Climate Change and Sea Level Rise Impacts at Ports and a Consistent Methodology to Evaluate Vulnerability and Risk

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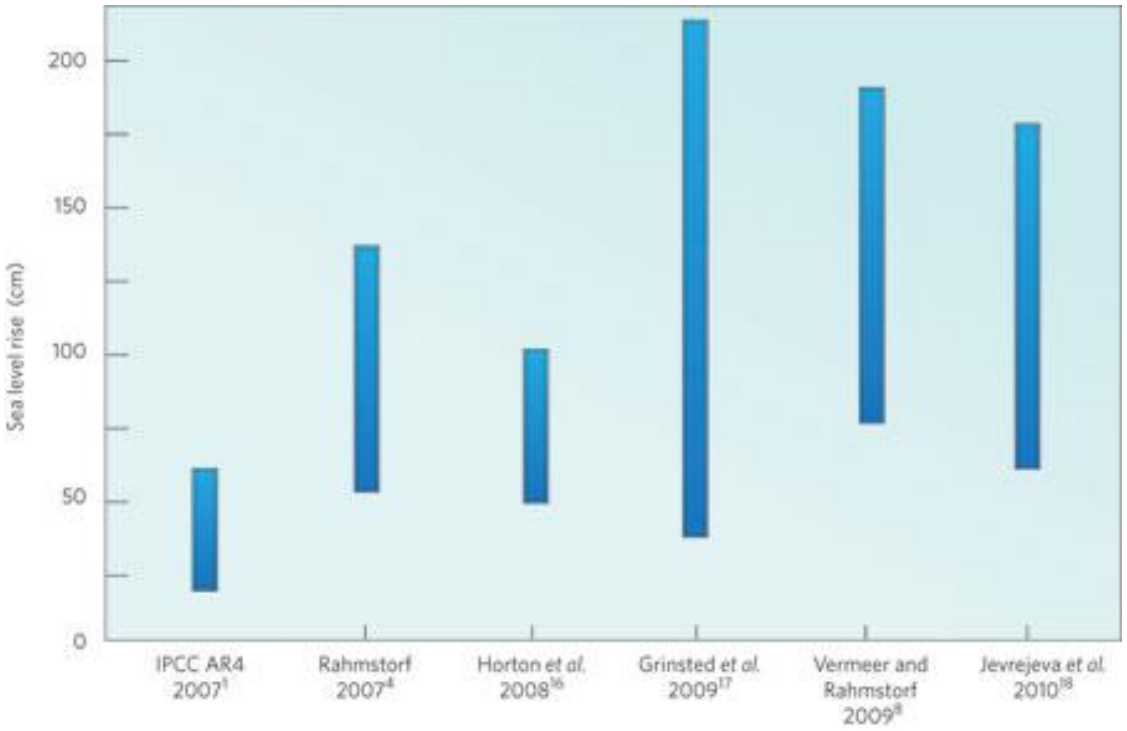
Overview

- Impacts to Ports
- Planning Challenges
- Evaluation Methodology Case Study
  - Develop GIS model
  - Assess likelihood and consequences of impacts
  - Overall risk assessment
- Evaluation and Comparison of Risks and Adaptation Strategy Development – NESA Framework

Climate Change Impacts at Ports

- Active Area of Research
  - NY/NJ (post Sandy), San Diego, LA, Rotterdam, Australia
- Threats From SLR and Flooding are Substantial
  - 75% of global trade by weight occurs by maritime transport and 59% by value
  - 13.3 million jobs in the United States
- Port Authorities are Stewards for Many Activities
  - Cargo, Marinas, Recreation, Natural Lands

Sea Level Rise Impacts to Coastal Areas by 2100



From Rahmstorf, S., 2010. A new view on sea level rise, Nature Reports Climate Change, 4, 44-45

