Shoreline Highway at Highway 101. Credit: Caltrans

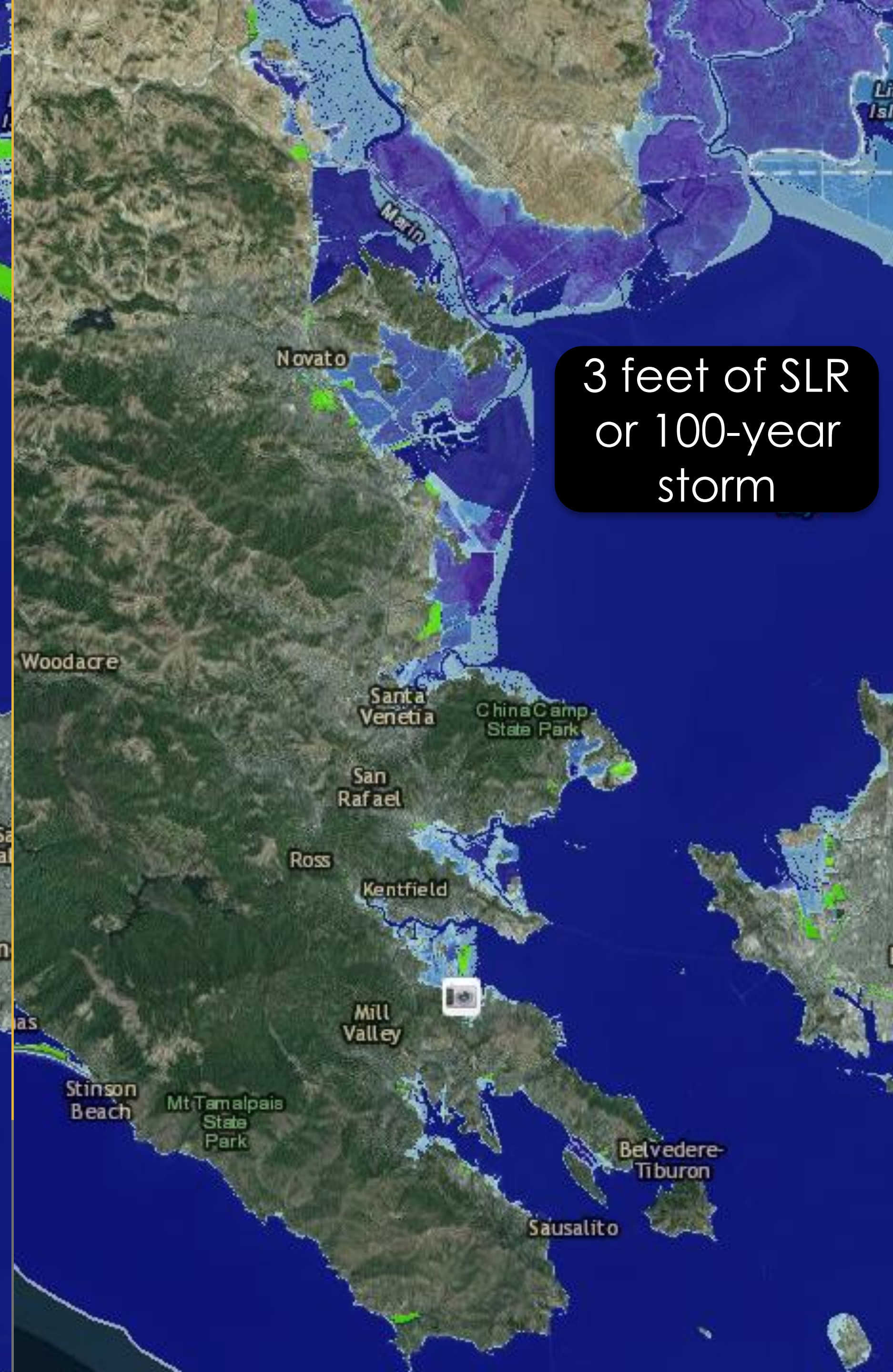
Marin Countywide Sea Level Rise Planning

COUNTY OF MARIN

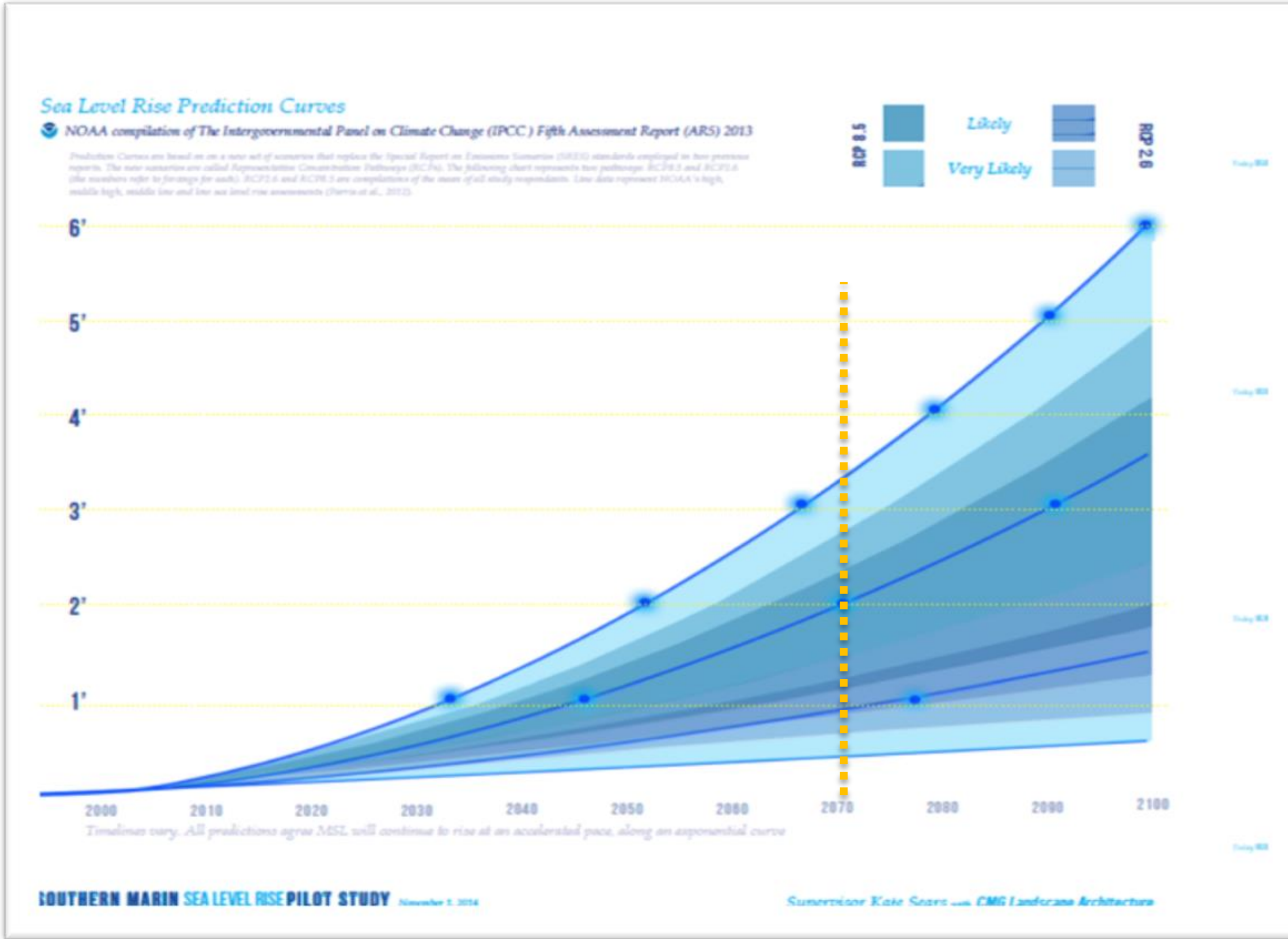
BAYWAVE AND CSMART VULNERABILITY ASSESSMENTS

Tidal Flooding in Southern Marin


1 foot of SLR
or King Tide
Little Island
Marin
Novato
Woodacre
Santa Venetia
China Camp State Park
San Rafael
Ross
Kentfield
Mill Valley
Stinson Beach
Mt Tamalpais State Park
Belvedere-Tiburon
Sausalito


3 feet of SLR
or 100-year
storm
Marin
Novato
Woodacre
Santa Venetia
China Camp State Park
San Rafael
Ross
Kentfield
Mill Valley
Stinson Beach
Mt Tamalpais State Park
Belvedere-Tiburon
Sausalito

Uncertainty in Estimates

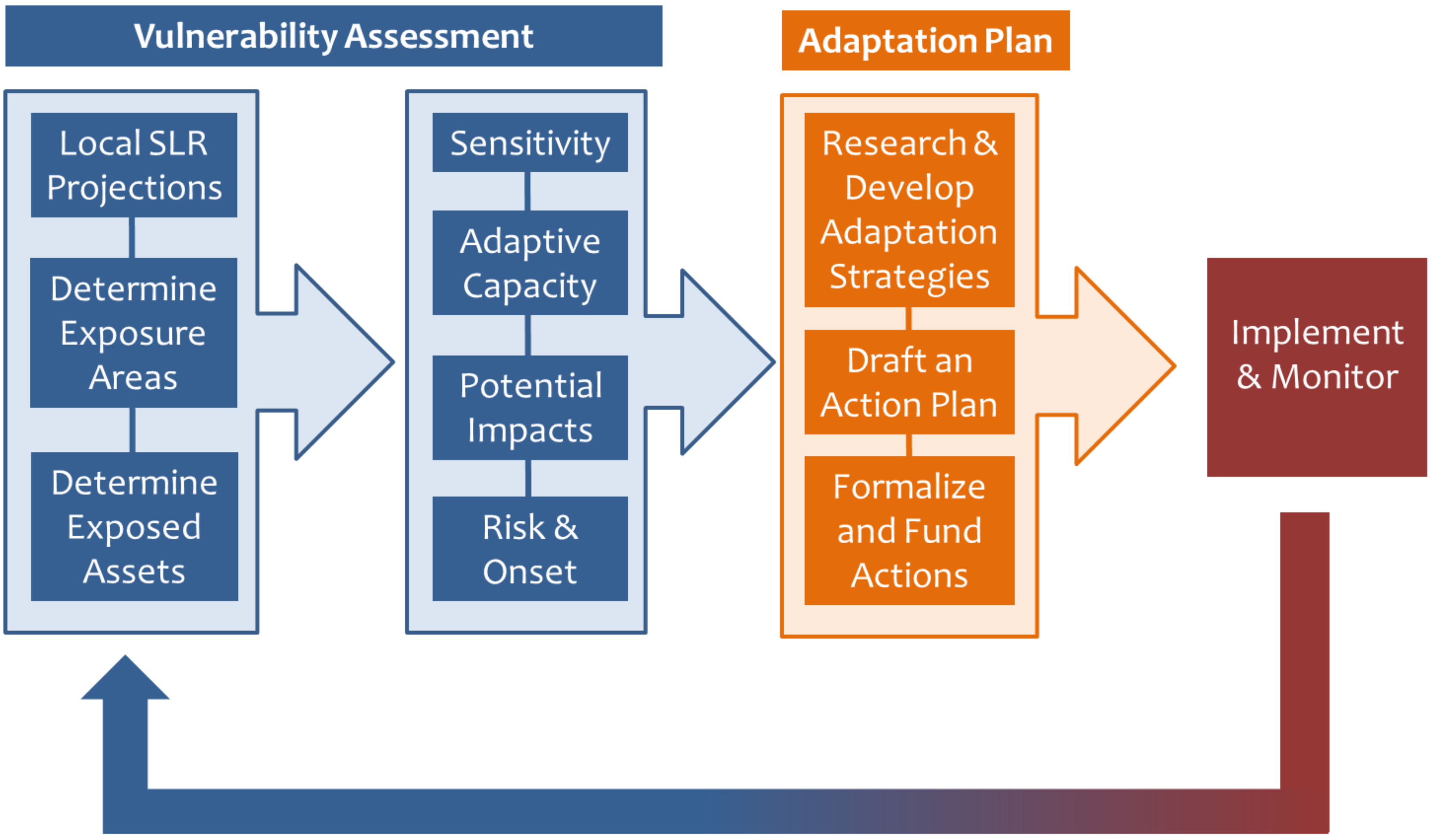


Vulnerability Assessment

A risk-based evaluation of the likely sensitivity and response capacity of natural and human systems to the effects of expected phenomena.

- **Russell**, N. **Griggs. G. January 2012. Adapting to Sea Level Rise: A Guide for California's Coastal Communities**

