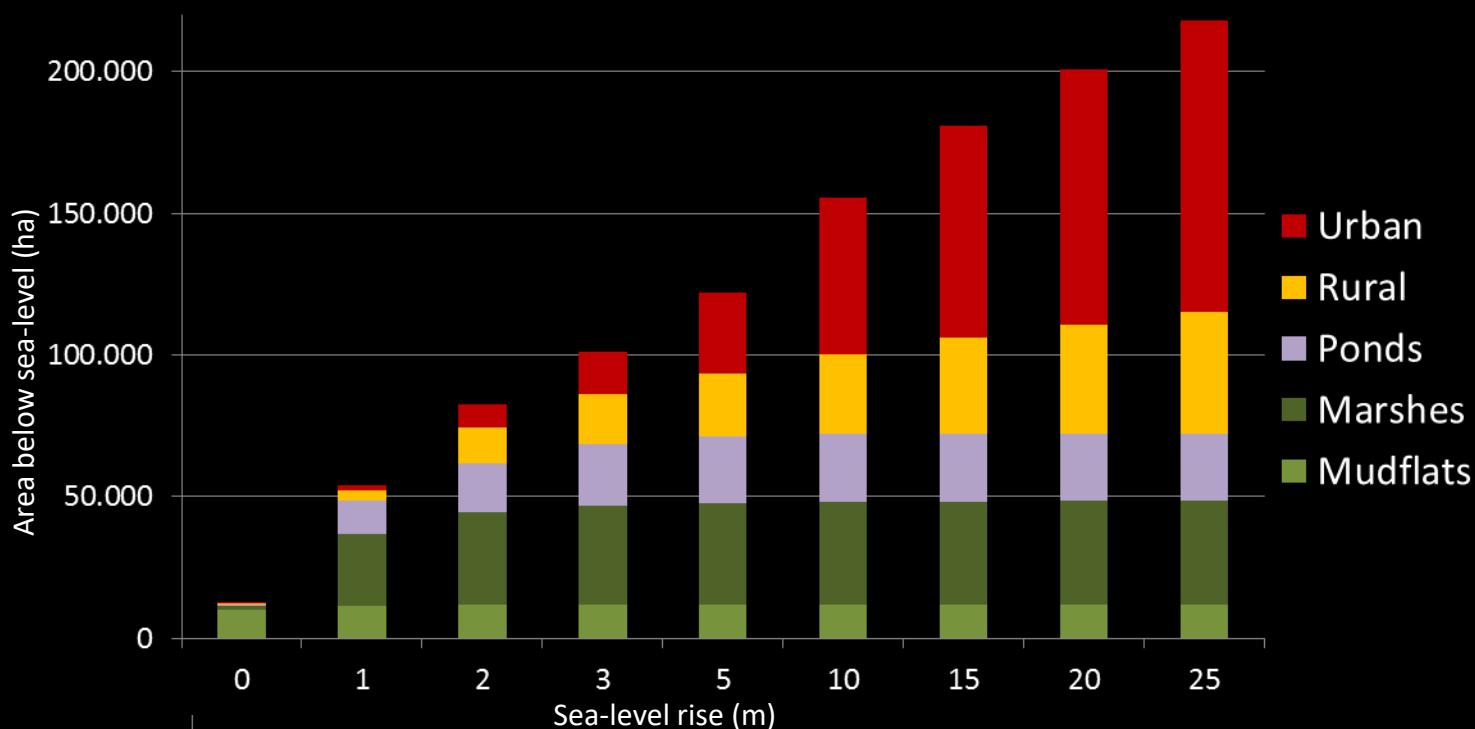
- Built-up areas
- Farmland
- Wetlands



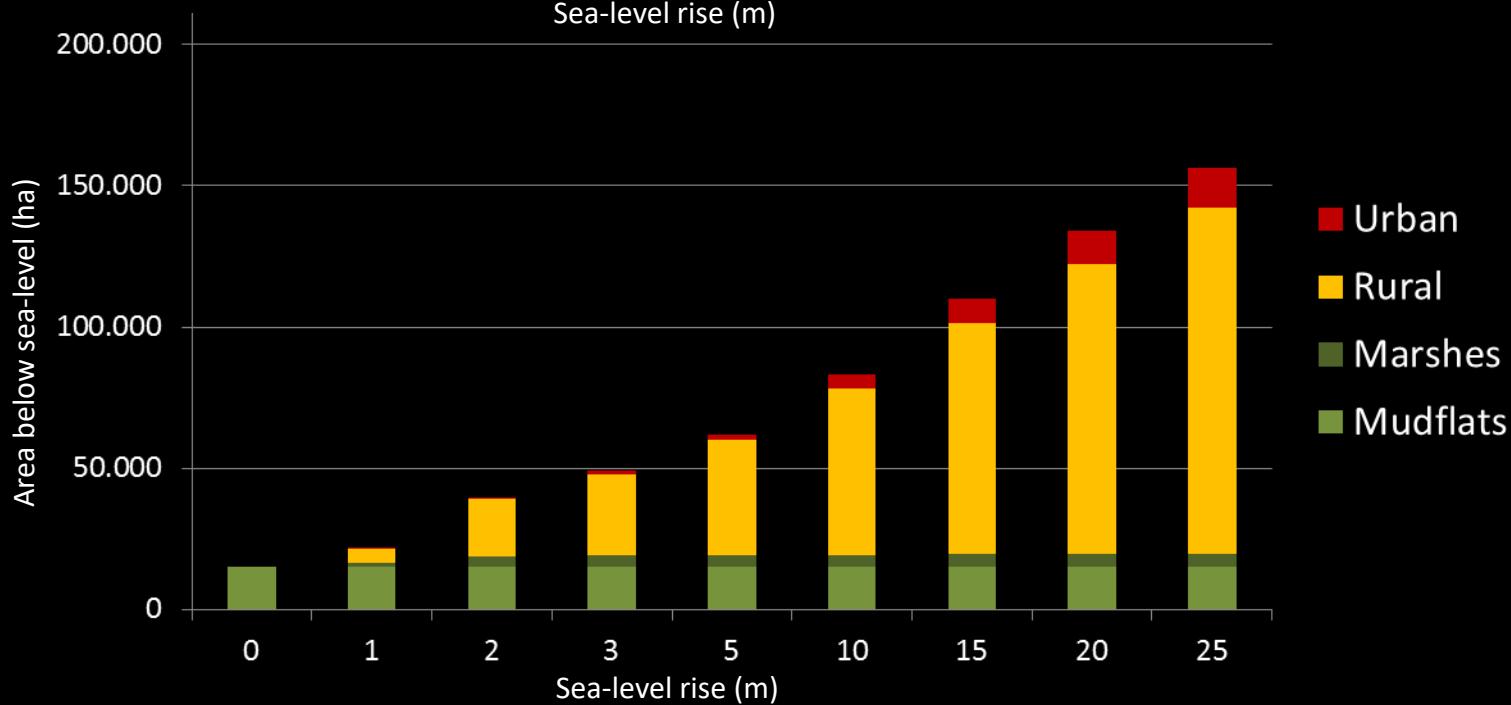
**+10m/33ft above current sea-level**



# SAN FRANCISCO

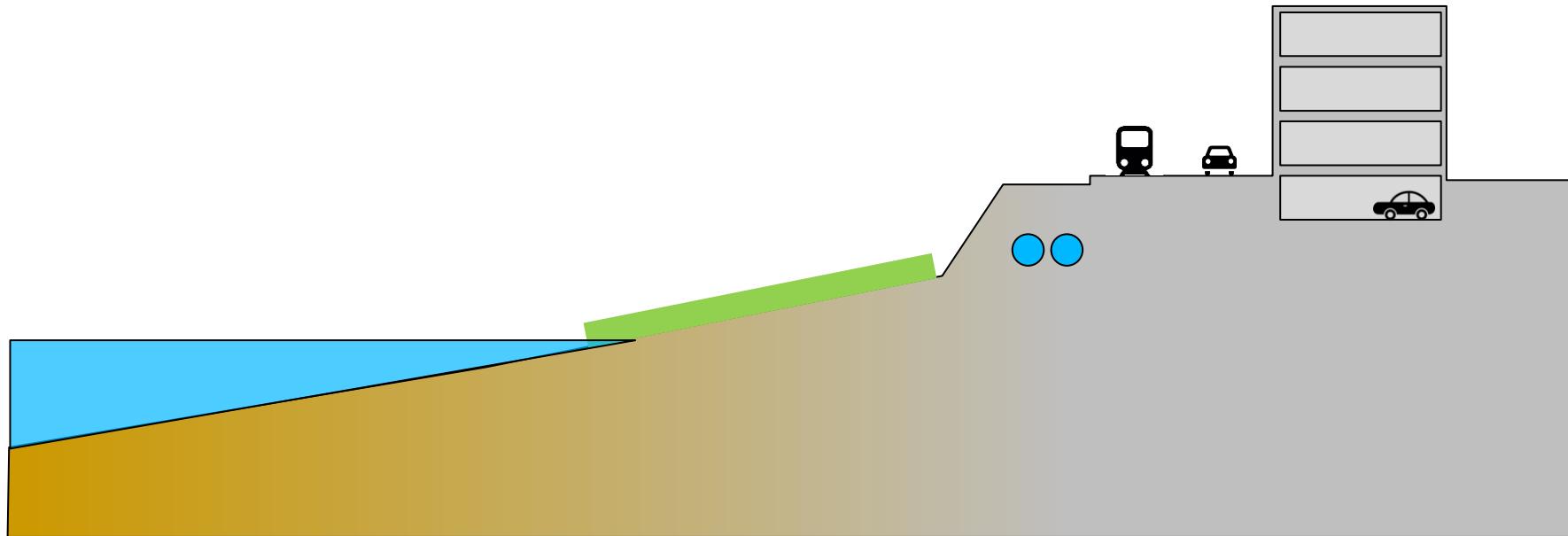