Climatic Shifts Affecting Coastal Areas

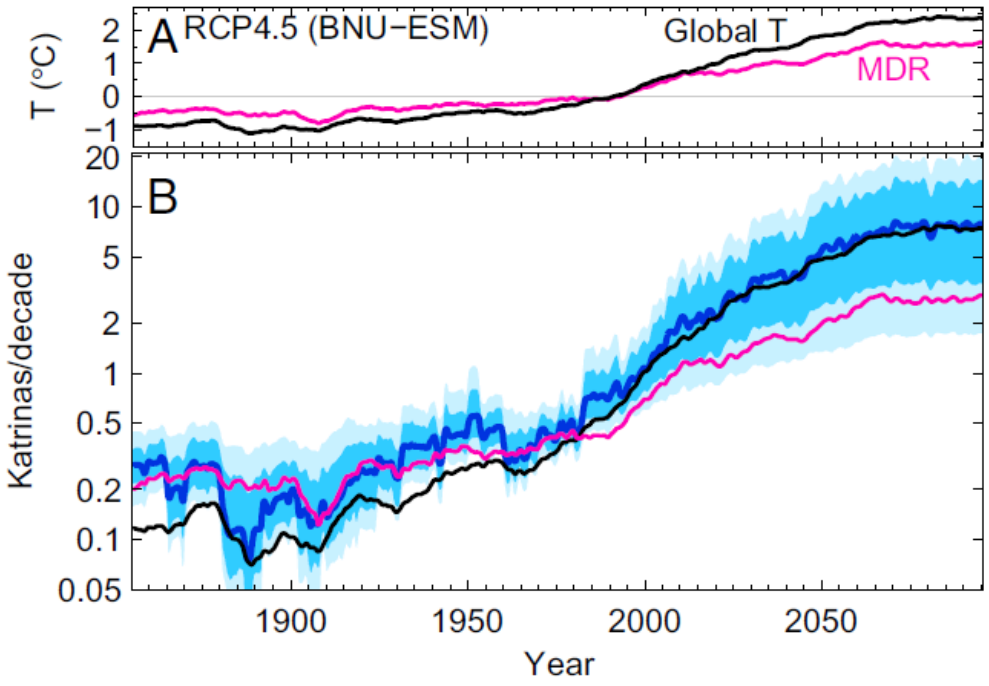


Fig. 3. Number of Katrina magnitude surge events per decade (*B*) hindcast and projected changes in temperatures from BNU-ESM under for RCP4.5 (*A*). The thick blue line shows the projection using the full spatial gridded temperatures and confidence interval (5–16–84–95%); magenta and black show the projections using only MDR and global average surface temperature. Confidence intervals for MDR and global *T* (not shown for clarity) are about the same size as for the gridded model.

From Grinsted, et. al, (2014) "Projected Atlantic hurricane surge threat from rising temperatures" http://www.pnas.org/content/early/2013/03/14/1209980110

Climate Change Impacts at Ports

- Port of Gulfport Elevating by 4.5 Meter After Katrina
- How Should Active Ports Plan?
  - Armoring, seawalls, elevation, managed retreat?
  - Different land use types and services
  - Tradeoffs – erosion increases at non-armoured areas
  - Several SLR scenarios

Case Study – Port of San Diego

- Port Specific Adaptation Planning Began in 2010
- Following on Regional Adaptation Planning Work (2007-9, San Diego Foundation) and Bay Wide Study (2009-10, ICLEI)
- Key Concerns are SLR, Localized Flooding, Habitat Inundation, Beach Erosion Impacts

Methodology Overview

- GIS Model to Map SLR Inundation
- Calculation of Inundated Areas
  - Overall Port Jurisdiction (“Port-wide”)
  - By Planning District
- Assess Consequences of SLR
- Ratings and Risk
  - Risk based on Likelihood and Consequence Ratings

SLR Inundation Model

- Two Scenarios Based on State Guidance and Local/Regional Studies
- 2050 Scenario: Predicted Global SLR (0.5m) + Adjusted Local Mean Sea Level (0.77m) + Storm Event (1.58m) = 2.85m
- 2100 Scenario: Predicted Global SLR (1.5m) + Adjusted Local Mean Sea Level (0.77m) + Storm Event (1.58m) = 3.08m

Calculation of Inundated Area and Impacts

- Evaluated for 4 Port Functions
  - Working Port
  - Safe Port
  - Green Port
  - Public Port
- Impacts Evaluated as Percentages of Inundated Areas Compared to Total Area of that Port Function by
  - Overall Port Jurisdiction (“Port-wide”)
  - By Planning District