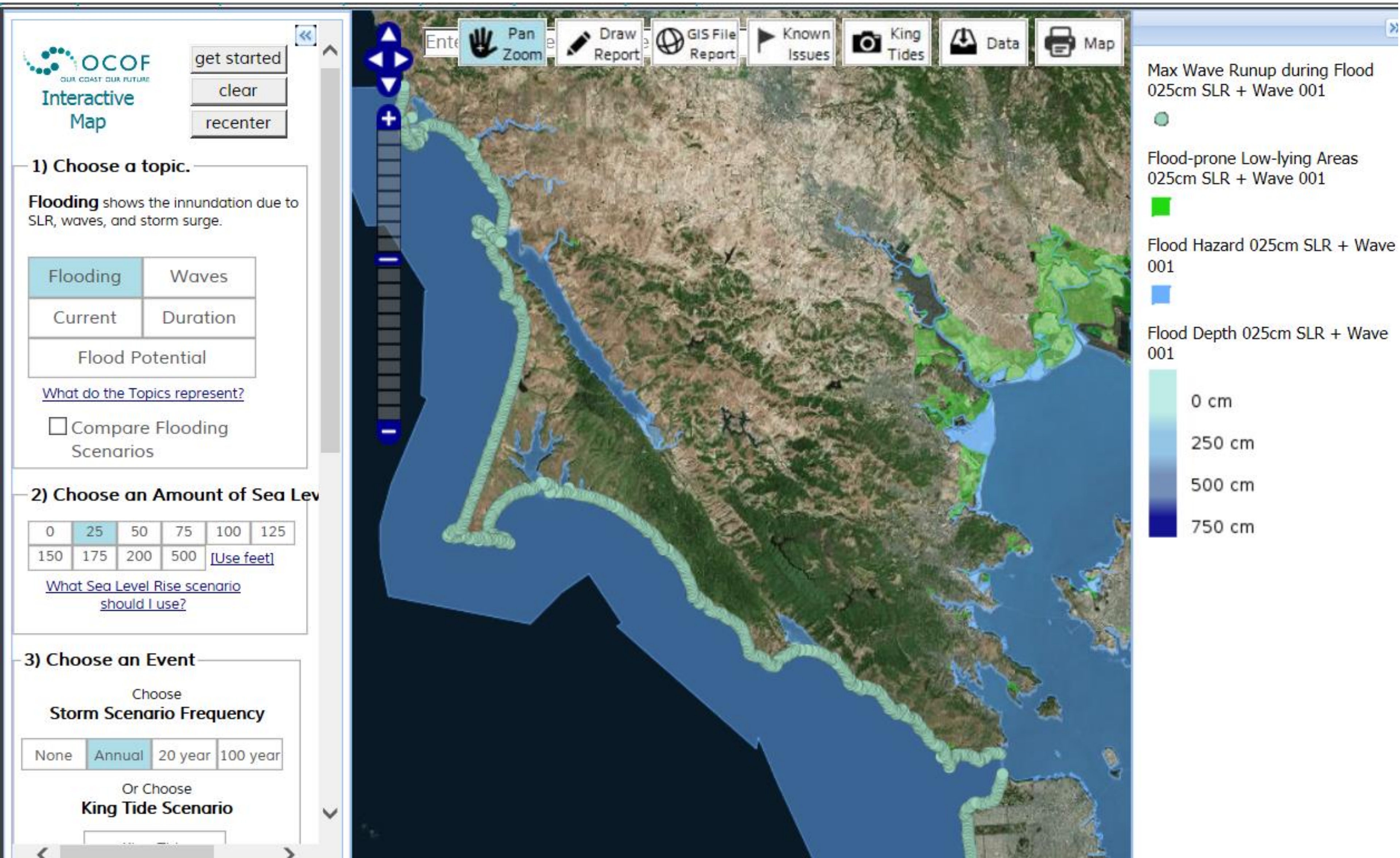
CSMART and BayWAVE Process

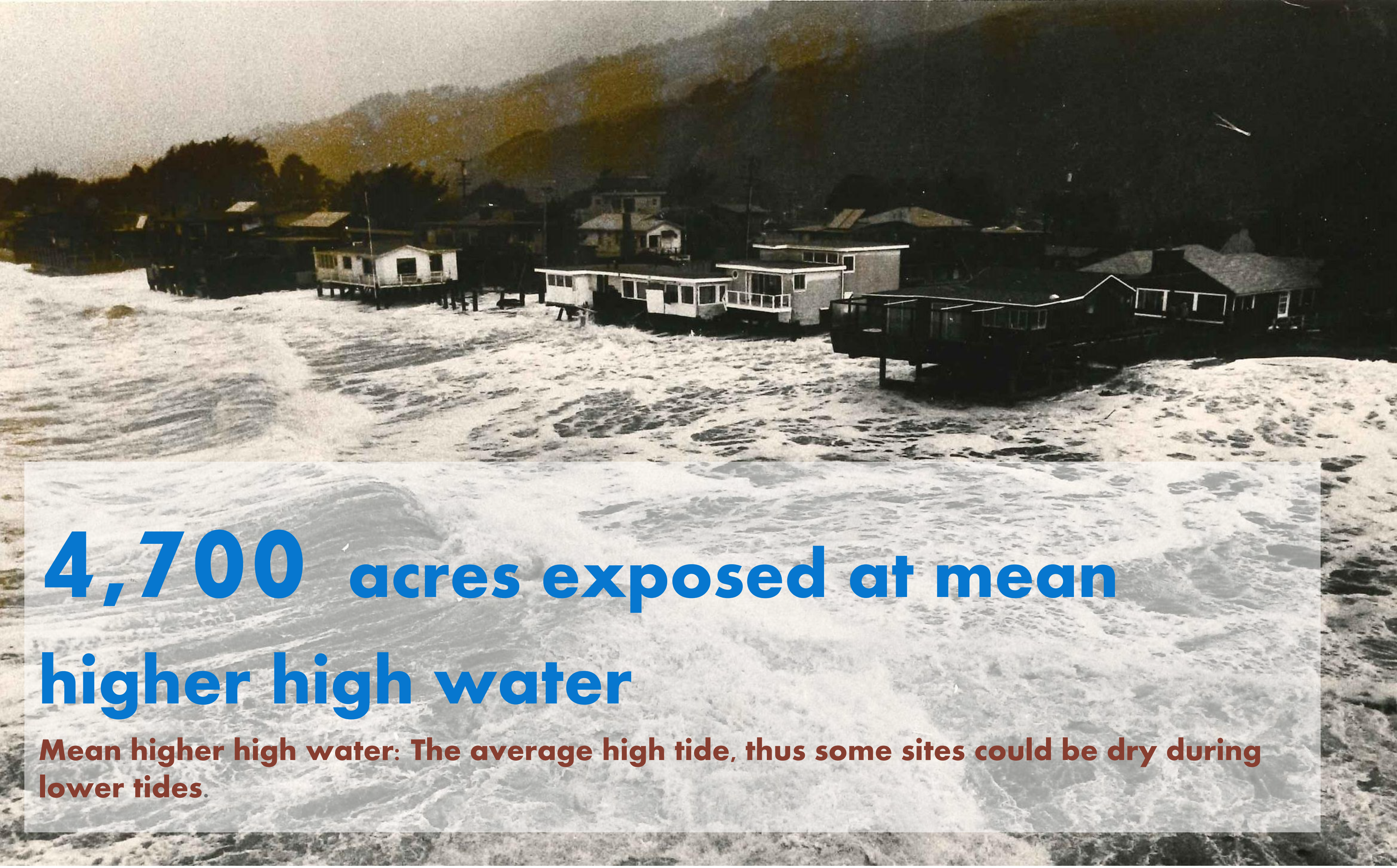


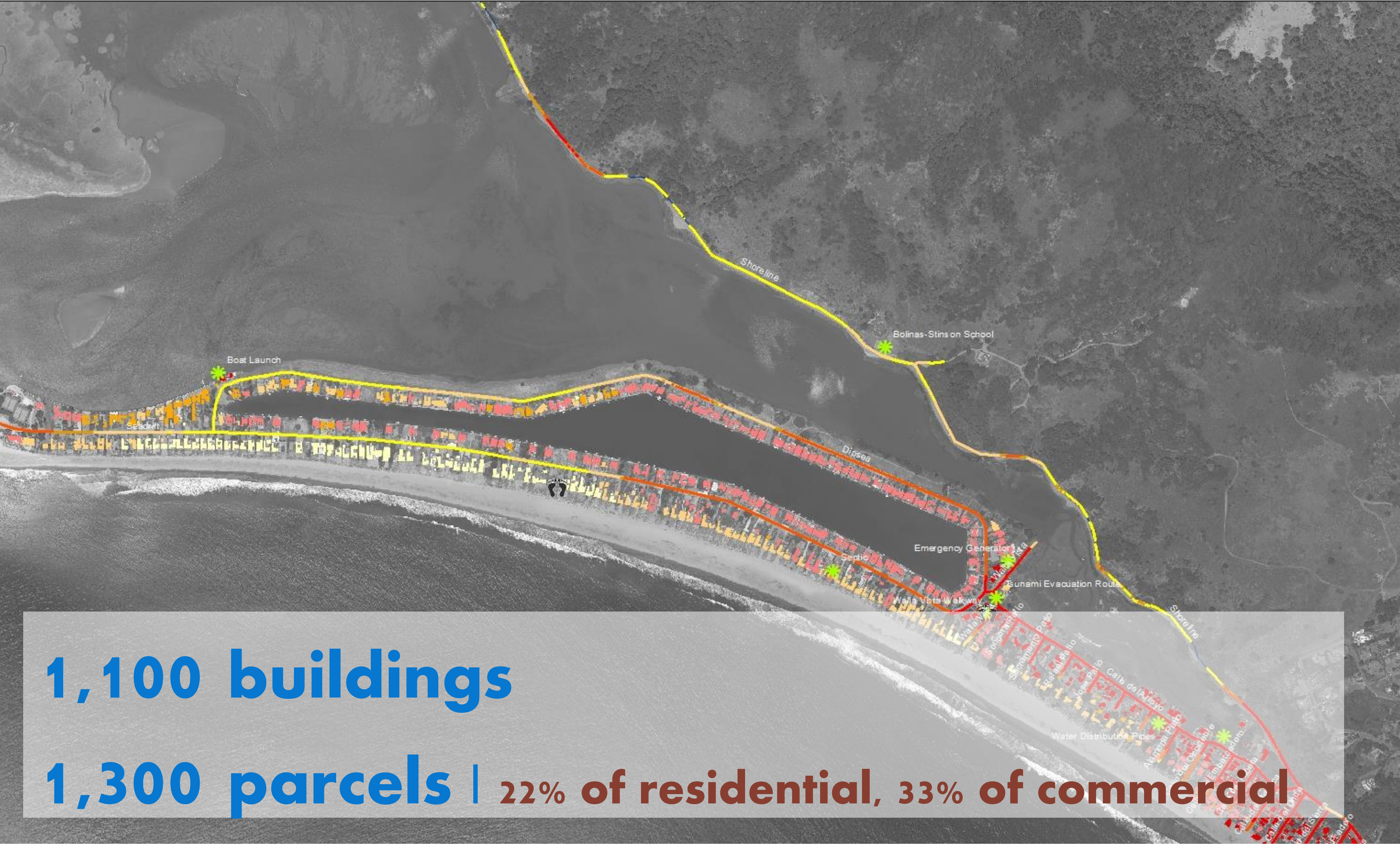
Vulnerability Assessment Sections

- Asset Profiles
  - Key Issues
  - Short-, Med-, and Long-term assessment with figures and tables
  - Maps by community
  - Other Considerations: Economic, Environmental, Equity, Management
- Community Profiles
  - Key Issues
  - Vulnerable Assets by Asset w/ figures and tables
  - Maps for developed and natural resource assets

Our Coast Our Future Online Viewer

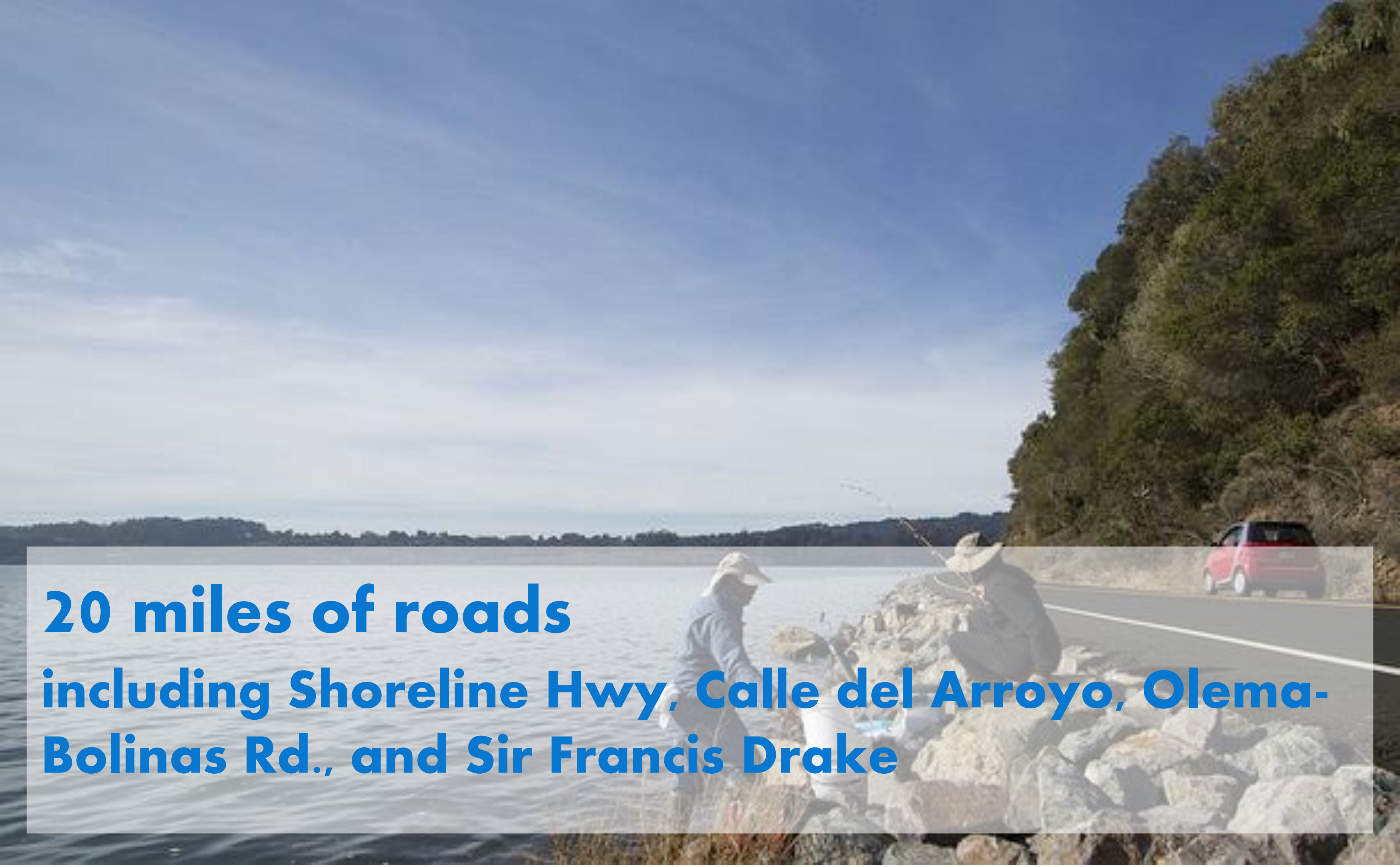



4,700 acres exposed at mean higher high water
Mean higher high water: The average high tide, thus some sites could be dry during lower tides.