# LISBON



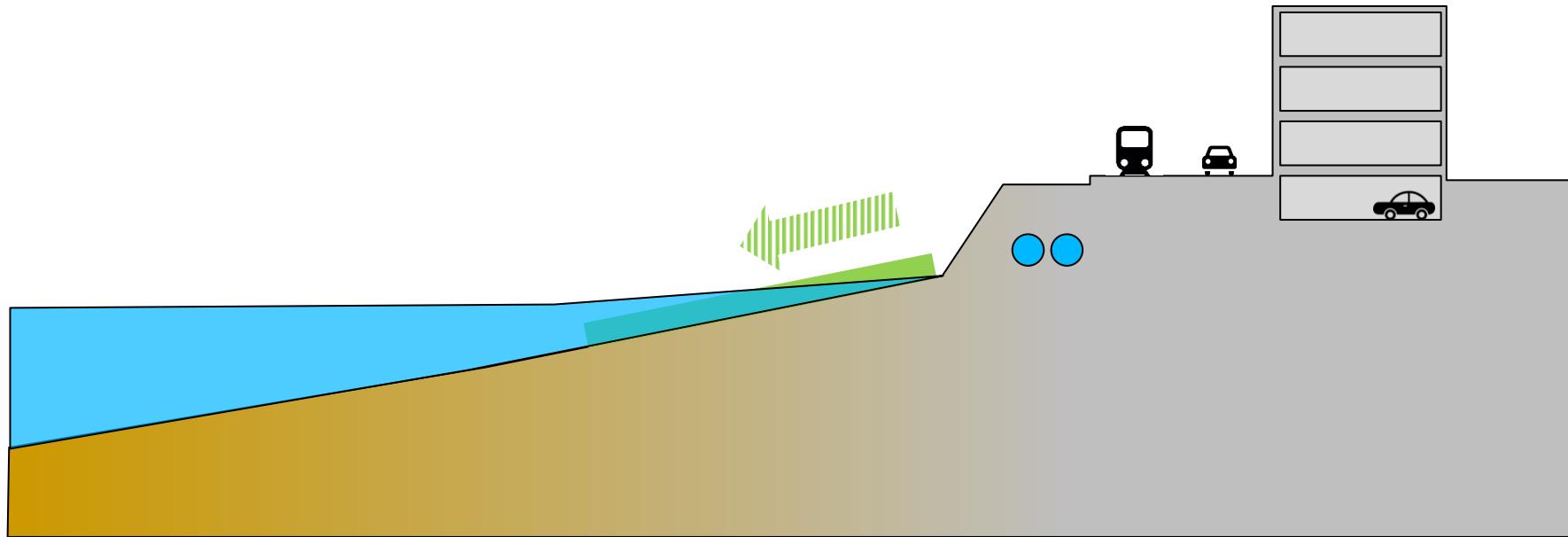
# Impacts are progressive, cumulative, and foreshadowed by extreme events

Today, infrastructure is largely unaffected by high tides and storm surges. Wetlands may help dampen wave action