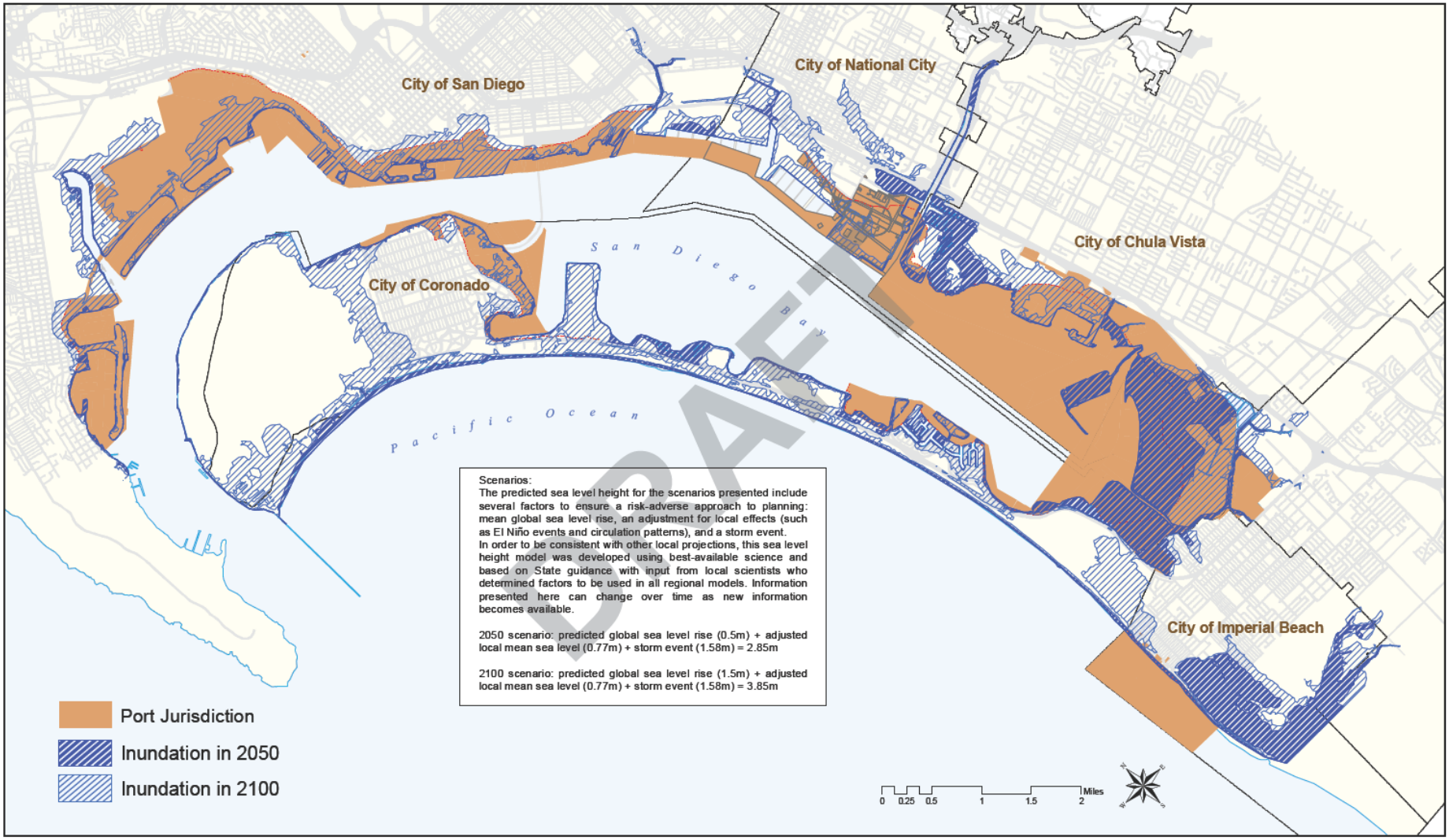


FIGURE #

San Diego Bay

Sea Level Rise in 2050 and 2100

Disclaimer: This map has been developed to communicate the potential risks, impacts, and exposure of future sea level rise inundation to Port tidelands. This map is intended to inform policymaking and should not be used for site-specific decision-making purposes. Actual impacts of inundation may vary depending on the resolution of topographic features and elevation