1,100 buildings

1,300 parcels | 22% of residential, 33% of commercial



20 miles of roads

including Shoreline Hwy, Calle del Arroyo, Olema-Bolinas Rd., and Sir Francis Drake

Beaches could flood and erode

Marshes could convert to mud flats, and may move upland

Richardson Bay Shoreline Study and the Game of Floods

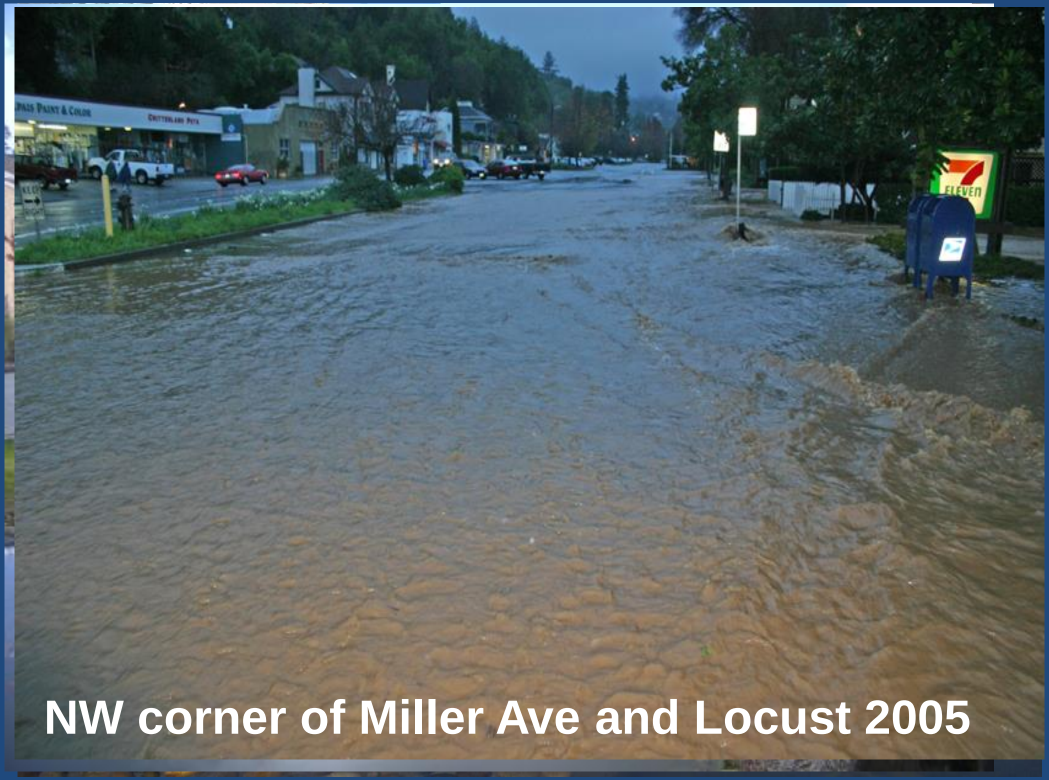
Roger Leventhal, P.E.
Senior Engineer
Marin County FCD

Miller Ave King Tide 2012

Mill Valley Shoreline

Planning for Richardson Bay

- Currently floods on "King" tides
- Flooding from both ends (river/tidal)
- SLR Impacts to everything…
  - infrastructure flooding
  - residential/commercial
  - roads/utilities
  - wetlands
  - public access/users


NW corner of Miller Ave and Locust 2005

Shoreline Study- Part I

Part I – Vulnerability Assessment (what is impacted)

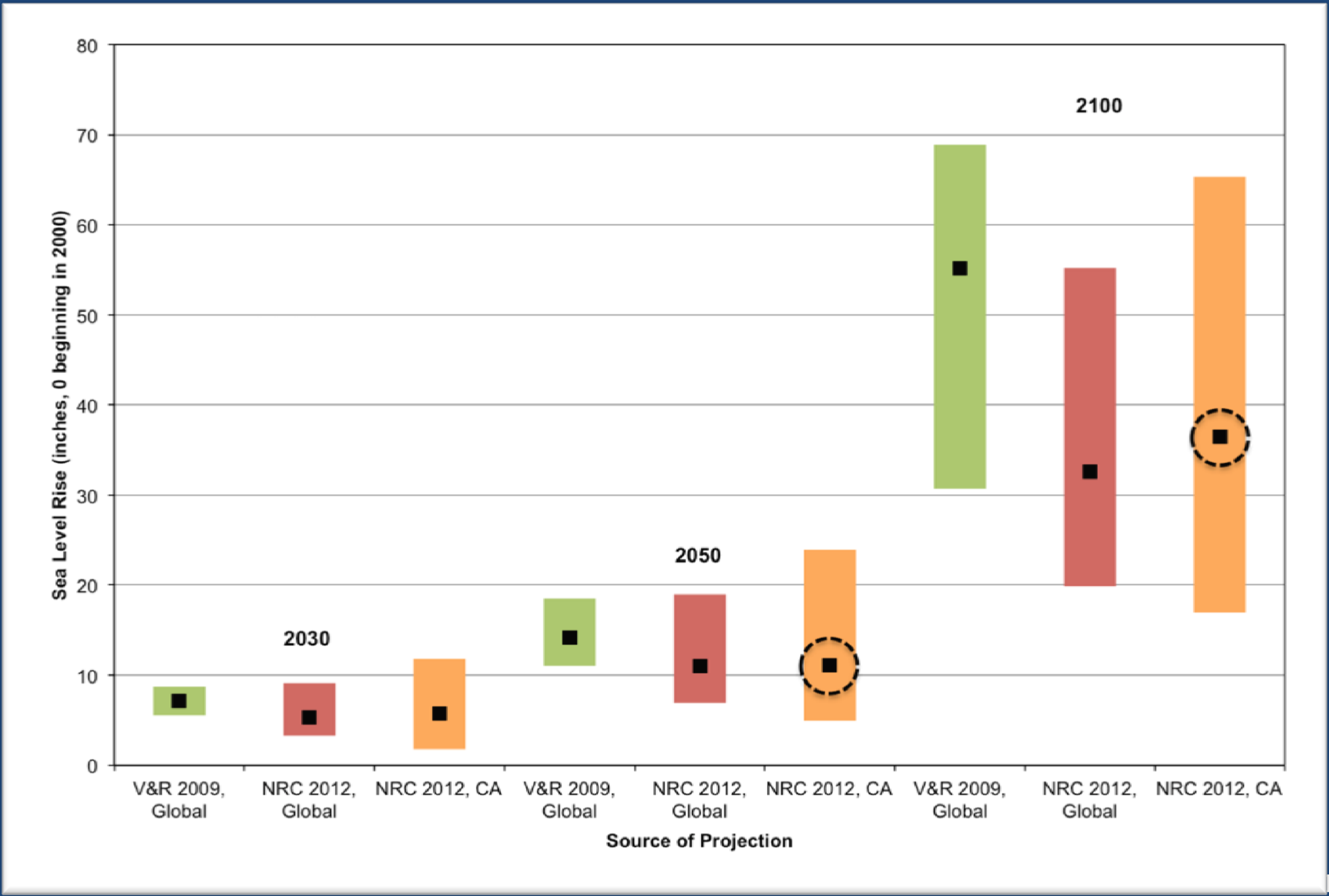
- What is flooded under 3 future SLR scenarios (1, 3 and 5 feet)?
- Adds up impacted assets and rough costs
- SLR added onto MHHW (not storm tides)
- Mapped impacted assets from MarinMap

Shoreline Study- Part II

Part II – Adaptation Options

- Describes adaptation options (pros/cons, $) – focus on engineering barrier options
- Presents different alignments to inhibit daily tides (protects built edge)
- Adds up concept level costs (min/max)
- Discusses impacts and limitations

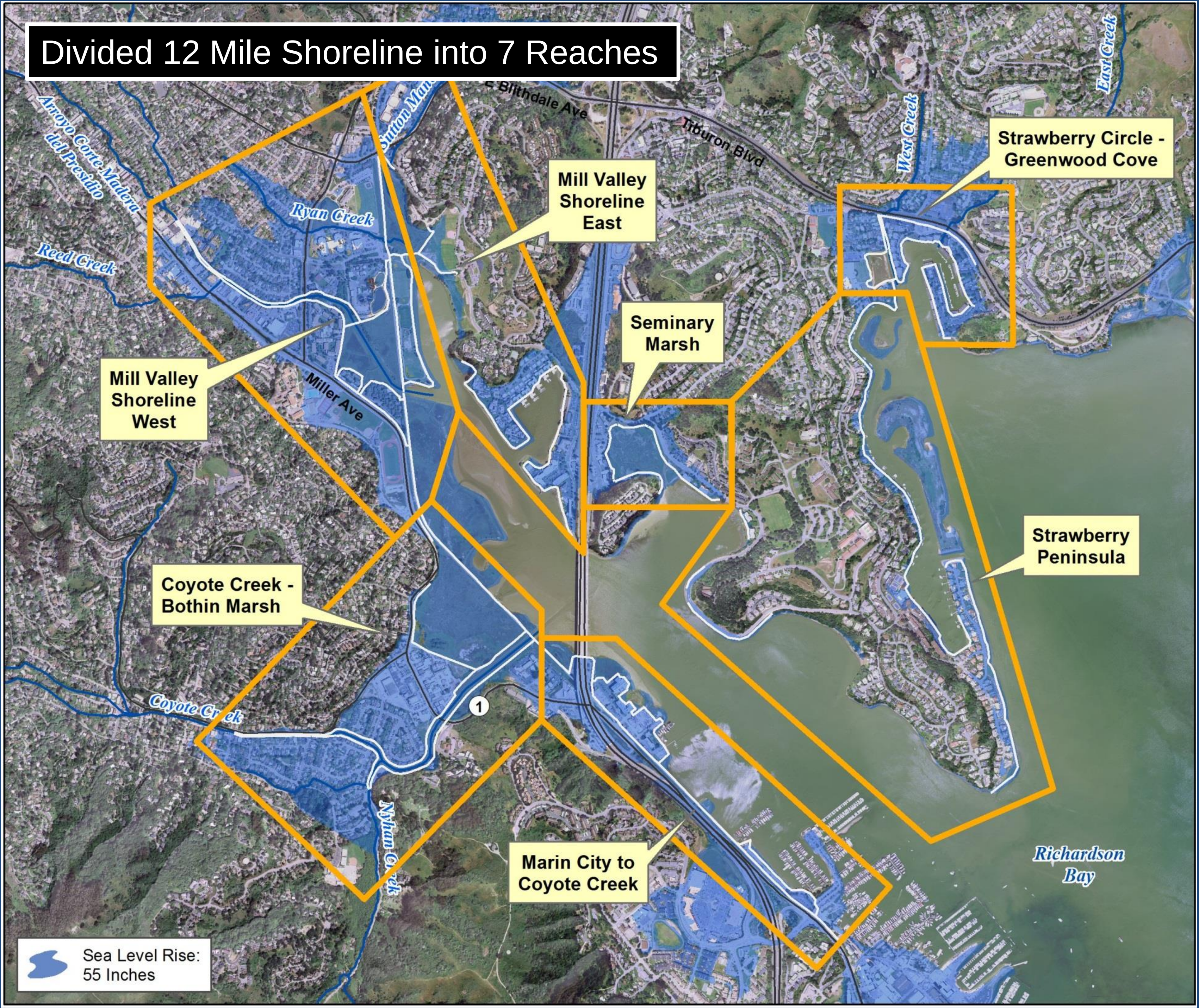
Various SLR Studies



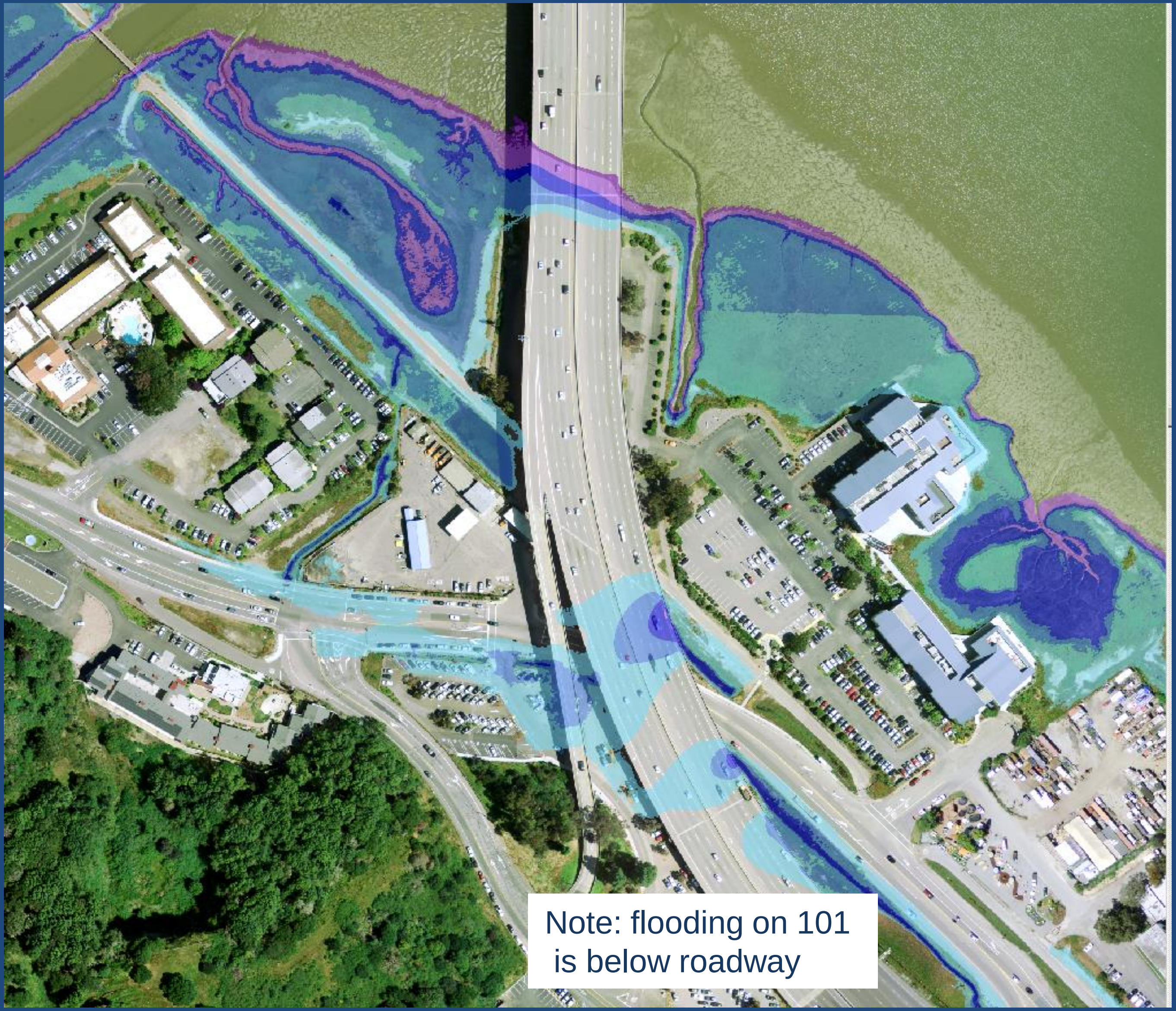
Projections – NRC 2012

	from NRC 2012 for Northern California		
year	Range low (in)	Mean (in)	Range high (in)
2030	1.7	5.7	11.7
2050	4.8	11.0	23.9
2100	16.7	36.1	65.5