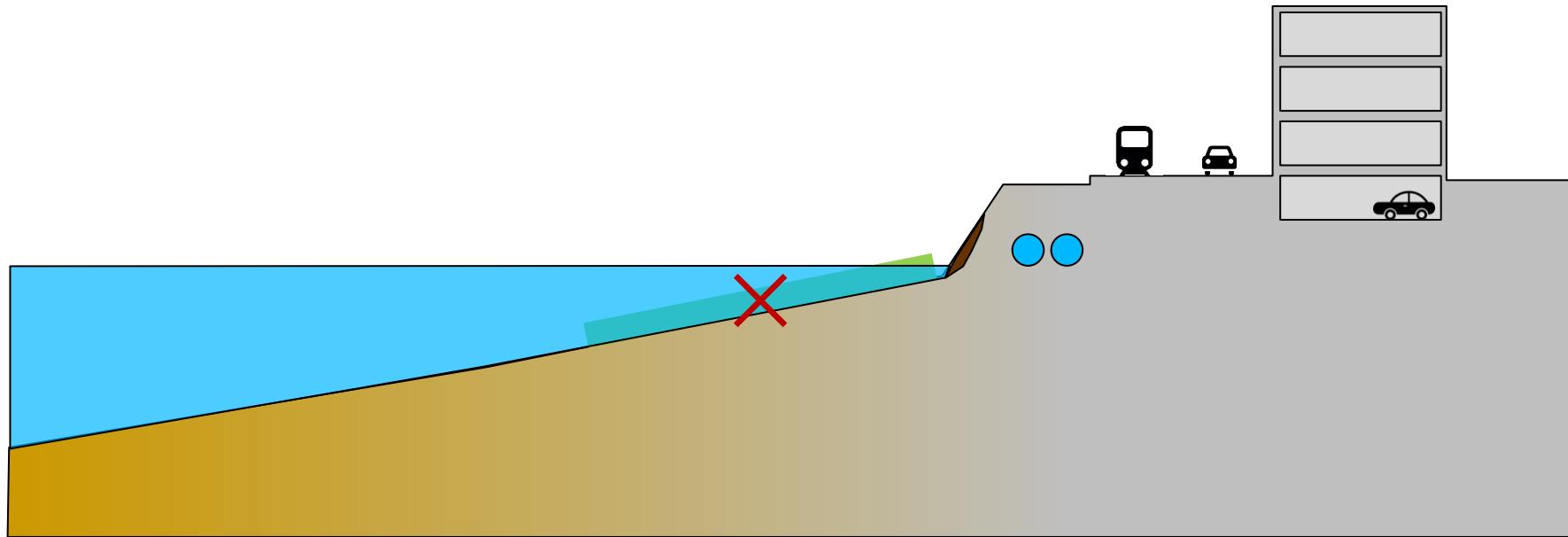
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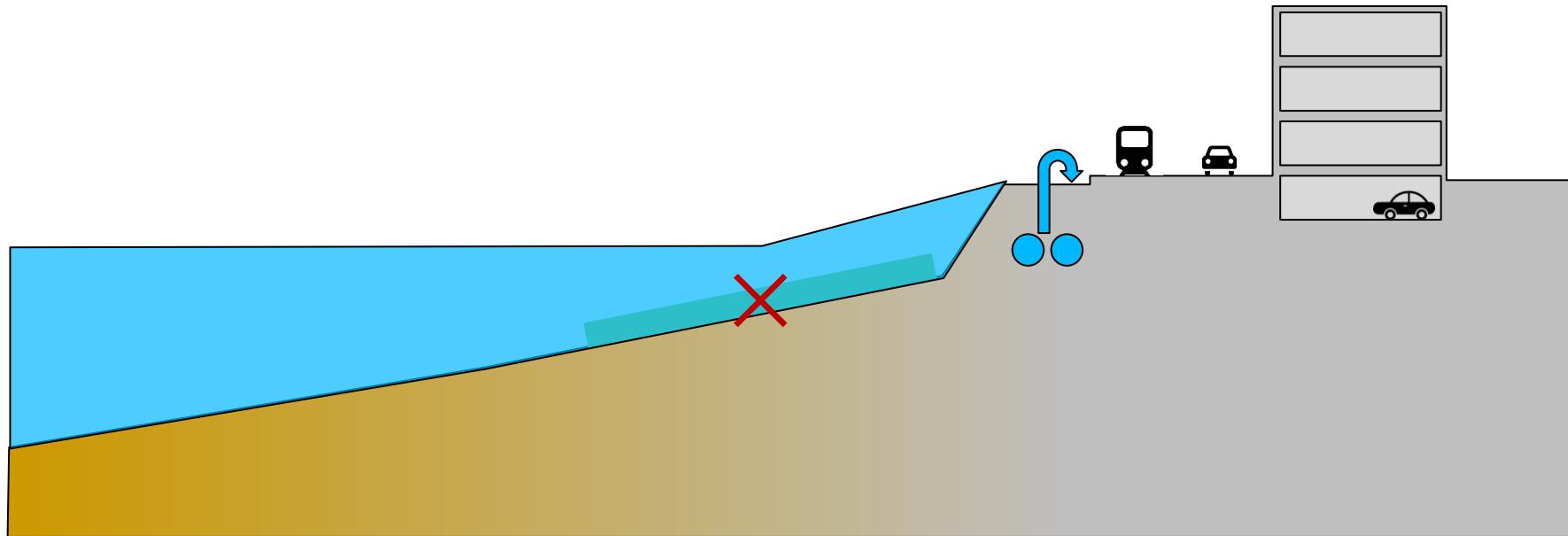
# Impacts are progressive, cumulative, and foreshadowed by extreme events

When constricted by infrastructure, wetlands will not be able to migrate, will drown, and expose infrastructures to direct wave action