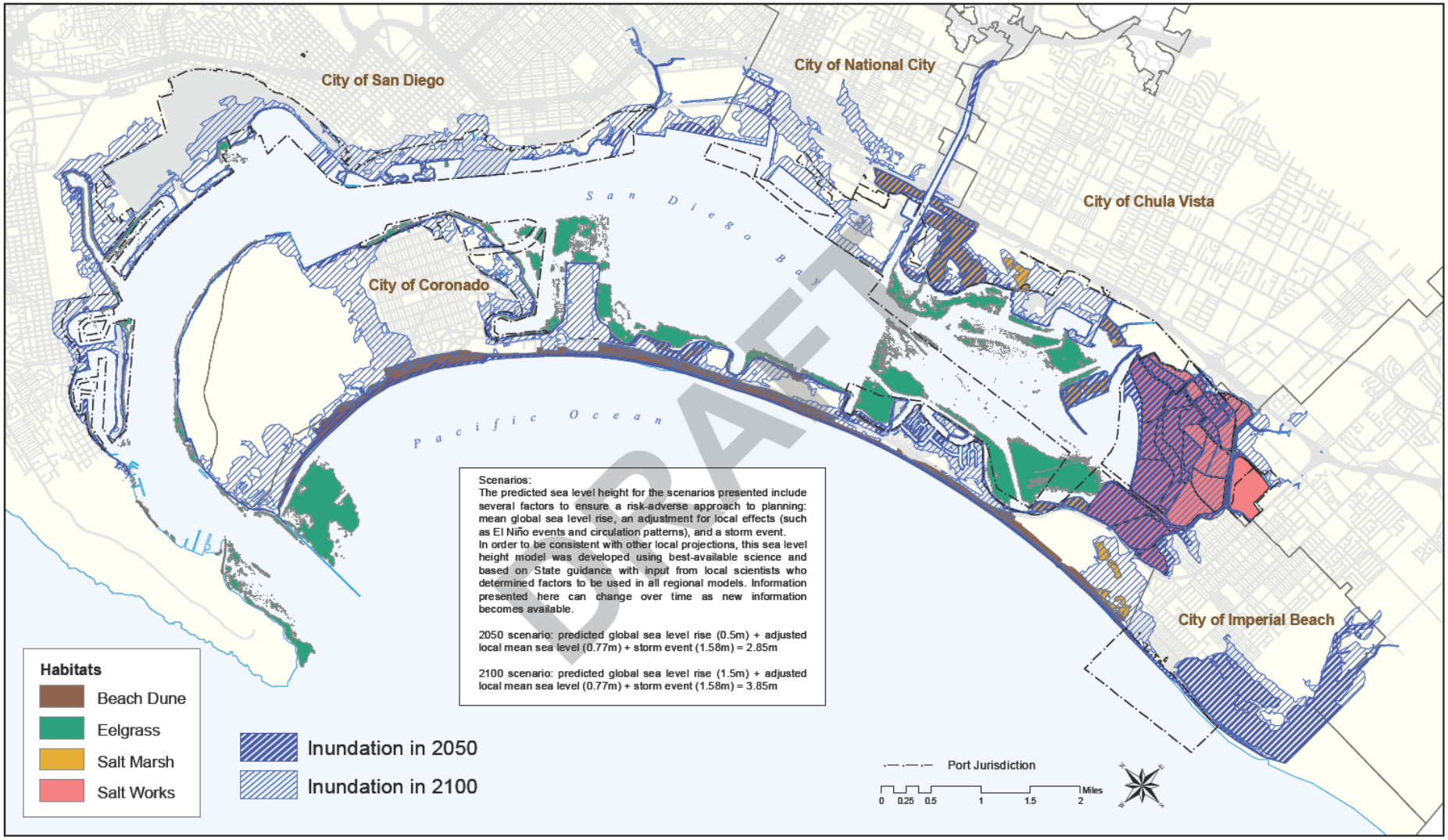


FIGURE #

San Diego Bay

Marine and Coastal Habitats

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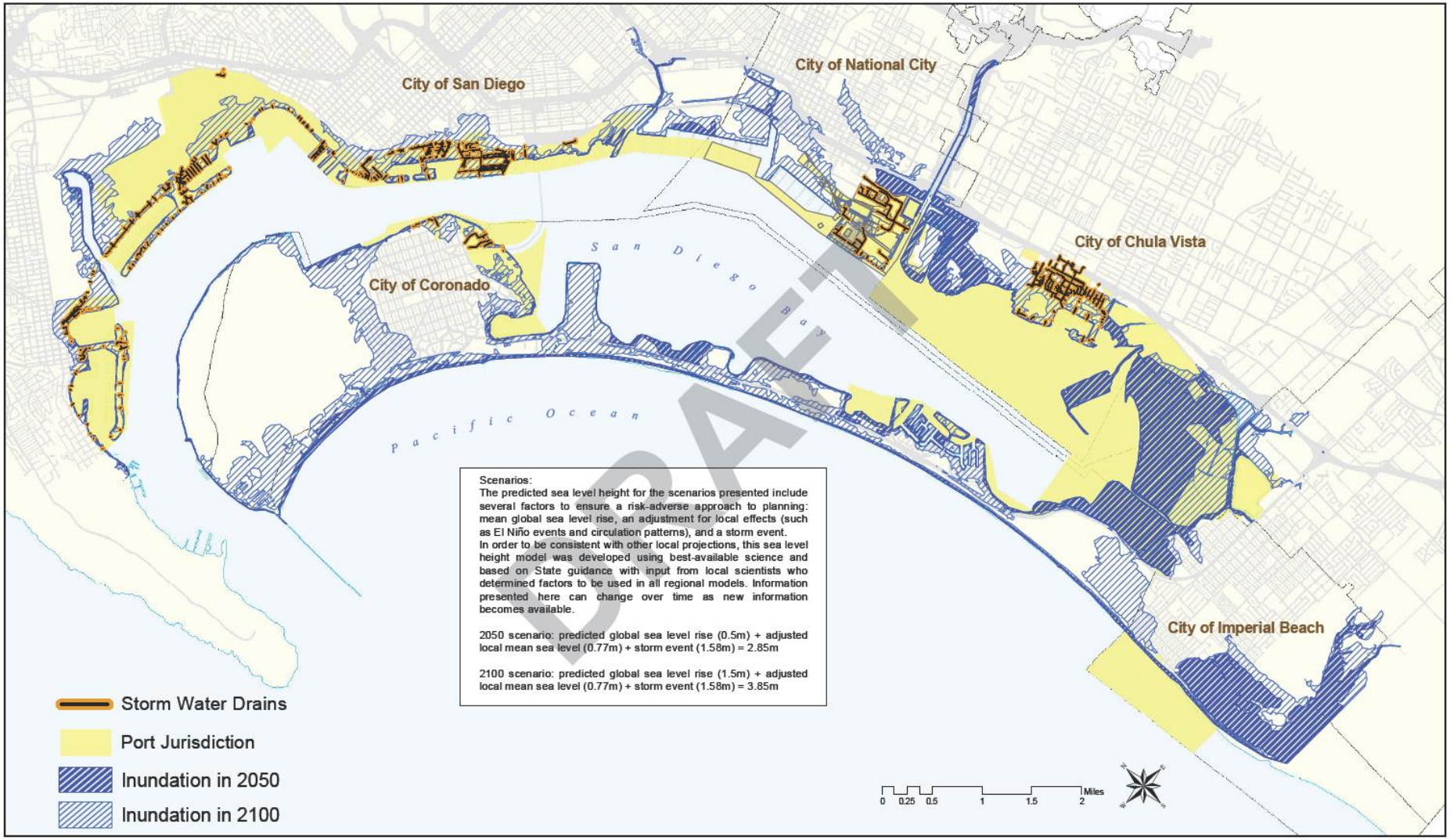