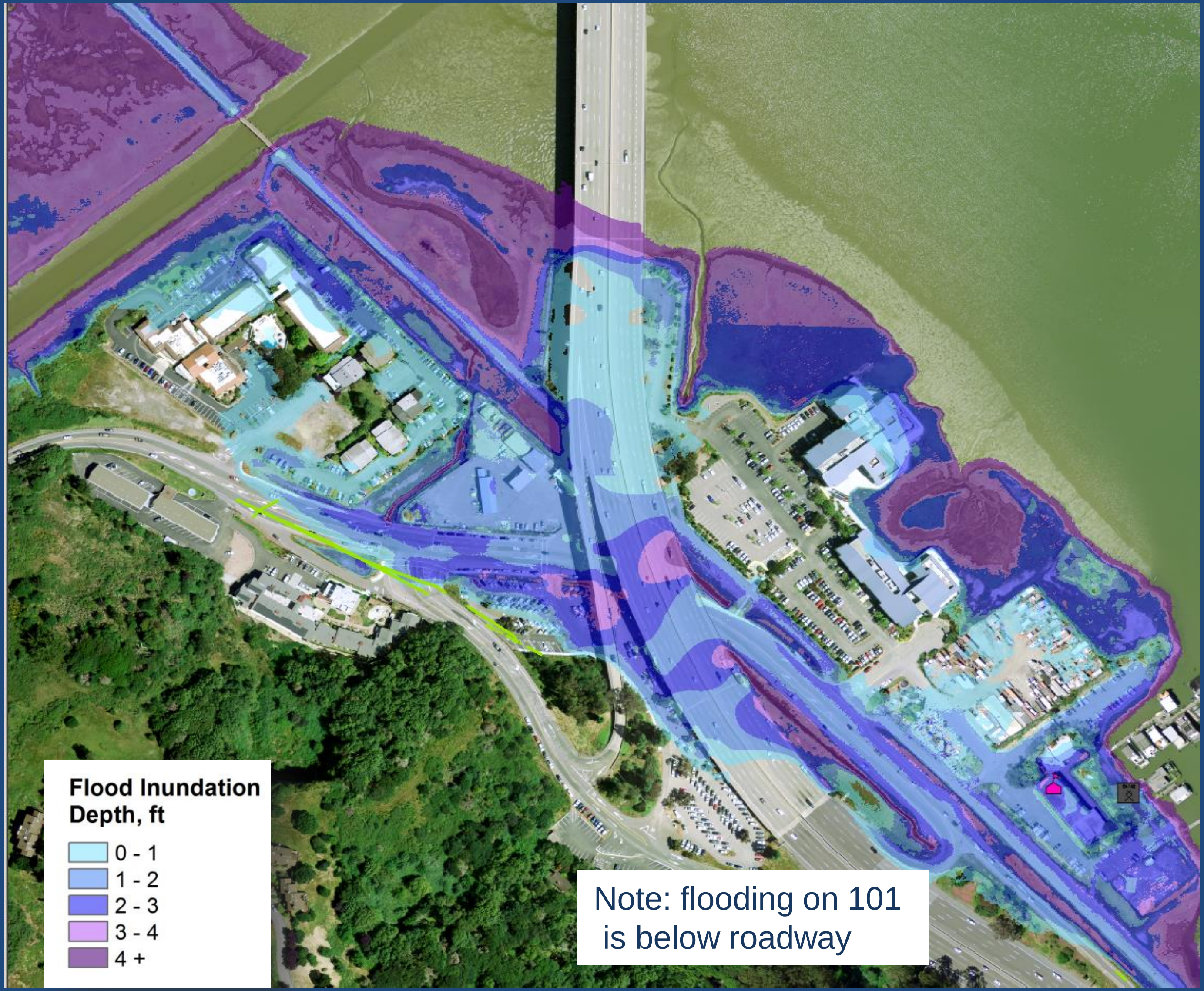
Divided 12 Mile Shoreline into 7 Reaches



Manzanita "King Tide" Flooding



Manzanita 36-inch Flooding



Miller Avenue

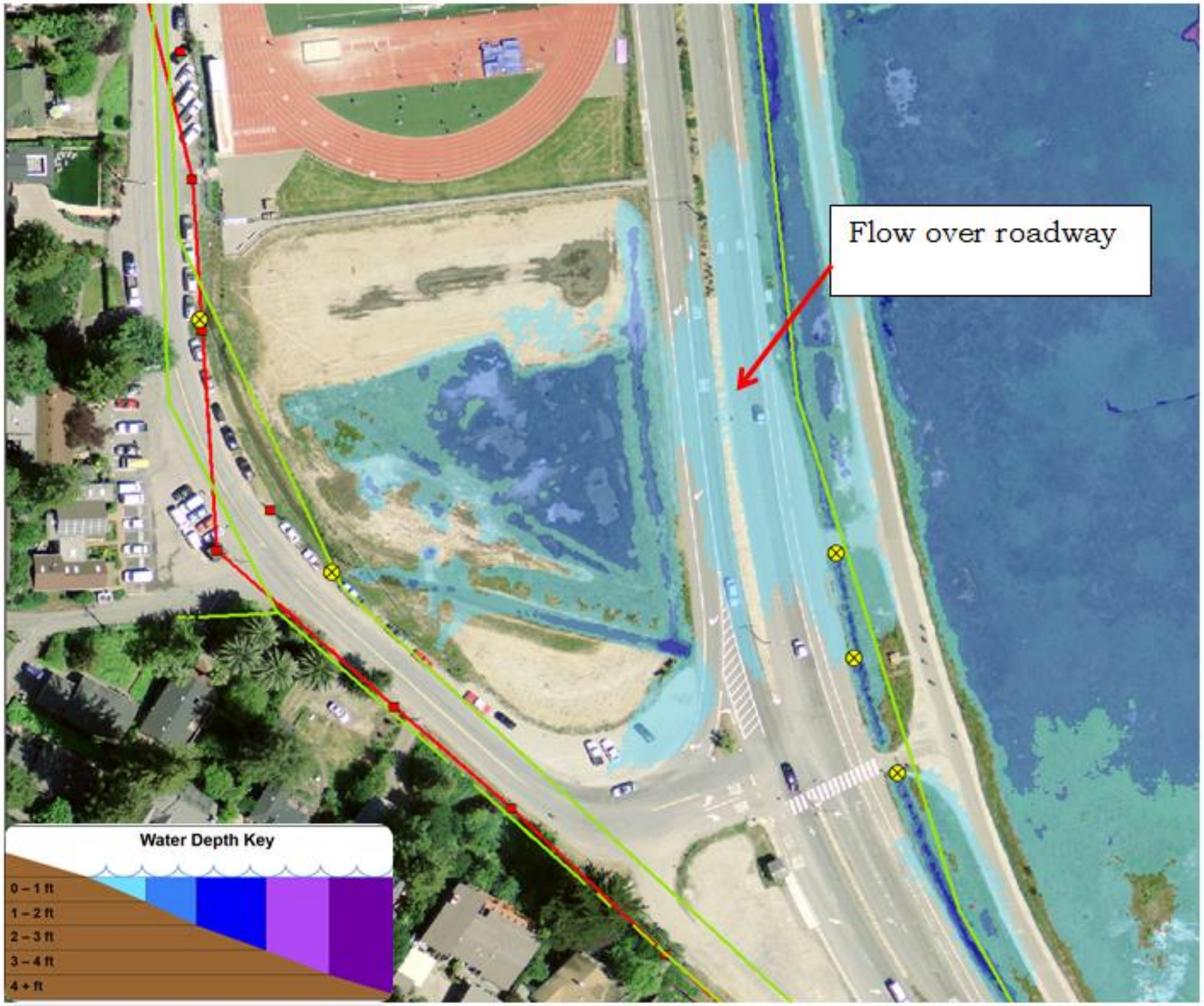
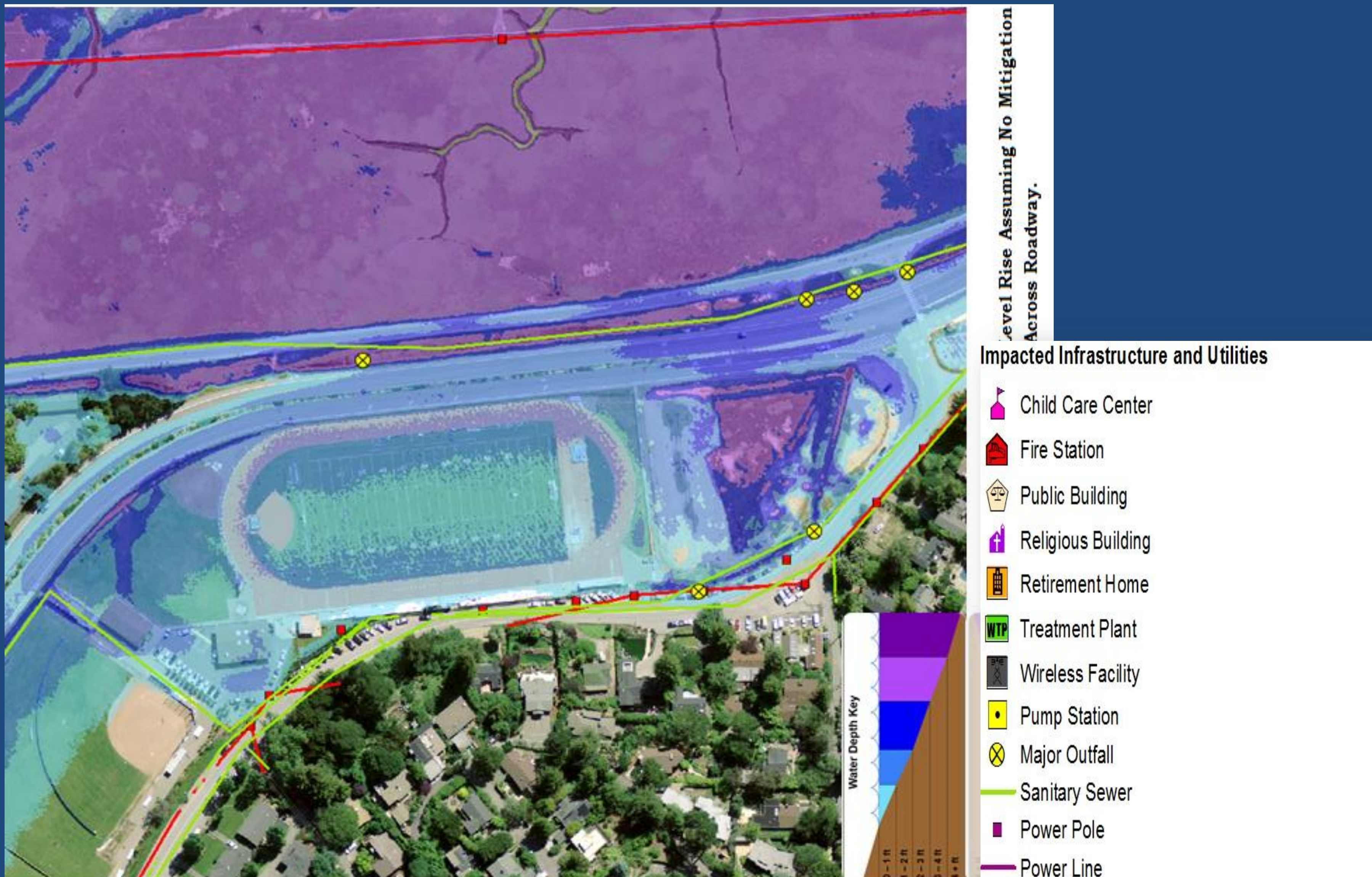


Figure 26: Flood Focus Figure Miller Avenue at Tam High. 12 Inch Sea Level Rise.

Mill Valley 36 inches SLR



Added Up Parcel Tax ID Impacts

SLR Scenario	Count	Land Value	Improved Value	Total Value[7]
Parcels intersecting 1 foot SLR	394	$187,592,105	$211,296,297	$398,888,402
Parcels intersecting 3 feet SLR	889	$371,298,461	$366,134,667	$737,433,128
Parcels intersecting 5 feet SLR	1545	$649,217,099	$636,736,662	$1,285,953,761

[illegible]	[illegible]	[illegible]	[illegible]
Park And Ride Lot	1	3	3
Pump Station	1	7	7
Religious Facility	0	0	1
Wireless Facility	1	3	5

Major Adaptation Strategies

Protect

- HARD
  - Build dikes, seawalls (armoring)
  - Install tide gates (small/large)
  - Raise grades
  - Increase pumping
- SOFT
- Natural beach systems
- Tidal wetlands
- Horizontal levees

Manage Retreat

- Land and structure acquisition /relocation
- Building/Planning code and regulation changes
- Allow erosion /migration of natural areas (phasing)

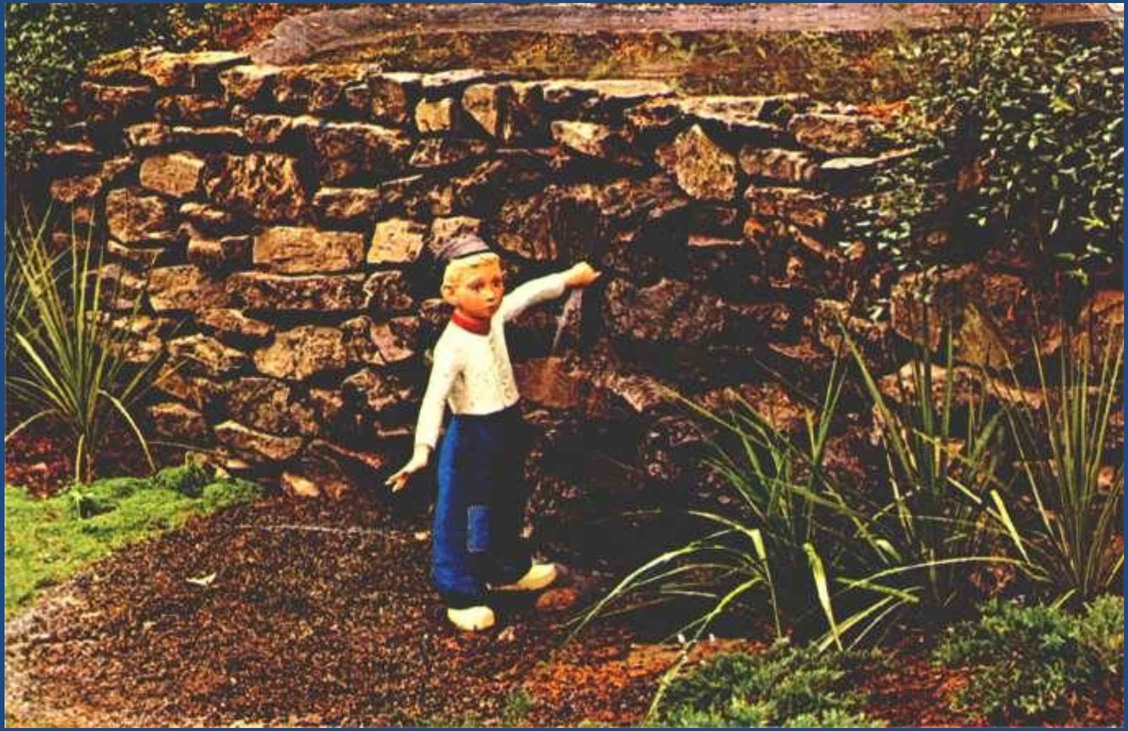
Accommodate

- Elevate buildings and infrastructure
- Floodproof critical structures
- Floodable buildings/tiered developments

…and combinations of any above

Famous adaptors throughout history…

Dutch Boy built protection



Moses implemented phased managed retreat

Noah went for accommodation (floodable structures)

Part II: Major Adaptation Strategies

Hard

- Flood/sea walls
- Levees/dikes
- High tide gates
- Rock Rip-rap

Soft

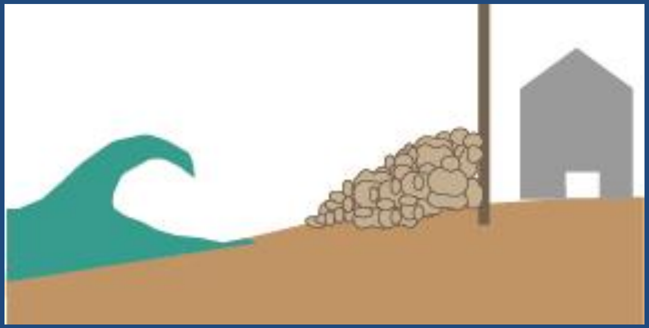
- Wetlands creation/enhancement
- Engineered beaches shoreline
- T-zone creation