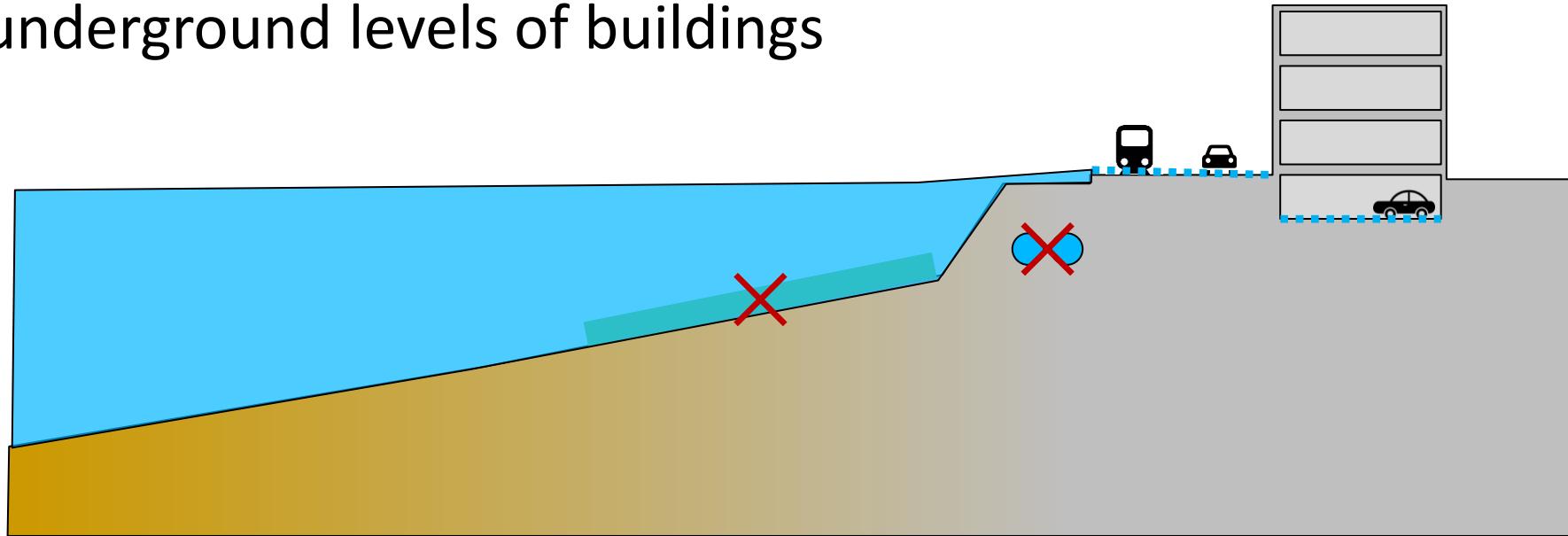
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Wave runup will affect sewage systems, causing backup and overflow



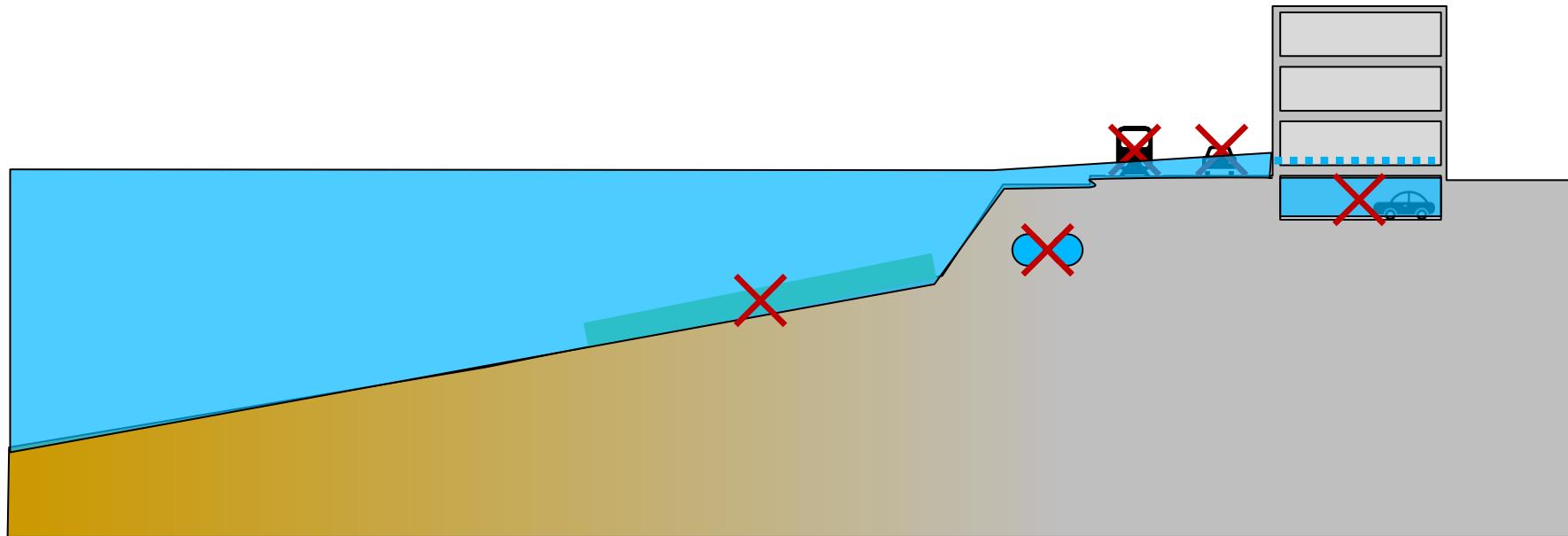
# Impacts are progressive, cumulative, and foreshadowed by extreme events

Frequent flooding of street level will render sewage systems inoperable, cause frequent closings of low-lying roads and rails and flood underground levels of buildings



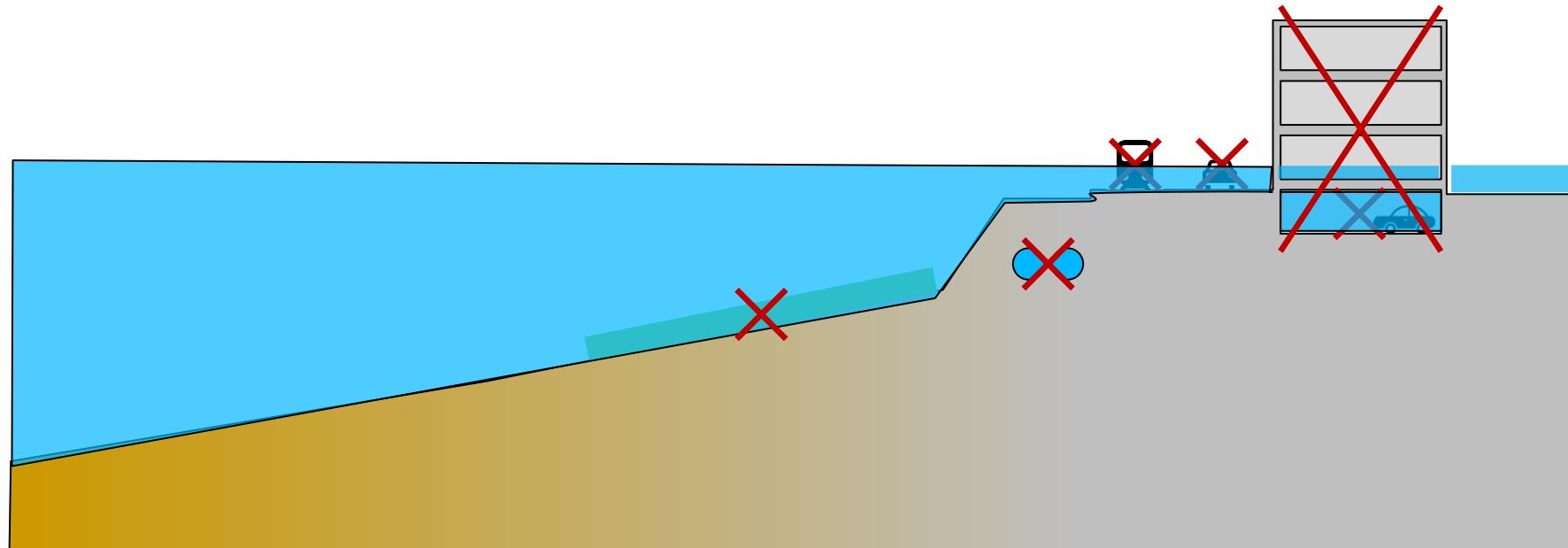
# Impacts are progressive, cumulative, and foreshadowed by extreme events