FIGURE #

San Diego Bay Storm Drain Infrastructure

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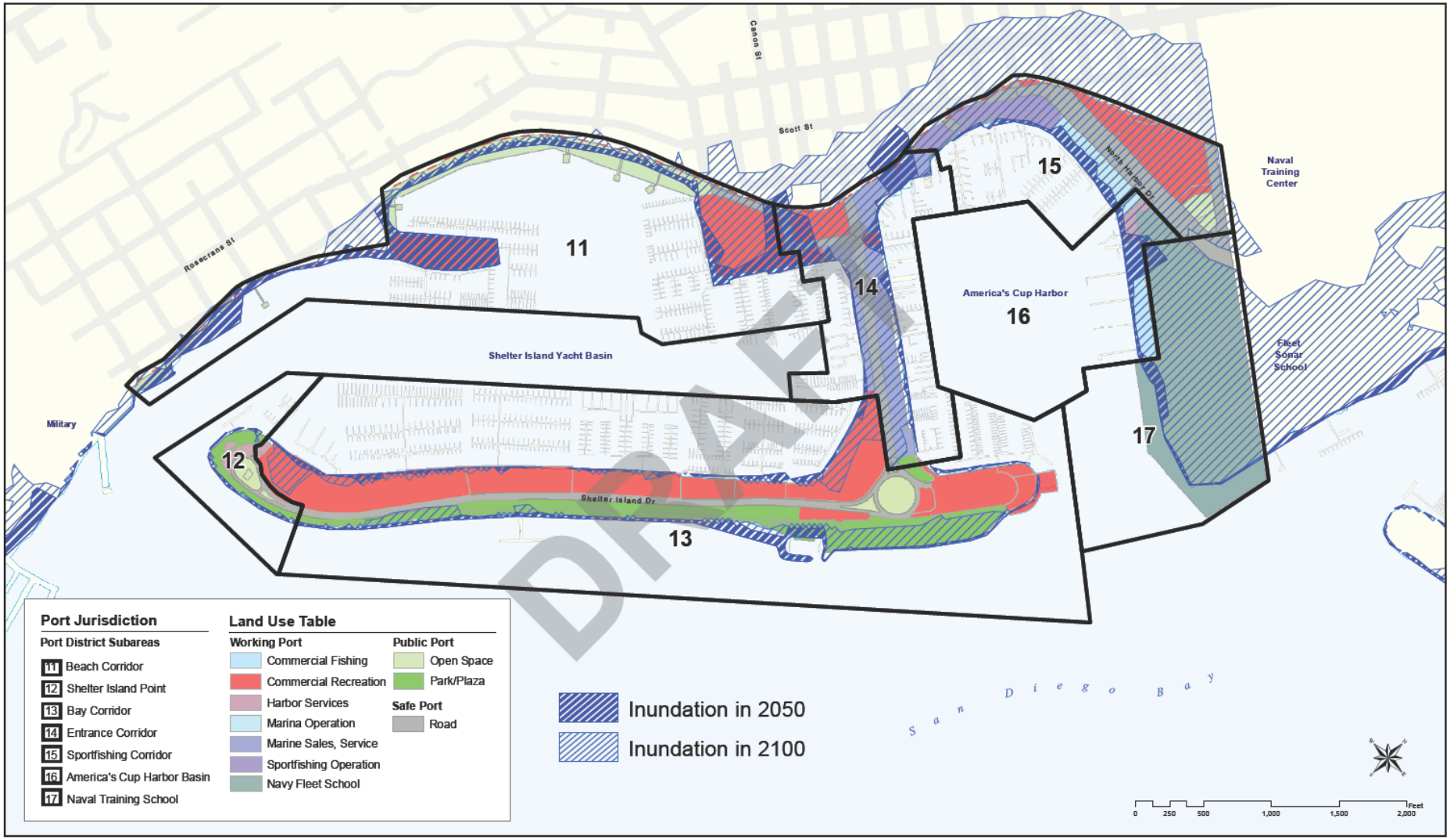

FIGURE #

Planning District 1 - Shelter Island/La Playa

Impacts to Land Use from Sea Level Rise in 2050 and 2100

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SLR Likelihood Determinations

Inundation Likelihoods		
LIKELIHOOD RATINGS		
Almost certain	5	Expect this event almost annually. Highly likely (>90% susceptibility).
Probable	4	Expect this event several times by 2050/2100. Likely to occur (50-90% susceptibility).
Possible	3	Expect this event to possibly occur once by 2050/2100. Not very likely, but still appreciable chance of occurring (10-50% susceptibility).
Unlikely	2	Event hasn't occurred yet, but could occur at some time by 2050/2100. Unlikely but not negligible (1-10% susceptibility).
Rare	1	Event has occurred in other regions of the world, but only in exceptional circumstances. Not expected to occur near the Port (<1% susceptibility).