Infrastructure/ Lifestyle

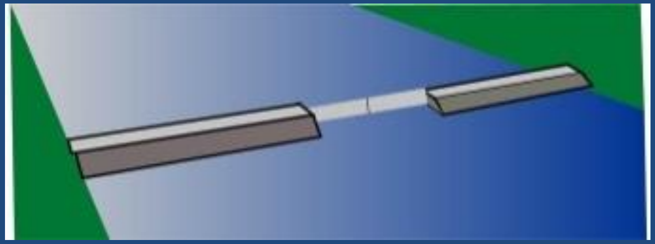
- Elevate structures
- Raise grades
- Lifestyle adaptation
- Zoning changes
- Planned retreat

1.
PROTECT
Hard (Traditional) Engineering

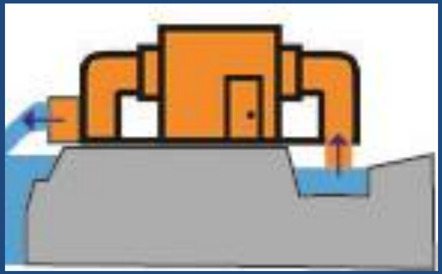
Traditional levee



Seawall/Revetment



Tide gate



Flood wall & Pump station

Seawall

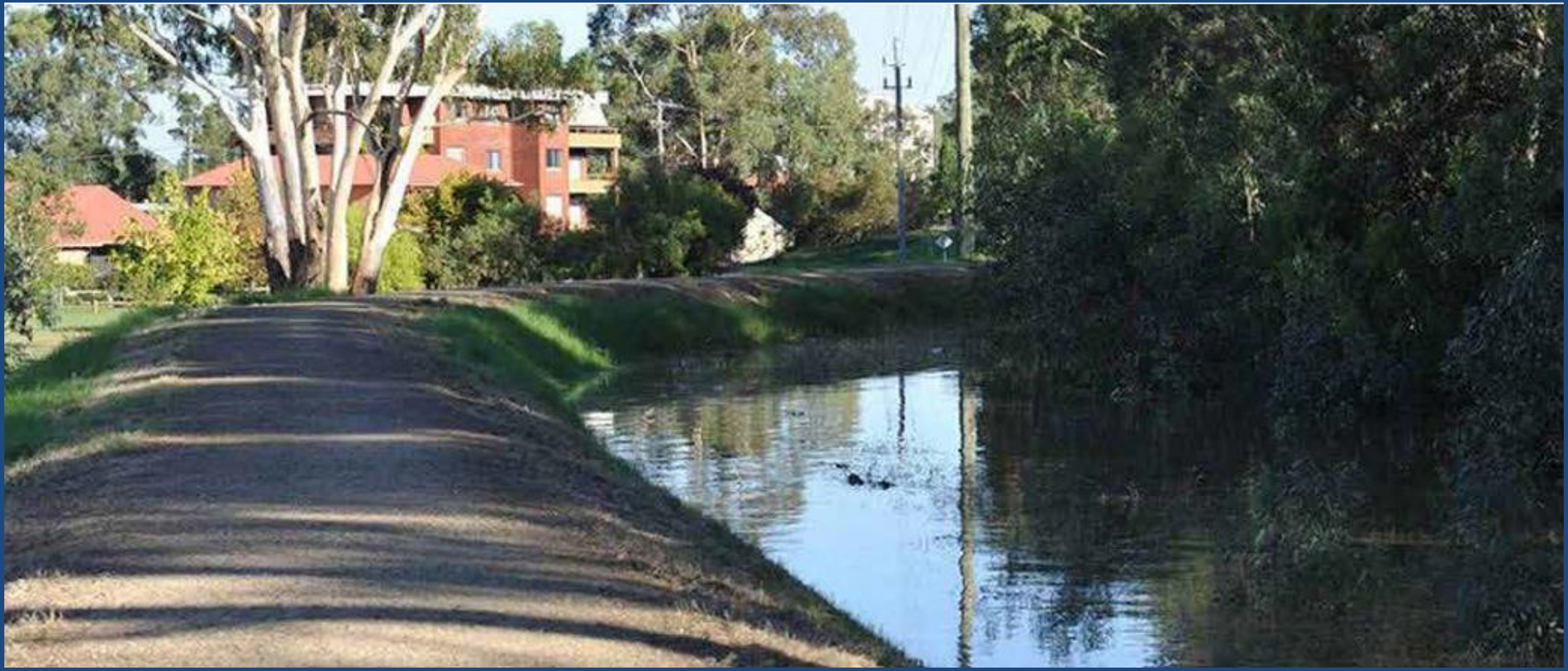
Pros: Limited ROW required
Cons: Cost, Impacts

Bulkhead seawall in Seadrift neighborhood

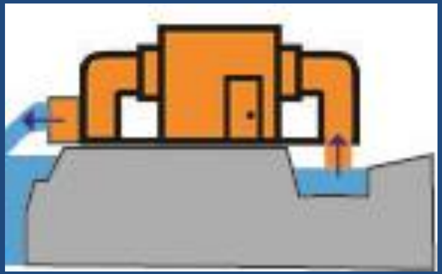
Westhoff

Levee

Pros: Stability if maintained, Cost lower then wall
Cons: Large ROW required

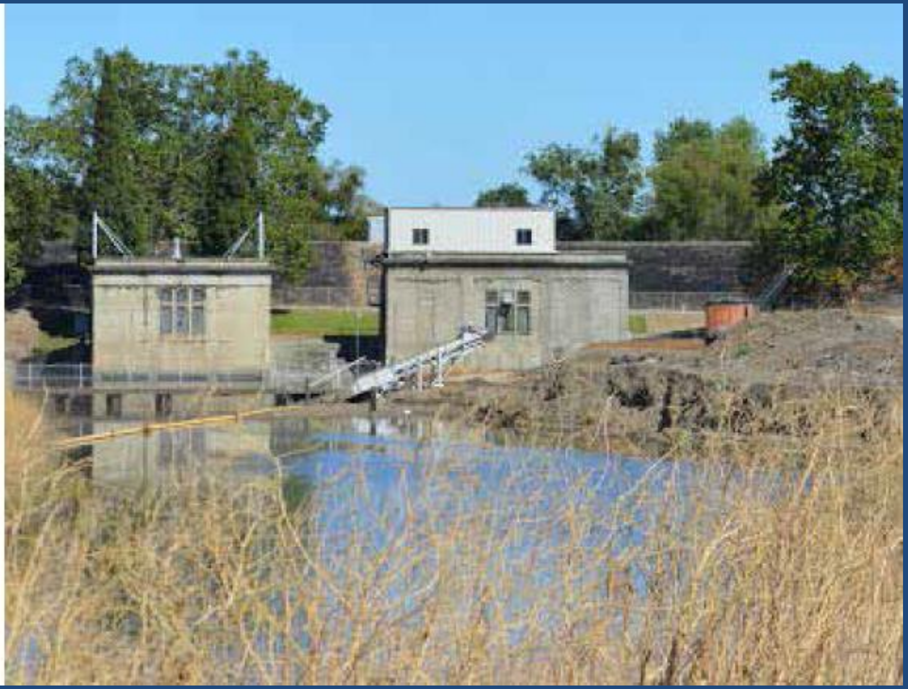


Flood wall & Pump station



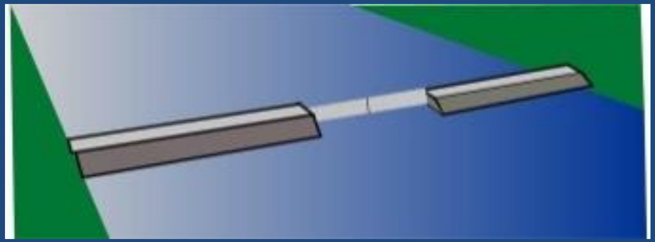
Pros: Lower ROW than levees

Cons: Capital and maintenance costs



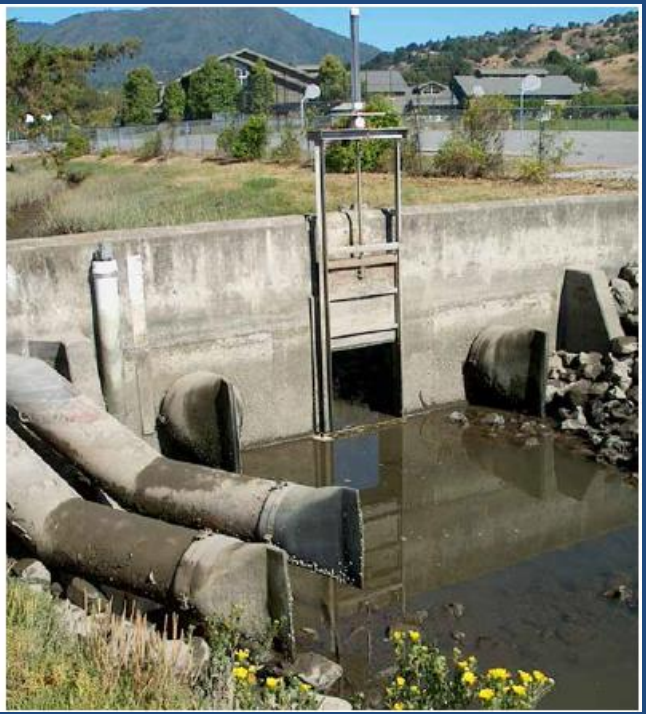
Holland and Germany Large Gates…

Tidal gate



Pros: Temp solution to tidal riverine flooding

Cons: Cost, limited effectiveness over time




101
Richardson
Bay Bridge
Tidal Barrier
1
Richardson
Bay
"Folding Water™"

Major Adaptation Strategies

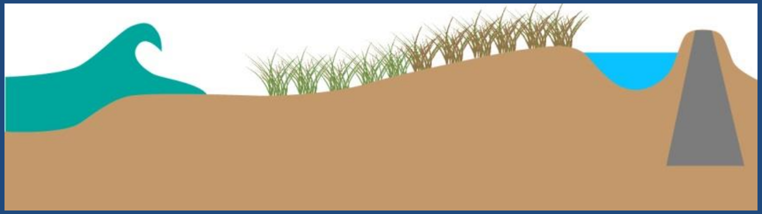
Hard
- Flood/sea walls
- Levees/dikes
- High tide gates
- Rock Rip-rap

Soft
- Ecotone Levees
- Wetlands creation/enhancement
- Engineered beaches shoreline

Infrastructure/ Lifestyle
- Elevate structures
- Raise grades
- Lifestyle adaptation
- Zoning changes
- Planned retreat

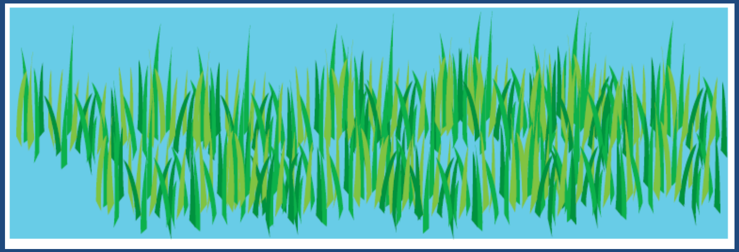
1. PROTECT

Soft (Nature-based) Engineering

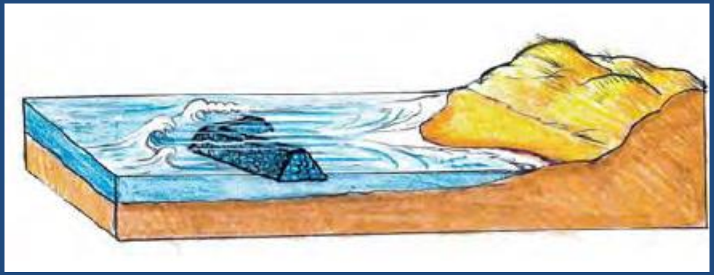


Horizontal levee

Dune restoration & Beach maintenance

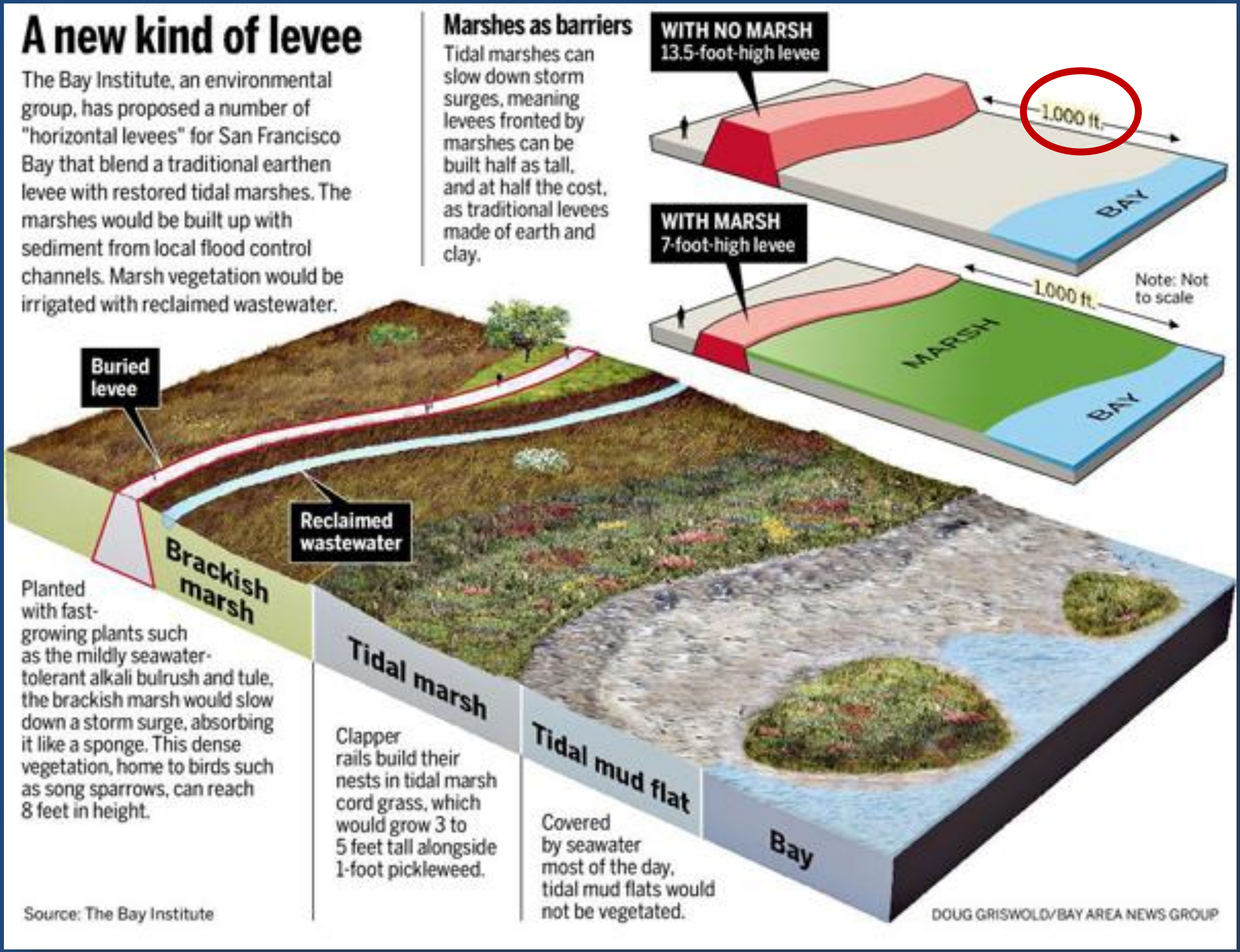


Wetland/ shoreline vegetation

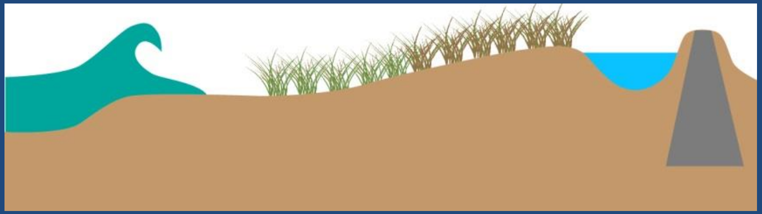


Offshore structure

Horizontal "Eco" Levee

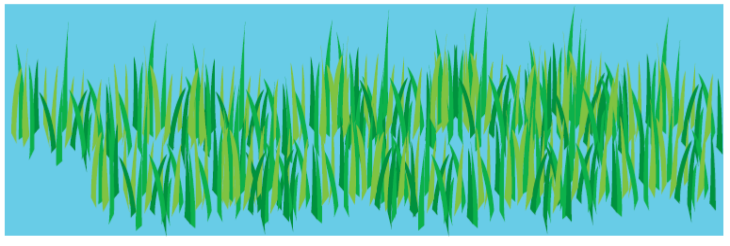


Horizontal levee



Pros: Uses landscape to attenuate waves, provides habitat
Cons: Cost for earthwork, larger ROW