Eventually, shoreline roads and underground levels will be abandoned, and street level of buildings will experience frequent flooding



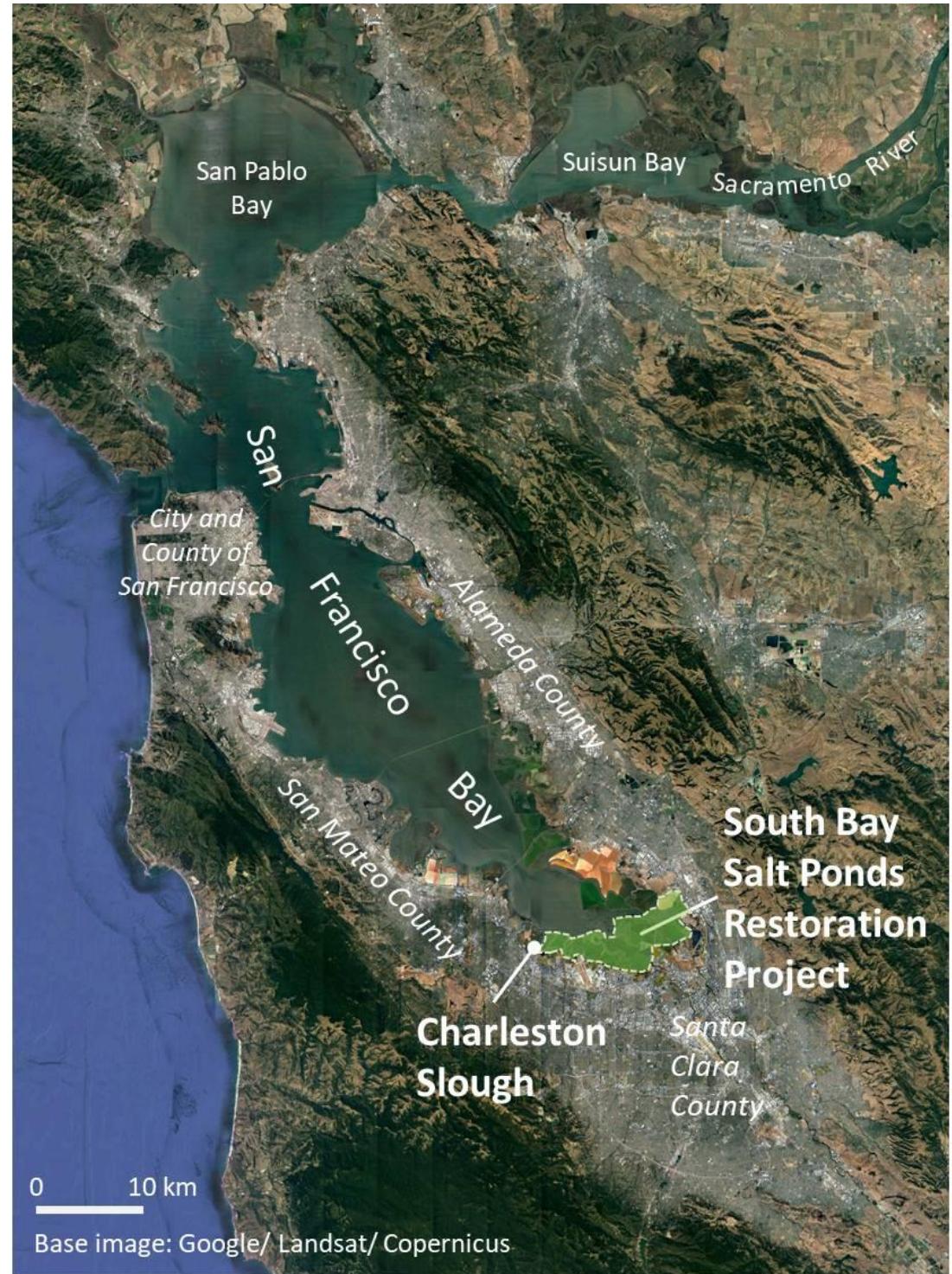
# Impacts are progressive, cumulative, and foreshadowed by extreme events

Shortly after, buildings on low ground will be deemed unviable and abandoned



# Emerging governance issues in sea level rise adaptation

Pinto, P. J., Kondolf, G. M., & Wong, P. L. R. (2018). Adapting to sea level rise: Emerging governance issues in the San Francisco Bay Region. *Environmental science & policy*, 90, 28-37.