SLR Consequence Determinations

Inundation Consequence Rating Quantitative Criteria		
Port-Wide Impact	Planning District Impact	Consequence Rating
Highest or > 10%	N/A	5
2 to 10%	>75%	5
2 to 10%	<75%	4
<2%	>10%	3
<2%	5 to <10%	2
<2%	<5%	1

Risk Matrix to Prioritize Actions

		CONSEQUENCE				
		1	2	3	4	5
LIKELI-HOOD	5	Medium	High	Very high	Very high	Very high
	4	Medium	Medium	High	Very high	Very high
	3	Low	Medium	Medium	High	Very high
	2	Low	Low	Medium	Medium	High
	1	N/A	Low	Low	Medium	Medium

Adaptation Strategies: Implementation Considerations

- Coordination with Existing Port Master Plan
  - Incorporate into project planning process
- Framework for Collaboration/Coordination with City/Regional/Agency Adaptation Strategies
  - Land use planning in areas impacted by SLR
  - Emergency preparedness/response
  - Additional research/studies

Example Risk Analysis Results: Working Port

2050

N/A	Low	Medium	High	Very High
1. Lindberg Field/Harbor Island 2. South Bay Saltlands 3. Imperial Beach	1. Centre City Embarcadero 2. Tenth Avenue Marine Terminal 3. National City Bayfront 4. Chula Vista Bayfront	1. Coronado Bayfront 2. Silver Strand South		1. Shelter Island

2100

N/A	Low	Medium	High	Very High
	1. South Bay Saltlands 2. Imperial Beach	1. National City Bayfront	1. Lindberg Field/Harbor Island 2. Coronado Bayfront 3. Silver Strand South	1. Shelter Island 2. Centre City Embarcadero 3. Tenth Avenue Marine Terminal 4. Chula Vista Bayfront

Adaptation Strategies

Identified adaptation strategies from local efforts and other recent adaptation references

- **Port Operations**
  - Goods movement/storage
  - Flood protection
  - Technology efficiency
  - Black-out prevention
  - Public education
  - Community planning
- **General Infrastructure**
  - Coastal buffer/flood zone setbacks
  - Subsidence/erosion
  - Road/causeway
  - Critical infrastructure inventory
  - Stormwater infrastructure
  - Heat stress reduction measures
- **Ecosystem**
  - Wetland/coastal Habitats
  - Non-native/invasive species
  - Monitoring
  - Collaboration
  - Ecosystem services/climate change
  - Setbacks/managed retreat
- **Coastline Preservation**
  - Seawalls, bulkheads, etc.
  - Beach erosion
  - Water diversion
  - Tide/flood monitoring
  - Coastal access/open space

Adaptation Strategies Continued

- **Water Supply/Quality**
  - Recycling/conservation
  - Reduce runoff
  - Stormwater management
  - Salt water intrusion
  - Supply/treatment
  - Drought management
  - Impervious surfaces
  - Groundwater recharge
- **Human Health**
  - Health/climate concerns
  - Emergency response
  - Worker H&S plan
  - Increased shading
  - Contaminated site assessment

DRAFT Evaluation Criteria and Categories
Port of San Diego Climate Mitigation and Adaptation Plan (CMAP)
Planning District 1 – Shelter Island – 2050 Summary Table