Wetland/ shoreline vegetation

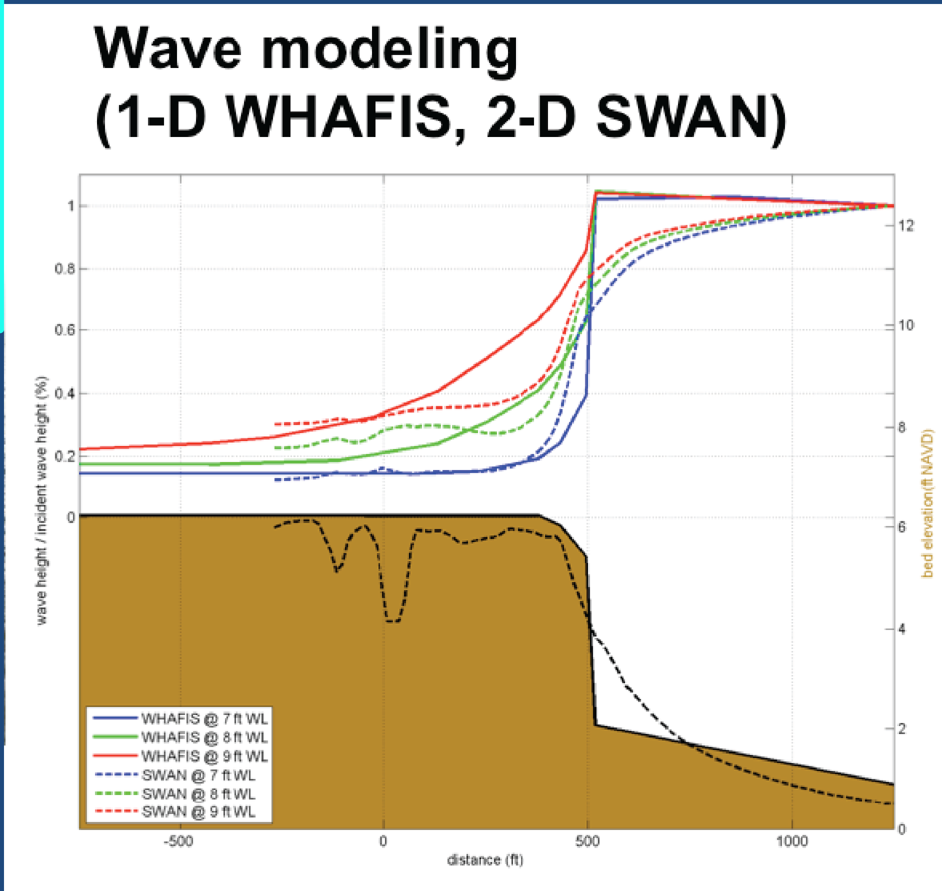


Pros: Habitat improvement and flood reduction

Cons: Large ROW required

Giacomini Wetland Restoration, 2008

Tidal Wetlands and Eco Levees



Dune Restoration & Beach Maintenance

Pros: Recreation and flood reduction benefits
Cons: Costs for replenishment

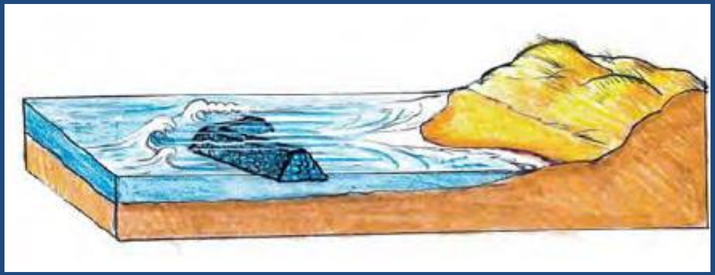
Engineered Bay Beach
Spring-Summer 2013 Aramburu Beach

Winter storm gravel and shell berm persists

Sand beachface slope accretes, steepens

Sand partially buries winter storm berm

Offshore structures

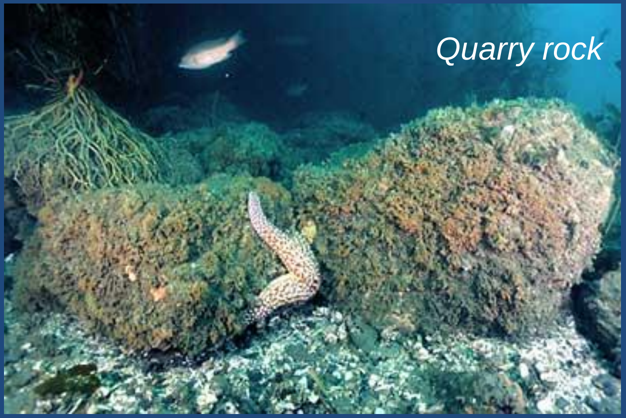


Pros: Reduces waves impacts – more when structure is higher

Cons: Costs to construct, maintain and limited effectiveness for SLR

San Clemente artificial reef experiment


Concrete


Quarry rock

Major Adaptation Strategies

Hard

- Flood/sea walls
- Levees/dikes
- High tide gates
- Rock Rip-rap

Soft

- Wetlands creation/enhancement
- Engineered beaches shoreline
- T-zone creation

Infrastructure/ Lifestyle

- Elevate structures
- Raise grades
- Lifestyle adaptation
- Zoning changes
- Planned retreat

2. ACCOMMODATE

New floodable development

Elevate buildings

New/elevate road

Elevate buildings

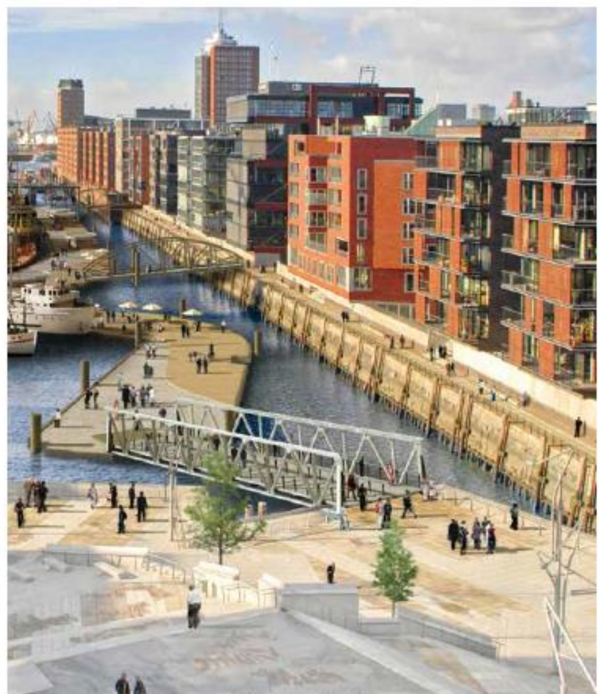
Pros: Effective for storm flooding

Cons: Costs, not effective for permanent tidal flooding

Floodable development

Pros: Potential solution that generates revenue

Cons: Impacts from more development – higher density to pay for costs


New/elevate road

Pros: Protects roads when designed correctly

Cons: Very high cost, ROW

3. RETREAT

Retreat

Rebuild here

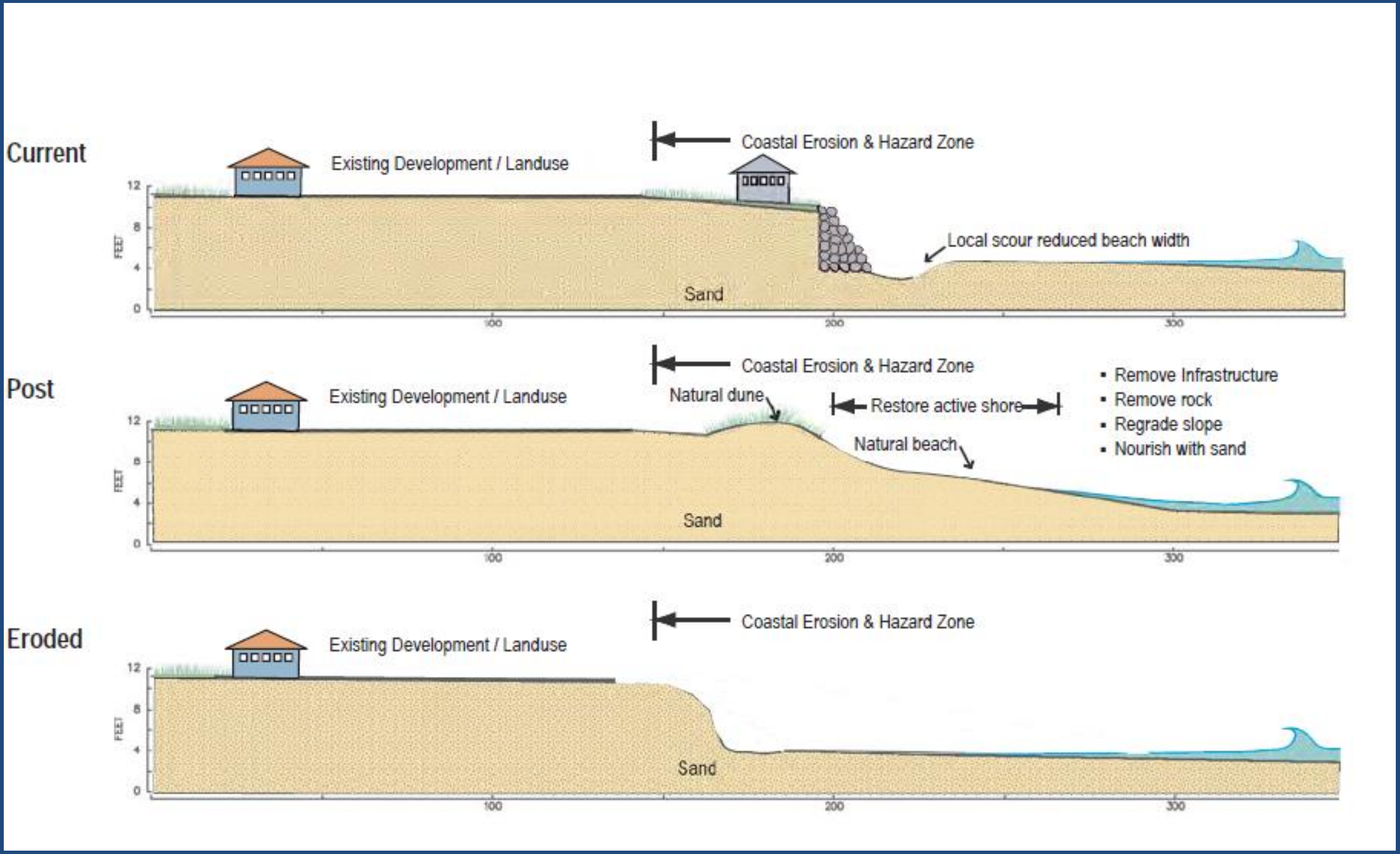
Post-storm prohibitions

Stricter land use zoning

Managed Retreat

Pros: Lower costs if no buyout

Cons: Costs for buy-out and community impacts, new infrastructure



Post Storm Restrictions and Stricter Land Use Zoning

- No or restricted rebuilding after storms?
- Rolling easements
- Extra technical studies
- Use of stricter codes (FEMA V)

Richardson Bay Shoreline Study

Evaluation of Sea Level Rise Impacts and Adaptation Alternatives

Roger Leventhal, P.E.
Senior Engineer

PUBLIC REVIEW DRAFT

October 14, 2015***

Limit of Direct Coastal Flood Barrier Alignments

- Evaluated several alignments to inhibit direct coastal flooding (not a CIP design list)
- Added up public versus private ROWs
- Added up costs for various hard versus soft engineering adaptation alternatives