alltrails.com

# Charleston Slough:

## Institutional coordination is fundamental for effective adaptation





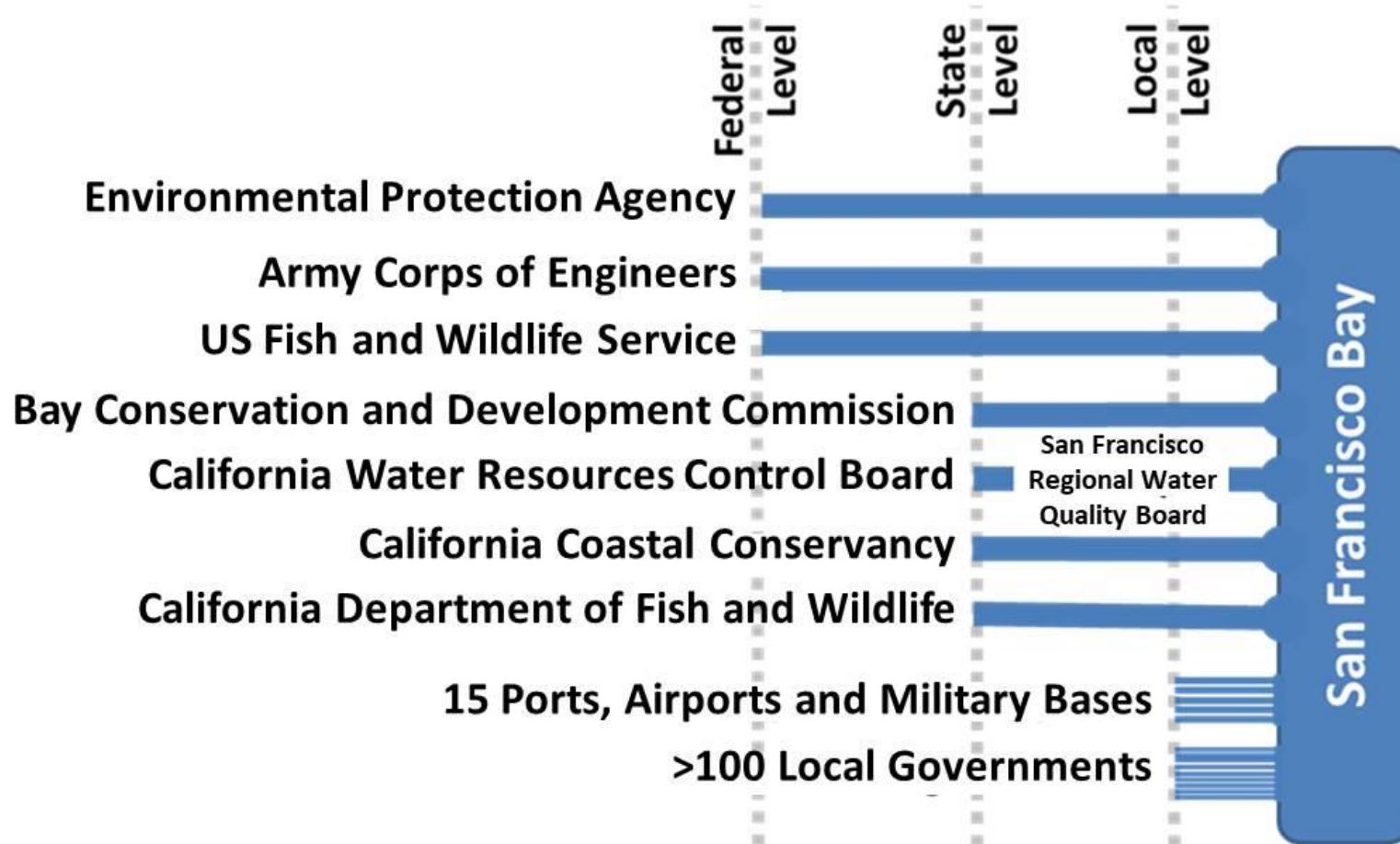
# Redwood City Salt Ponds:

## Urban development of floodplains should not be allowed

kqed.org



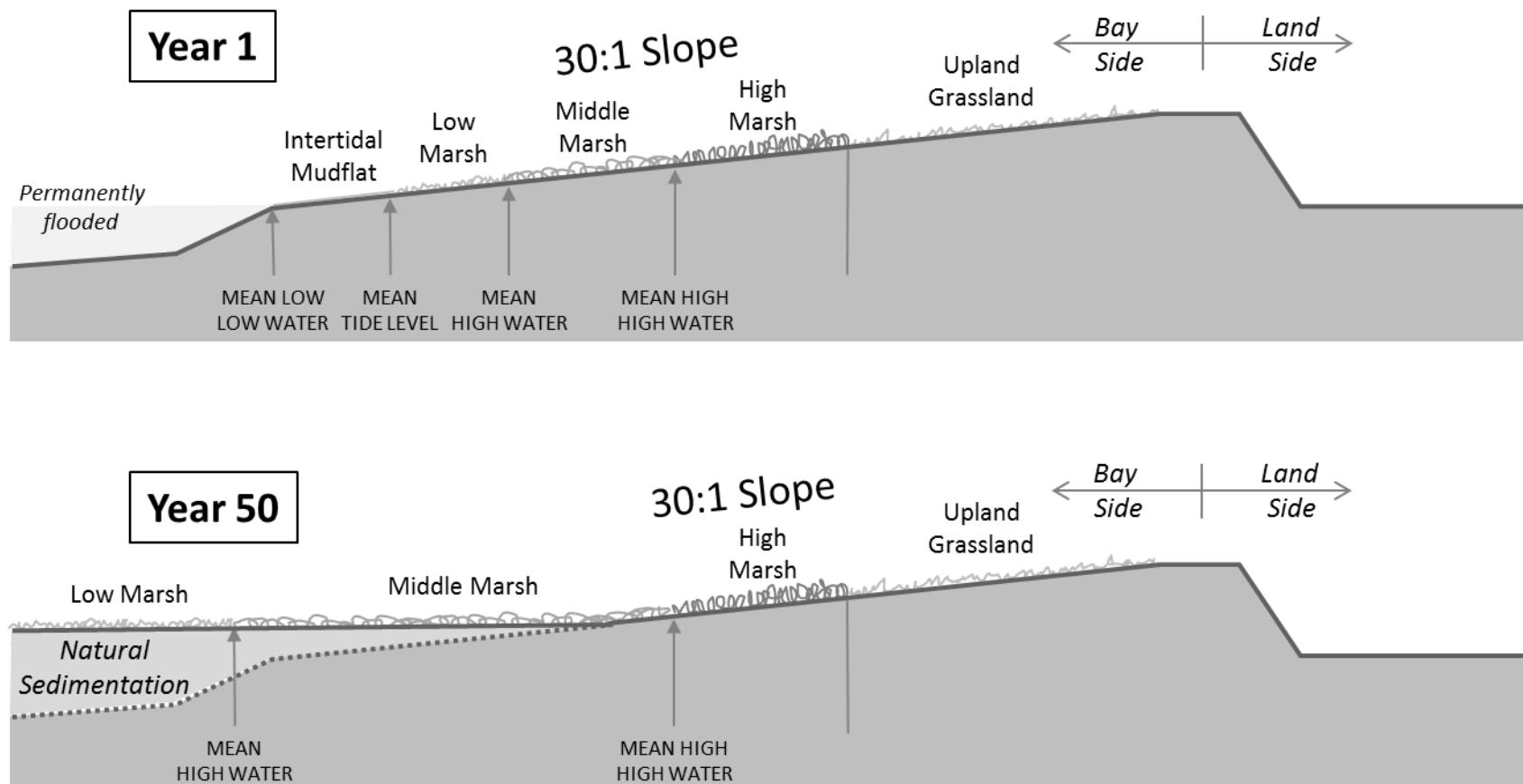
**Complex multi-level governance** structures require leadership, adequate moderation of emerging conflicts, and a clear sense of public interest in SLR adaptation