Do Not Quote or Cite
For Discussion Purposes Only

Port Function	Likelihood (1-5)	Consequence (1-5)	Risk Level	Shelter Island Planning District Impact by Port Function	Port-wide Impact by Port Function	Risk Assessment Comments	Planning Subareas Affected by Inundation	Adaptation Strategies
Working Port	3	5	Very High	13.4%	0.9%	Overall Port-wide impacts are minimal, but this is highest impact Port-wide for this Port function in 2050. Storm water infrastructure present near the areas of impact may assist in limiting impact duration.	**Beach Corridor (Subarea 11):** La Playa and Kellogg Beaches, Southwestern, La Playa and San Diego Yacht Clubs, A-1 small craft anchorage in La Playa Cove.	PO4, PO5, PO7, GI1, GI6, G8-11, GI14, EC5, CP2, CP5
							Shelter Island Point (Subarea 12): Harbor Police and Fire, Customs, and Coast Guard functions – piers, docks and boat berthing areas.	PO2, PO4, PO7, GI5, G8-11, CP2, CP3
							Bay Corridor (Subarea 13): Beach and shoreline park areas, 7 piers, docks, boat berths, boat mooring anchorages, and boat launching ramps. Humphreys Restaurant and the Bay Club Hotel Marina.	PO4, PO5, PO7, GI3-6, GI8-14, CP2, CP3
							Entrance Corridor (Subarea 14): 21 piers, docks and berths, Anchorage Ln. and Canon St., parking areas, unpaved open space, and the Red Sails Inn.	PO4, PO5, PO7, GI4-6, GI8-11, GI14, CP2, CP3
							Sportfishing Corridor (Subarea 15): 11 piers, docks and boat berths. Vagabond Sportfishing, Mitch's Seafood, H&M Landing, Sun Harbor Marina and Pier 32 Marina.	PO1, PO3-5, PO7, GI1, GI2, GI8 G13, GI14, CP2, CP3
							American Cup Harbor Basin (Subarea 16): 5 piers, docks and boat mooring facilities. Confident Communicator building, Naval Fleet Anti-Submarine Warfare Training Center, other Naval Center buildings, parking and access.	PO2, PO5, PO7, GI1, GI4, GI8-GI11, GI13, GI14, CP2, CP3
							Naval Training School (Subarea 17): 3 buildings of Naval Fleet Anti-Submarine Warfare Training Center and parking areas along Torpedo Point.	PO1, PO3, PO6, PO7, GI6, GI8-11, GI13, GI14
Safe Port	2	5	High	3.5%	0.8%	Overall Port-wide impacts are minimal, but this is the highest impact Port-wide to the Safe Port function in 2050. A small percentage occurs in a heavily commercial/industrial area; storm water infrastructure may assist in limiting impact duration.	**Entrance Corridor (Subarea14):** Anchorage Ln. and Canon St.	PO7, GI4-6, GI8-11, GI14, WS1-5, HH2, HH4
Green Port	4	5	Very High	Beach dune 89.5%	Beach dune 36.0%	Over 1/3 of beach dune within Port jurisdiction may be lost. Little to no capacity for landward migration of eelgrass exists.	**Beach Corridor (Subarea 11):** Beach Dune	EC3-5, EC7, EC9, CP5, CP8
	5	5	Very High	Eelgrass 100%	Eelgrass 6.4%		**Shelter Island Point (Subarea 12):** Eelgrass	EC3-5, EC7, EC9, CP5, CP8, EC1, EC2
							Bay Corridor (Subarea 13): Beach Dune, Eelgrass	EC3-5, EC7, EC9, CP5, CP8
Public Port	3	3	Medium	11.1%	1.6%	Impacts to commercial recreation and open space. Land uses are heavily commercial/industrial with storm water infrastructure that may assist in limiting impact duration.	**Beach Corridor (Subarea 11):** La Playa and Kellogg Beaches, Bessemer Path,Shelter Island Shoreline Park	GI8-11, EC1, EC3-5, EC9, CP3, CP5
							Bay Corridor (Subarea 13): beach and shoreline parks, piers, docks and boat ramp.	GI8-11, EC1, EC3-5, EC9, CP2, CP3, CP5
							Entrance Corridor (Subarea14): piers, docks and berths, Anchorage Ln. and Canon St., parking areas, unpaved open space.	GI8-11, EC1, EC3-5, EC9, CP2, CP3, CP5

Correlating and Comparing Risks

- **Economic and Net Ecosystem Services Analysis**
  - Unites benefit-cost analysis and environmental decision-making
  - Brings together financial benefits and costs with environmental and other benefits and costs to facilitate decision-making
- **Methodology Founded Upon**
  - US Army Corps of Engineers (USACE) benefit-cost Analysis for public infrastructure investment;
  - International Finance Corporation (IFC) performance standards that screen for ecosystem service risks and impacts;
  - Millennium Ecosystem Assessment (MEA) ecosystem services framework

NESA Approach

- Step 1. Define the Boundaries of the Analysis
  - Geographic
  - Demographic
  - Temporal
- Step 2. Establish Baseline Scenario and Alternatives
  - Baseline – Business as usual; or 'do nothing' scenario. Could be defined as current conditions in a static state, or could be forecast of what will happen in the absence of any adaptation measures
  - Alternatives –Goal of defining alternatives is to be able to measure gains and losses of each alternative against the baseline

NESA Approach

- Step 3. Select Metrics for Evaluating Baseline; Alternatives
  - Financial metrics key importance
  - Also environmental metrics
  - Non-market community metrics also matter
  - **Examples:**

Port Function	Potential Metric
Working Port	Annual Revenue; Jobs Supported; Occupancy; TEUs IM/EX
Safe Port	Annual Injuries; Illnesses; Fatalities
Green Port	Habitat; Fish Populations; Air Quality
Public Port	Annual Visitors; Recreational Trips

NESA Approach

- Step 4. Measure Gains and Losses for Each Metric and Alternative Through Time
  - Subtract losses from gains for overall net annual result for each metric.
  - Repeat process for each alternative.
  - Aggregate losses and gains over time using Net Present Value (NPV) calculations.

- **Net Present value (NPV) of the stream of net social benefits over the relevant time horizon:**

$$NPV = \Sigma_i (B_i - C_i)/(1+r)^i$$

$$i = 1, 2, \ldots, n.$$

- **$(B_i - C_i)$ = net social benefit "i" years from present**
- **"r" = discount rate**
- **NPV = "collapsed" value estimate for stream of future gains/losses**
- **"n" = end period of total time horizon (years from present)**