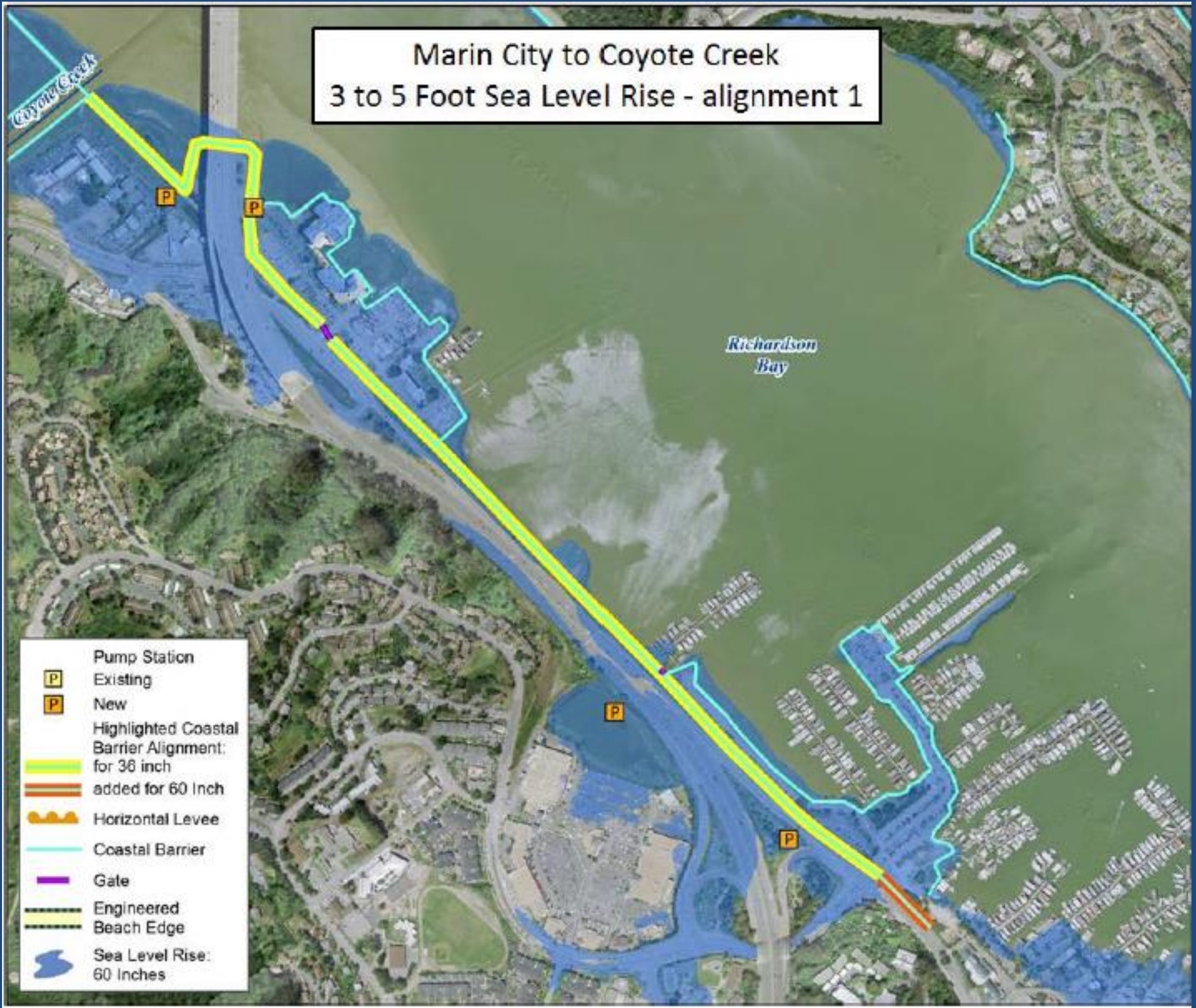
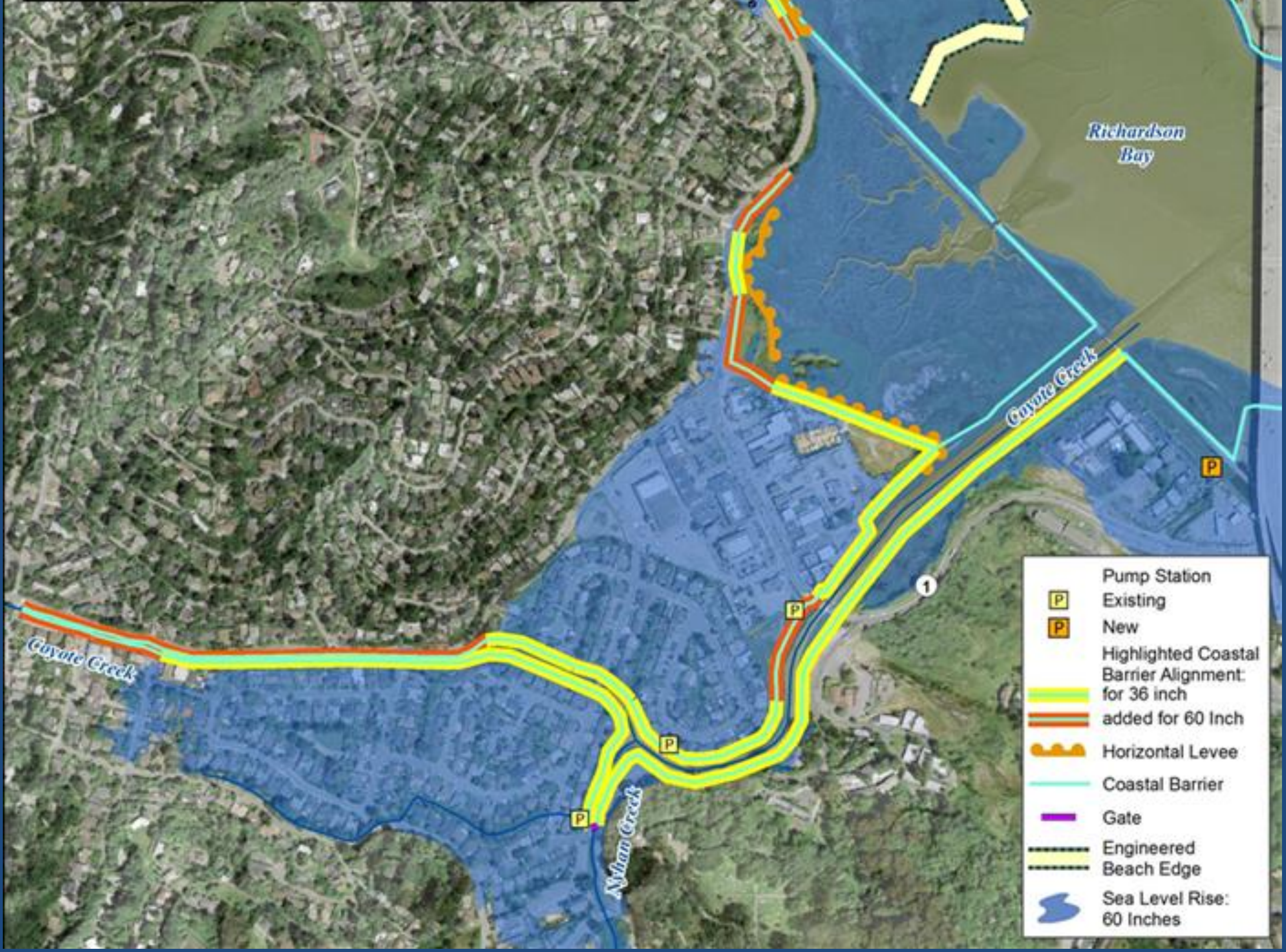


Figure 40: Reach 1, Alignment 1. 36 and 60 Inch Sea Level Rise LDCF Alignment (60 Inch Sea Level Rise Extensions In Red).


Coyote Creek – Bothin Marsh
1 Foot Sea Level Rise - alignment 1
Miller Ave
Richardson Bay
Coyote Creek
Coyote Creek
Nyhan Creek
1
Pump Station
Existing
New
Highlighted Coastal Barrier Alignment
Horizontal Levee
Coastal Barrier
Gate
Engineered Beach Edge
Sea Level Rise: 12 Inches

Coyote Creek – Bothin Marsh
3 to 5 Foot Sea Level Rise - alignment 1



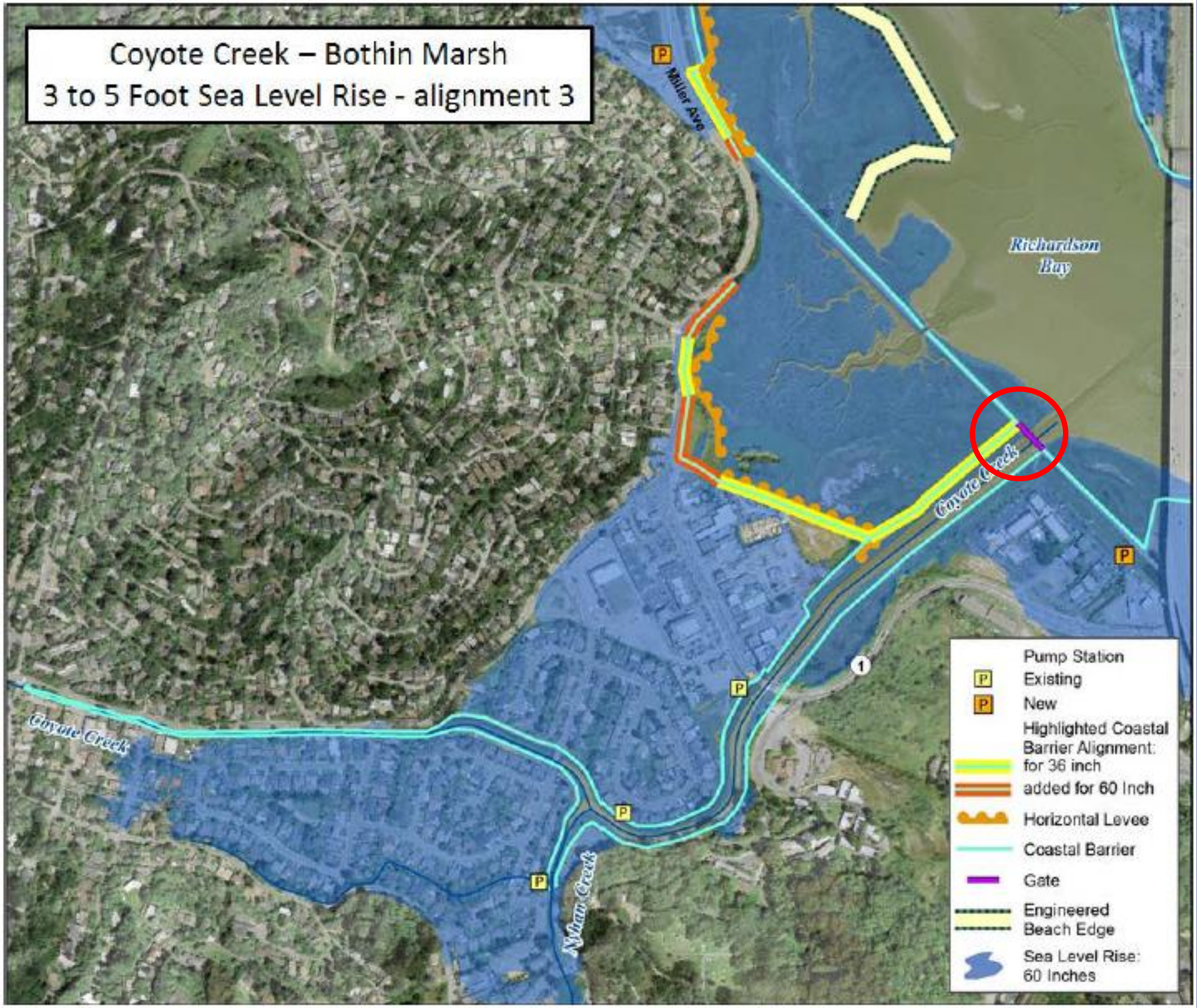
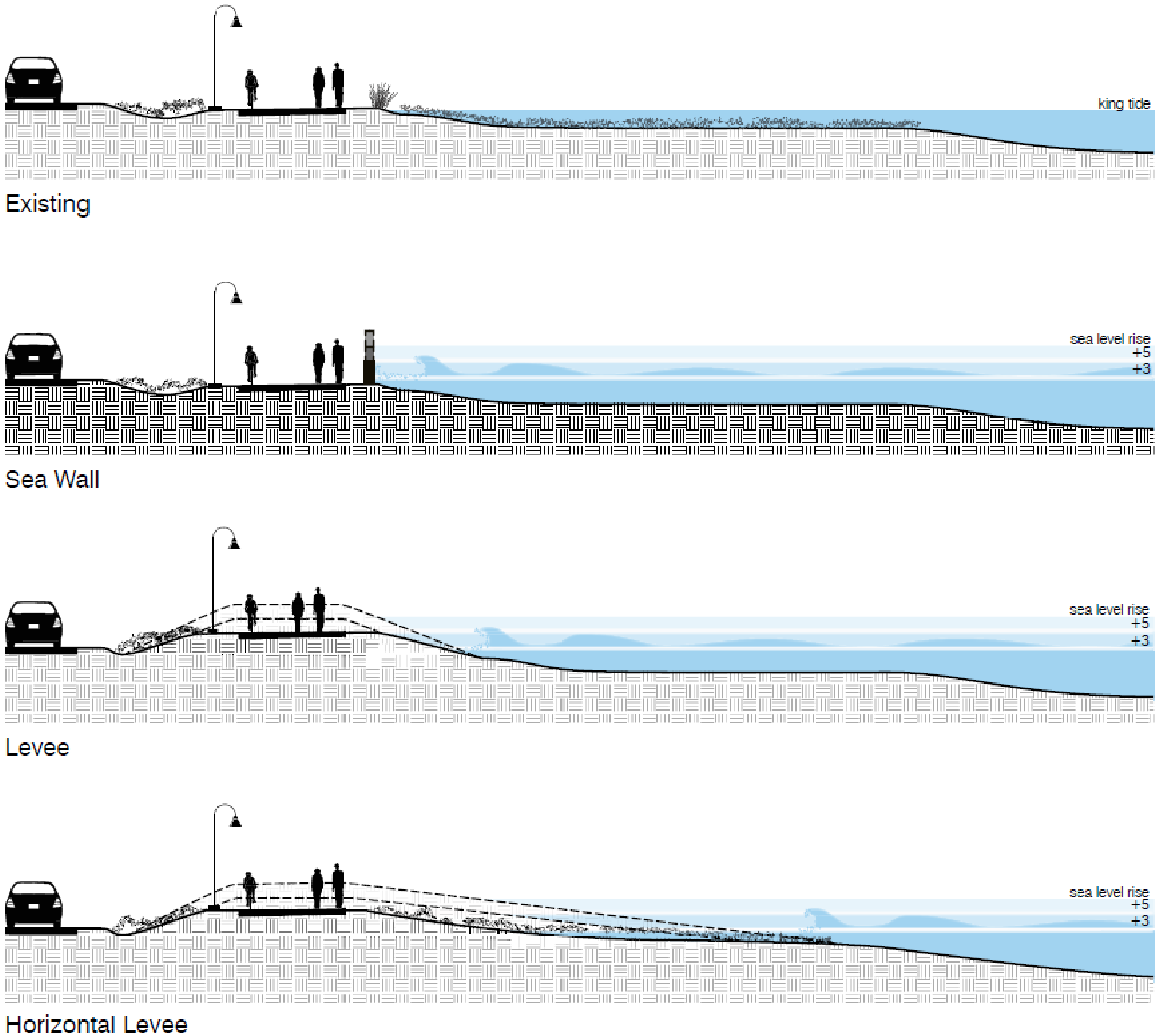


Figure 44: Reach 2, Alignment 3. 36- and 60- Inch LDCF Alignments.

Table 17. Reach 2, Coyote Creek-Bothin Marsh Barrier Lengths (36 Inch Sea Level Rise).

Reach	Length Public ROW (feet)	Length Private ROW (feet)	Total Length (feet)	Number of Hydraulic Gate Structures
Alignment 1	5,675	4,006	9,681	1
Alignment 2 – protects bike path Requires mitigation for wetlands impacts	8,017	3,267	11,284	2
Alignment 3 – high tide barrier at creek mouth	1,697	738	2,435	1 (major tide gate across mouth of Coyote Creek)



Southern Marin Sea Level Rise Diagrams

Restoration Design Group 07.02.15

Figure 6: The costs of flood protection in the Bay Area

The costs of flood protection vary by strategy. Generally, seawalls and levees bring additional costs, such as increasing erosion and removing habitat, while wetlands bring numerous additional benefits, including enhancing habitat and sequestering carbon.