**Increased cost of habitat restoration** is often dictated by  
the need to protect **built-up areas**

<b>TAGUS ESTUARY</b>		<b>SF BAY</b>
<b>EVOA</b>	<b>Samouco</b>	<b>South Bay</b>
70ha	360ha	6.111ha
€200K	€500K	>€200.000K
<b>~€2,900/ha</b>	<b>~€1,400/ha</b>	<b>&gt;\$32,700/ha</b>
3 managers/ 3 partners	3 managers	11 managers
2 donors	1 donor	15 donors

# Resilient solutions are being tested, such as “Horizontal levees”



Levee with “ecotone” zone. Adapted from HDR, 2015: Figs. 3.6-3 and 3.6-4



# “Low regrets”, multifunctional solutions are more resilient and cost-effective

				Cost		Scale		Time horizon		Regrets	
				Low	High	Small	Large	Short	Long	No/Low	High
Structural Hard	H1					X		X			X
	H2					X		X		X	
	H3						X		X		X
	H4						X	X			X
	H5							X			X
	H6							X			X
	H7					X			X		X
	H8						X	X		X	
	H9							X		X	X
	H10								X		X
	H11							X			X
	H12							X		X	X

# Small-scale adaptation and policy reform are crucial

		Cost		Scale		Time horizon		Regrets		
		Low	High	Small	Large	Short	Long	No/Low	High	
Structural	Green	Actively manage existing <b>wetlands</b> so as to increase their <b>resilience</b> and promote their expansion		X		X	X	X		
		Reduce peak surface <b>runoff</b> by introducing <b>green infrastructure</b> and improving infiltration and detention			X	X	X		X	
		Maintain <b>beach nourishment</b> projects to reduce the impacts of coastal erosion			X		X	X		X
		Create new <b>artificial wetlands</b> , namely by reconverting underused reclaimed landfill areas			X		X	X		X
	G5	<b>Protect existing wetlands</b> , beaches and dune systems		X			X	X		X
Non-Structural	S1	Identify <b>safe routes</b> alternative to flood-vulnerable roadways and transit lines			X	X		X		X
	S2	<b>Forbid</b> the construction of <b>basements</b> in flood-prone areas		X		X		X		X
	S3	<b>Remove</b> valuable or perishable <b>items</b> and sensitive infrastructure from basements and <b>flood-prone</b> ground floors			X	X		X		X
	S4	<b>Map risks, highlight vulnerable areas, and increase awareness</b>			X		X		X	X
	S5	<b>Forbid new construction</b> in vulnerable areas through local planning instruments		X			X	X		X
	S6	<b>Raise awareness</b> of politicians, civil protection agents, and populations to the impacts of coastal flooding and sea-level rise			X		X	X		X
	S7	<b>Revise building standards</b> so as to require higher ground floor clearance on new buildings or reconstructions		X			X		X	X
	S8	<b>Implement early flood warning</b> and monitoring systems (SMS, Media alerts, Sirens...)			X		X	X		X
	S9	Enact changes to <b>flood risk insurance policies</b> so as to increase accountability for "risky" location choices			X		X	X		X

Freire, P., Tavares, A. O., Sá, L., Oliveira, A., Fortunato, A. B., Dos Santos, P. P., ... & Pinto, P. J. (2016). A local-scale approach to estuarine flood risk management. *Natural Hazards*, 84(3), 1705-1739.

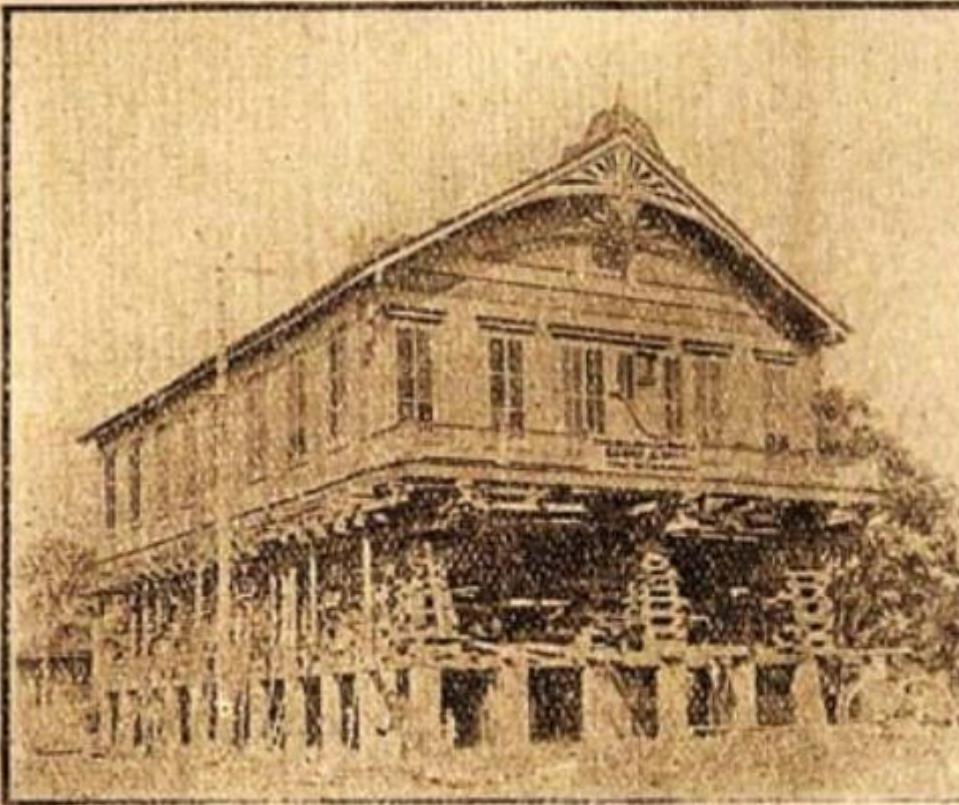
# Replace vulnerable structures



East Span of the Bay Bridge.  
SFGate

# Retrofit structures to increase resilience

**EMILE ABRY & SONS,**



**HOUSE RAISERS,  
Movers and Shorers,**

MAIN OFFICE :  
**126 CARONDELET ST.**  
C. PHONE 1877.