NESA Approach

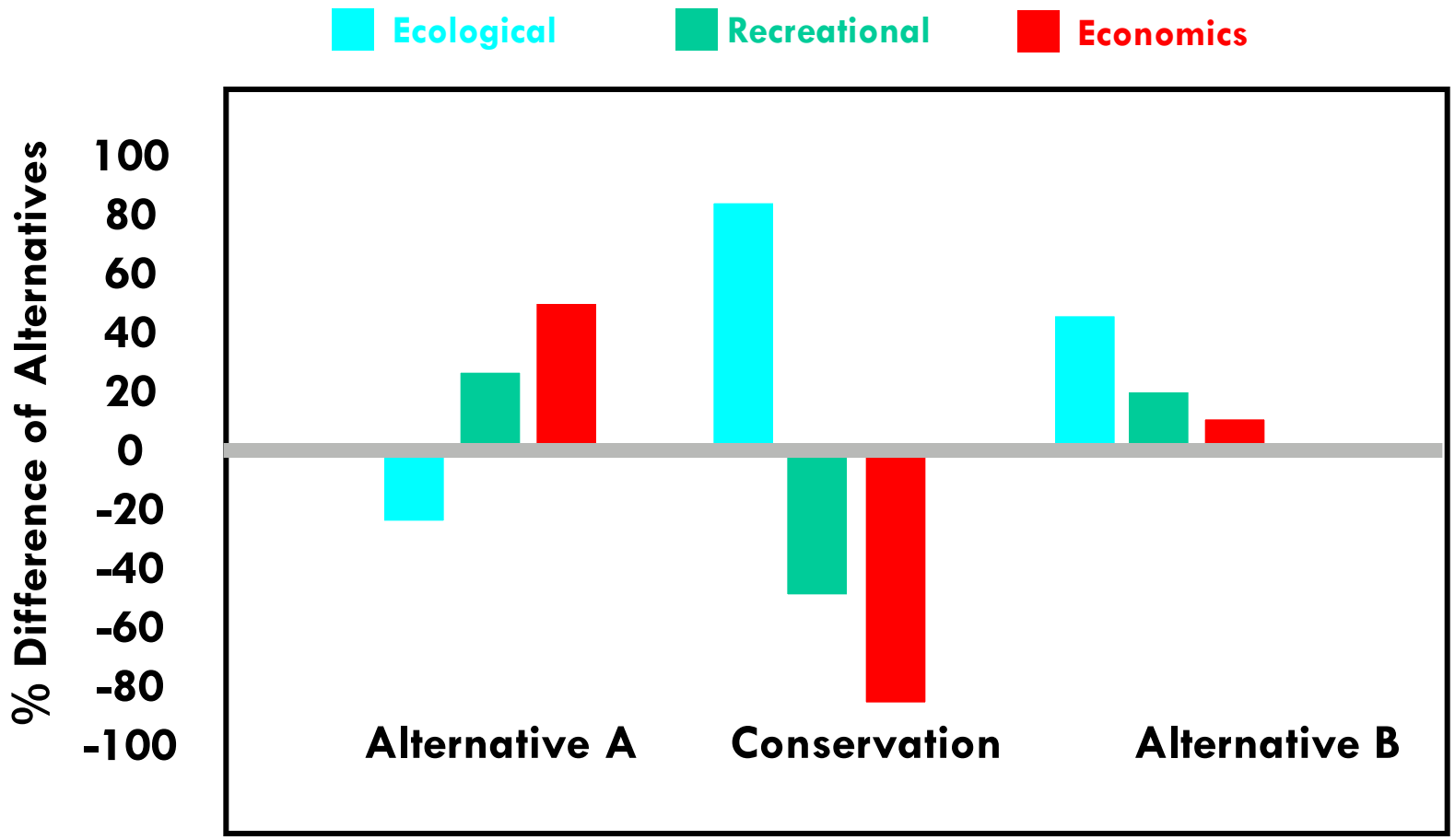
- Step 5. Make Strategy Decisions
  - Subtract the net gains and losses for each metric and alternative from the baseline scenario.
  - Compare the gains/losses under each alternative across metrics
  - Select best alternative or collection of alternatives

EXAMPLE

- Example of Results:

Summary of the preliminary net environmental benefits analysis for each River sediment remedy							
Adaptation Strategy	**Option Description**	**Working Port**	**Safe Port**	**Green Port**	**Public Port**	**Example Monetary Value of Green and Public**	**Midpoint Cost**
		$ Value of Damage Reduction	Injuries/ Fatalities	(DSAYs) [1]	(DVDs) [2]	($)	($)
G16	Gather elevation data						
GI14	Prioritize LID for impaired storm sewers						
EC3	Restore wetlands						
CP3	Construct breakwaters						
WS2	Review operations to minimize saltwater intrusion						
1. Discounted service acre-years (DSAYs)							
2. Discounted visitor days (DVDs)							

Example


Ecological
Recreational
Economics
% Difference of Alternatives
100
80
60
40
20
0
-20
-40
-60
-80
-100
Alternative A
Conservation
Alternative B

Conclusions

- Climate Risks to Ports are Significant
- Critical First Step Should Assess Future Sea Level Ranges Combined with Storm Surges and Portray Information Visually and Spatially
- The GIS-Based Methodology can be Readily Tailored for use in Other Coastal Jurisdictions to Establish Vulnerabilities and Risks
- The NESA Framework Allows Coastal Jurisdictions to Comparatively Evaluate the Costs and Benefits of Adaptation Strategies on a Common Platform





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