Type of protection	Range of costs from Bay Area projects (in year 2000 dollars)	Maintenance costs
New levee	\$725–\$2,228 per linear foot	10% annually
Raised/upgraded levee	\$223–\$1,085 per linear foot	10% annually
New seawall	\$2,646–\$6,173 per linear foot	1–4% annually
Restored tidal marsh	\$5,000–\$200,000 per acre	unknown

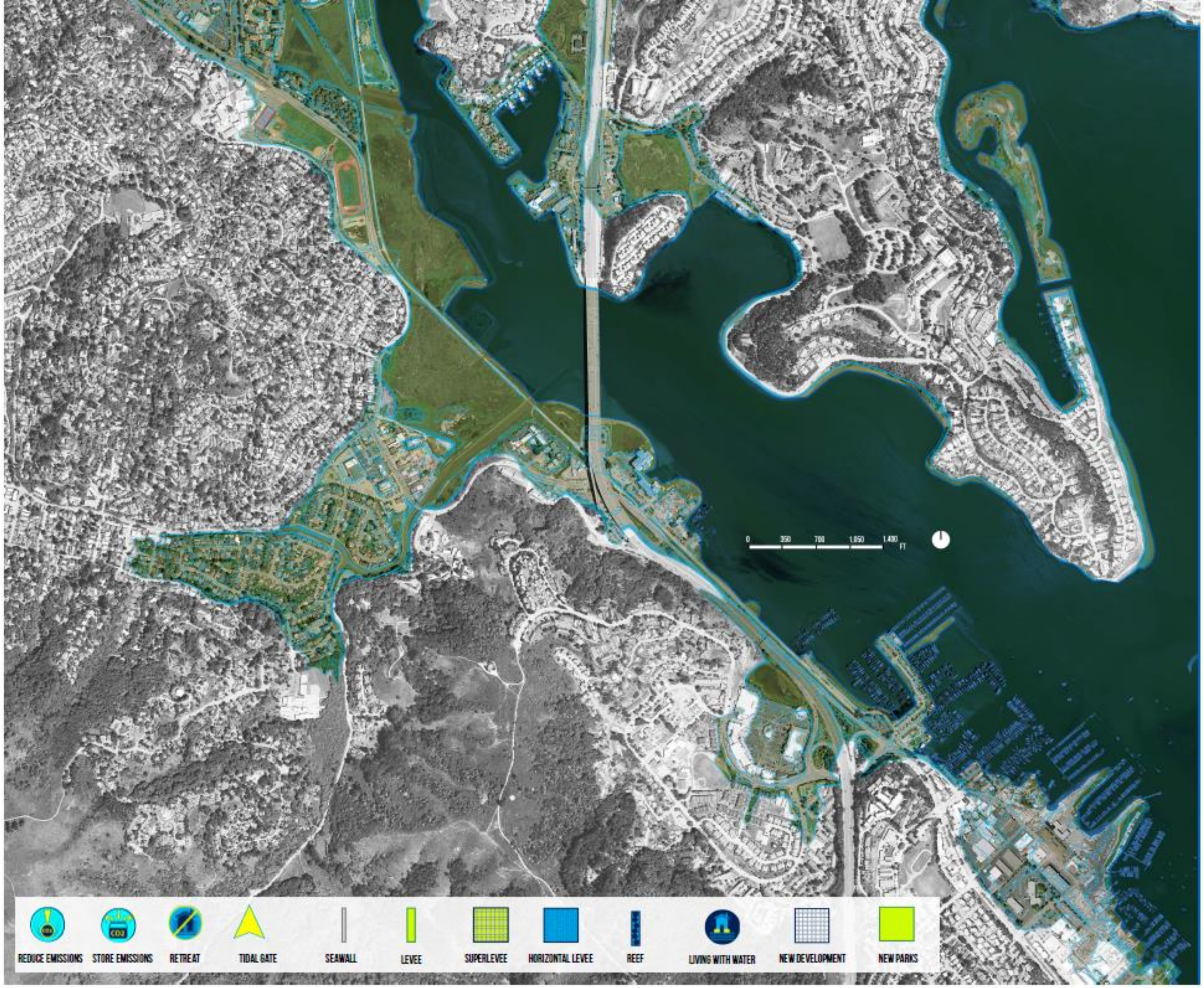
Table 36. Unit Capital Costs for 12 Inch Sea Level Rise Alternatives.

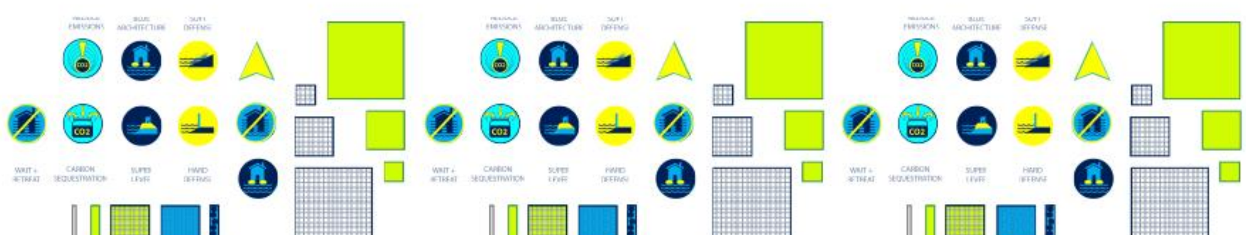
Adaptation Option	*MASTER COSTS for 12-INCH SLR*		*Notes*
	low estimate	*high estimate*	
flood/sea walls – good foundation soils (per foot)	$ 150	$ 300	based on published unit costs - not adjusted for actual wall height
flood/sea walls – poor foundation soils (per foot)	$ 200	$ 500	based on published unit costs - not adjusted for actual wall height
berms and levees – good foundation soils (per foot)	$ 150	$ 200	based on published costs
berms and levees – poor foundation soils (per foot)	$ 180	$ 250	based on published costs
new or expanded pump stations (each)	$ 500,000	$ 1,100,000	based on engineering experience
rock rip-rap (per foot)	$ 80	$ 100	based on published costs
wetlands enhancement (acre)	$ 50,000	$ 80,000	assumed costs based on engineering experience and SFBJV datbase of wetland projects
horizontal levee to attenuate waves (per foot)	$ 350	$ 500	see horizontal levee worksheet for assumptions
small culvert gate structures (each)	$ 400,000	$ 800,000	tide gate structures at small creek mouths - assumed costs based on engineering experience
tidal barrier structures at small creek mouth (each)	$ 1,000,000	$ 2,000,000	guesstimated assumed cost
natural beach enhancements at the shoreline edge (per foot)	$ 100	$ 150	assumed costs based on engineering experience at Aramburu

Note: Low end and high unit cost estimates are approximate for study comparison purposes and not based on site-specific design evaluations.

Retreat/Relocation not specifically evaluated

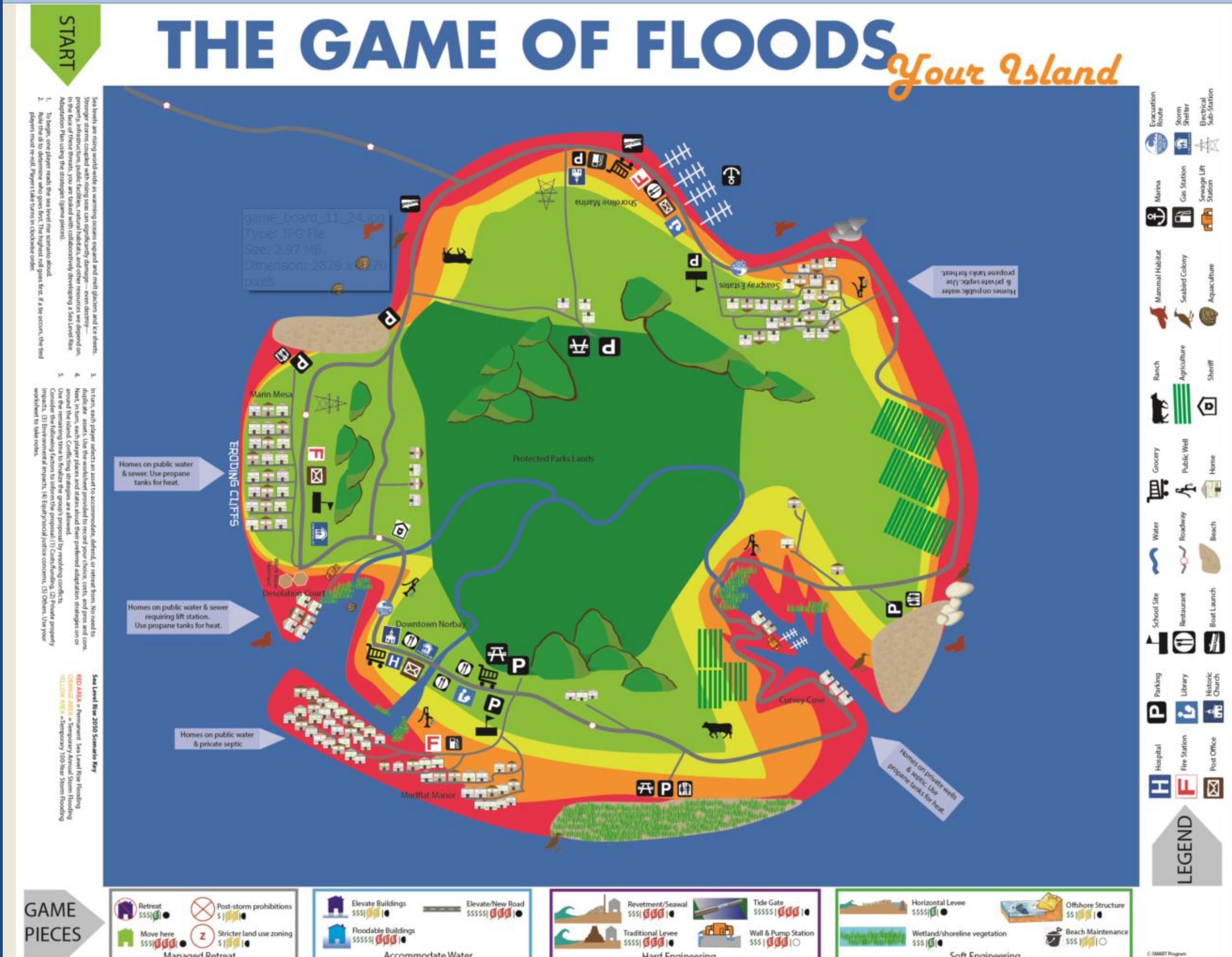
- Study protects the built edge
- Not possible for DPW to “retreat” areas
- Needs to be a result of planning efforts
- Always an alternative


0
350
700
1,050
1,400
FT
REDUCE EMISSIONS
STORE EMISSIONS
RETREAT
TIDAL GATE
SEAWALL
LEVEE
SUPERLEVEE
HORIZONTAL LEVEE
REEF
LIVING WITH WATER
NEW DEVELOPMENT
NEW PARKS


EMISSIONS
BLUE ARCHITECTURE
CARBON SEQUESTRATION
HARD DEFENSE


8
9
LEVEE
HORIZONTAL LEVEE
SUPERLEVEE
NEW PARKS
NEW WETLAND
REEF


① Spotted Owls (KD + VLO)


START
THE GAME OF FLOODS
Your Island
Shoreline Marina
Seaspray Estates
Homes on public water & private septic. Use propane tanks for heat.
Marin Mesa
ERODING CLIFFS
Homes on public water & sewer. Use propane tanks for heat.
Protected Parks Lands
Desolation Court
Homes on public water & sewer requiring lift station. Use propane tanks for heat.
Downtown Norbay
Homes on public water & private septic
Mudflat Manor
Curvey Cove
Homes on private wells & septic. Use propane tanks for heat.
Evacuation Route
Storm Shelter
Electrical Sub-Station
Marina
Gas Station
Sewage Lift Station
Mammal Habitat
Seabird Colony
Aquaculture
Ranch
Agriculture
Sheriff
Grocery
Public Well
Home
Water
Roadway
Beach
School Site
Restaurant
Boat Launch
Parking
Library
Historic Church
Hospital
Fire Station
Post Office
LEGEND
GAME PIECES
Retreat
Post-storm prohibitions
Move here
Stricter land use zoning
Managed Retreat
Elevate Buildings
Elevate/New Road
Floodable Buildings
Accommodate Water
Revetment/Seawal
Tide Gate
Traditional Levee
Wall & Pump Station
Hard Engineering
Horizontal Levee
Offshore Structure
Wetland/shoreline vegetation
Beach Maintenance
Soft Engineering
C-SMART Program
May 2015

Communities of North Bay Island

- Downtown Zappa
- Eroding Cliff Heights
- Mudflat Manors
- Desolation Road
- Shoreline Marina
- Twig Cove
- Seaspray Homes

Costs $$$

Real World – costs are messy and depend on many factors

+ planning & engineering

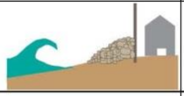
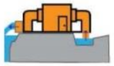
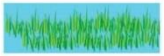
+ permitting

+ maintenance & repair

Game World – costs are simpler one-time costs and given to you per unit (i.e. mile or # of buildings)

Game of Floods *Marin Island*

Adaptation Game Piece Reference Sheet

Name	Piece	Units	Cost ($)	Env. Impact EEE or EE or E	Flood Protection Short, med, or long-term	Uses and Notes
Hard (Traditional) Engineering						
Traditional Levee		Mile	$$$$	EEE	med	Protects against temporary flooding, storm surge and some sea level rise. • Can increase wave run-up and overtopping. • In high wave energy environment on coast, need to armor levee slope.
Seawall/Revetment		Mile	$$$	EEE	med	Protects against erosion. • Can increase wave run-up and overtopping. • Increase erosion in adjacent areas.
Tidal Gate		Feet	$$$$$	EEE	med	Protects against temporary flooding, storm surge and some sea level rise. • High environmental impacts to hydrology. • Viable in sheltered estuaries and lagoons.
Flood wall & pump station		Mile	$$$	EEE	short	Protects against temporary flooding, storm surge and some sea level rise. • Can increase wave run-up and overtopping. • Require electricity and maintenance.
Soft Engineering						
"Horizontal" Levee		Mile	$$$$	E	med/long	Protects against temporary flooding, storm surge, some sea level rise, and wave impacts. • Viable in sheltered estuaries and lagoons.
Wetland/shoreline vegetation		Acre	$$$	E	short-med	Protects against temporary flooding, storm surge, and wave impacts. • Viable in sheltered estuaries and lagoons.
Dune Restoration and Beach Maintenance (nourishment & groins)		Mile	$$$	EE	short/med	Protects against temporary flooding and storm surge. • Even nourished beaches can erode and expose infrastructure to wave damage.

The Game

- Divide the island into two halves – one per team
- Look at each community in your half of the island
- Start adapting – place adaptation icons where your team feels appropriate – discuss and debate
- Add up the “costs”
- Review insights and lessons learned

Thank You

Visit www.MarinSLR.org for more information

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Novato Creek at Highway 101. Credit: Marin County staff