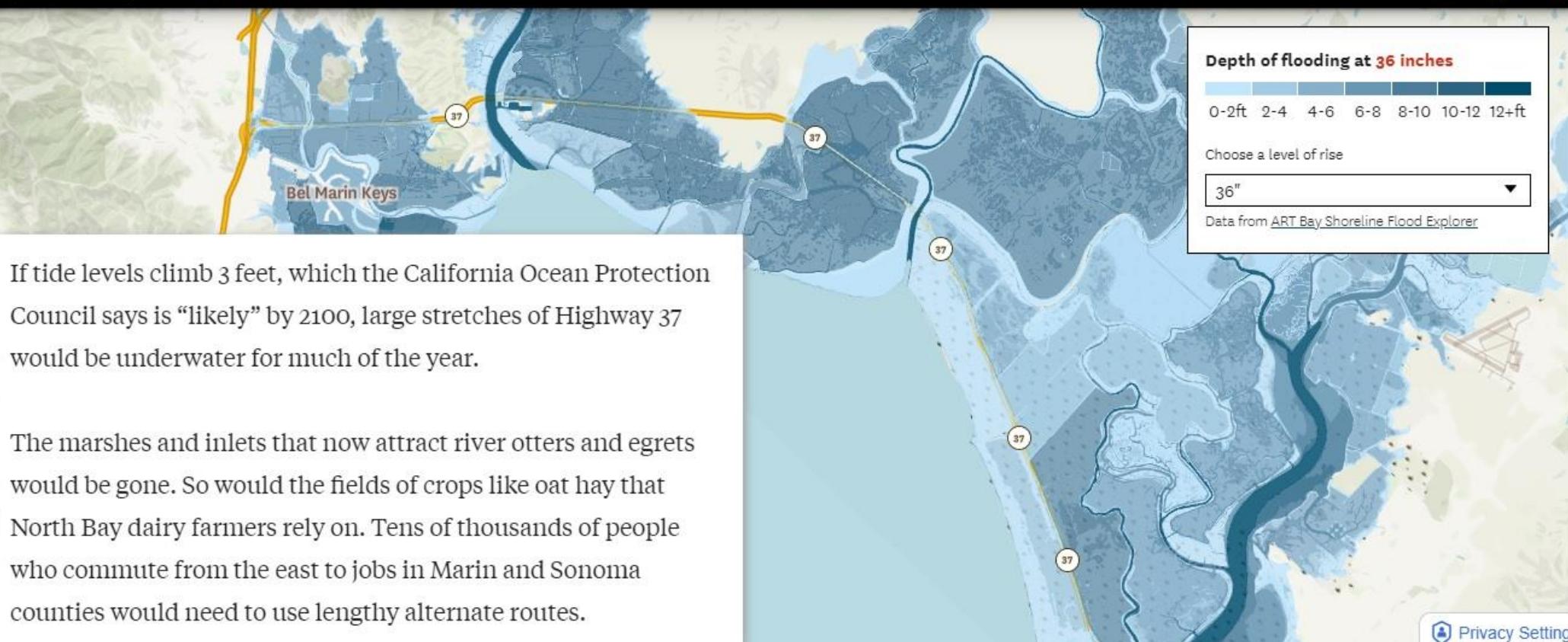
RESIDENCE :  
**816-818 N. Johnson St.**  
C. PHONE 2778-11.

YARDS :  
**ST. ANN, NEAR N. BROAD,**  
**NEW ORLEANS.**

The History of Building Elevation in New Orleans.  
URS/FEMA

# Retrofit structures to increase resilience

San Francisco Chronicle SPECIAL REPORT



<https://www.sfchronicle.com/projects/2021/san-francisco-bay-area-sea-level-rise-2021/highway-37>

# Build away from flood-prone areas



© Gerhard Launer/euroluftbild/ZB/picture alliance



© Polizei /dpa/picture alliance

Schuld, Germany, flooded in 2021 by the Ahr river. The village occupied an abandoned meander.  
DW.com

# Build away from flood-prone areas



Quinta do Braamcamp, Barreiro, Tagus Estuary.  
Idealista.pt and Jornal Rostos/ Saint Germain

## Encourage relocation

- Plans should clearly address SLR
- Transparent communication of expected impacts
- Eliminate public incentives to stay-in-place
- Compensate early relocation and support resettlement
- Progressively defund new flood insurances



© A Terceira Dimensão  
<http://portugalfotografiaaerea.blogspot.com>

The new Aldeia da Luz was rebuilt near the old one, drowned in 2002 by the reservoir of the Alqueva Dam, Southeast Portugal.  
[Observador](http://observador.pt) and [portugalfotografiaaerea.blogspot.com](http://portugalfotografiaaerea.blogspot.com)

# Preserve and nurture wetland ecosystems



Wave energy dissipation by  
cordgrass  
Walls (2016). Valuing Ecosystem  
Services of Coastal Wetlands.  
Social Coast Forum, Charleston  
SC.

# Learn to live with high tides



Sausalito floating homes. Shutterstock



Acqua Alta in San Marco Square, Venice, Italy. Italiarail

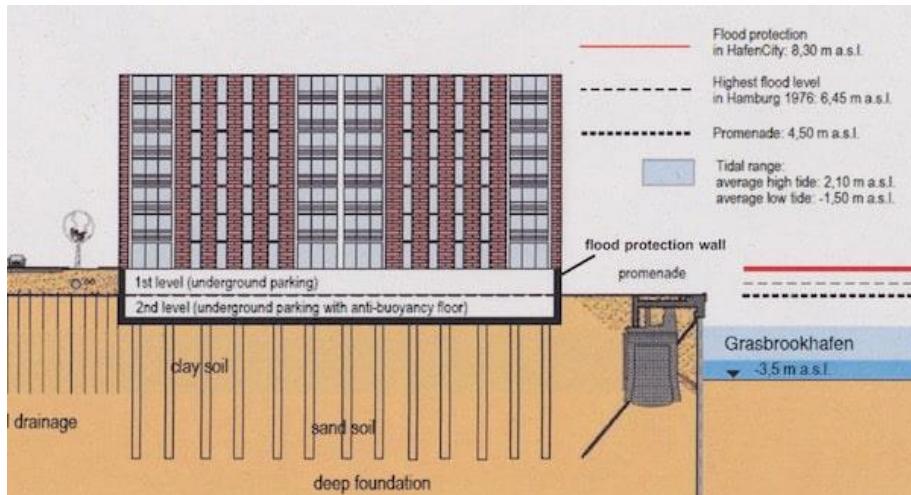


Yawngwe, Myanmar. 3coma14/wikicommons



Elevated homes on Bolivar Peninsula, Tx. FEMA/G. Henshall

# Learn to live with high tides: Hafencity, Hamburg, Germany



Promenade level designed for sporadic flooding. Upper (street) level remains accessible during flood. [Hafencity.com](http://Hafencity.com)



T.Krauss



Flood doors at Promenade level  
[Hafencity.com](http://Hafencity.com)



Flooded Promenade.  
[Cortescurrents.ca](http://Cortescurrents.ca)



Thank you.

*pedrojpinto@gmail.com*