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

Steven Messner, L. Moran, G. Reub, J. Campbell
ENVIRON International Corporation
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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

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
Scenarios:
The predicted sea level height for the scenarios presented include several factors to ensure a realistic and informed approach to planning: mean global sea level rise, an adjustment for local effects (such as El Niño events and circulation patterns), and a storm event. In order to be consistent with other local projections, this sea level height model was developed using best-available science and based on State guidance with input from local scientists who determined factors to be used in all regional models. Information presented here can change over time as new information becomes available.

2050 scenario: predicted global sea level rise (0.5 m) + adjusted local mean sea level (0.7 m) + storm event (1.5 m) = 2.85 m

2100 scenario: predicted global sea level rise (1.5 m) + adjusted local mean sea level (0.7 m) + storm event (1.5 m) = 3.85 m
Scenarios:
The predicted sea level height for the scenarios presented include several factors: to assume a mid-range approach to planning: mean global sea level rise, an adjustment for local effects (such as El Niño events and circulation patterns), and a storm event.
In order to be consistent with other local projections, this sea level height model was developed using best-available science and based on federal guidance with input from local scientists who determined factors to be used in all regional models. Information presented here can change over time as new information becomes available.

2050 scenario: predicted global sea level rise (0.6 m) + adjusted local mean sea level (0.7 m) ± storm event (1.5 m) = 2.85 m

2100 scenario: predicted global sea level rise (1.5 m) + adjusted local mean sea level (0.7 m) ± storm event (1.5 m) = 3.85 m

FIGURE #
San Diego Bay Marine and Coastal Habitats

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 policy making 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.
Scenarios:
The predicted sea level height for the scenarios presented include several factors to ensure a rise-adverse approach to planning: mean global sea level rise, an adjustment for local effects (such as El Niño events and circulation patterns), and a storm event.

In order to be consistent with other local projections, this sea level height model was developed using best-available science and based on State guidance with input from local scientists who determined factors to be used in all regional models. Information presented here can change over time as new information becomes available.

2050 scenario: predicted global sea level rise (0.5m) + adjusted local mean sea level (0.77m) + storm event (1.50m) = 2.85m

2100 scenario: predicted global sea level rise (1.5m) + adjusted local mean sea level (0.77m) + storm event (1.50m) = 3.85m

Disclaimers: This map has been developed to communicate the potential risks, impacts, and exposure of future sea level rise and inundation to Port facilities. 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.
# SLR Likelihood Determinations

## Inundation Likelihoods

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost certain</td>
<td>5</td>
<td>Expect this event almost annually. Highly likely (&gt;90% susceptibility).</td>
</tr>
<tr>
<td>Probable</td>
<td>4</td>
<td>Expect this event several times by 2050/2100. Likely to occur (50-90% susceptibility).</td>
</tr>
<tr>
<td>Possible</td>
<td>3</td>
<td>Expect this event to possibly occur once by 2050/2100. Not very likely, but still appreciable chance of occurring (10-50% susceptibility).</td>
</tr>
<tr>
<td>Unlikely</td>
<td>2</td>
<td>Event hasn't occurred yet, but could occur at some time by 2050/2100. Unlikely but not negligible (1-10% susceptibility).</td>
</tr>
<tr>
<td>Rare</td>
<td>1</td>
<td>Event has occurred in other regions of the world, but only in exceptional circumstances. Not expected to occur near the Port (&lt;1% susceptibility).</td>
</tr>
</tbody>
</table>
## SLR Consequence Determinations

### Inundation Consequence Rating Quantitative Criteria

<table>
<thead>
<tr>
<th>Port-Wide Impact</th>
<th>Planning District Impact</th>
<th>Consequence Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest or &gt; 10%</td>
<td>N/A</td>
<td>5</td>
</tr>
<tr>
<td>2 to 10%</td>
<td>&gt;75%</td>
<td>5</td>
</tr>
<tr>
<td>2 to 10%</td>
<td>&lt;75%</td>
<td>4</td>
</tr>
<tr>
<td>&lt;2%</td>
<td>&gt;10%</td>
<td>3</td>
</tr>
<tr>
<td>&lt;2%</td>
<td>5 to &lt;10%</td>
<td>2</td>
</tr>
<tr>
<td>&lt;2%</td>
<td>&lt;5%</td>
<td>1</td>
</tr>
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</table>
## Risk Matrix to Prioritize Actions

<table>
<thead>
<tr>
<th>LIKELIHOOD</th>
<th>CONSEQUENCE</th>
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<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
</tr>
<tr>
<td>1</td>
<td>N/A</td>
</tr>
</tbody>
</table>
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

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

## 2100

<table>
<thead>
<tr>
<th>N/A</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. South Bay Saltlands</td>
<td>1. National City Bayfront</td>
<td>1. Shelter Island</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Imperial Beach</td>
<td></td>
<td>2. Centre City Embarcadero</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Tenth Avenue Marine Terminal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Chula Vista Bayfront</td>
<td></td>
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</tr>
</tbody>
</table>
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
<table>
<thead>
<tr>
<th>Port Function</th>
<th>Likelihood (1-5)</th>
<th>Consequence (1-5)</th>
<th>Risk Level</th>
<th>Shelter Island Planning District Impact by Port Function</th>
<th>Port-wide Impact by Port Function</th>
<th>Risk Assessment Comments</th>
<th>Planning Subareas Affected by Inundation</th>
<th>Adaptation Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working Port</td>
<td>3</td>
<td>5</td>
<td>Very High</td>
<td>13.4%</td>
<td>0.9%</td>
<td>Overall Port-wide impacts are minimal, but this is the 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.</td>
<td>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.</td>
<td>P04, P05, P07, G11, G16, G18-11, G14, EC5, CP2, CP5</td>
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<td>Shelter Island Point (Subarea 12): Harbor Police and Fire, Customs, and Coast Guard functions – piers, docks and boat berthing areas.</td>
<td>P02, P04, P07, G15, G18-11, CP2, CP3</td>
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<td>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.</td>
<td>P04, P05, P07, G13-6, G18-14, CP2, CP3</td>
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<td>Entrance Corridor (Subarea 14): 21 piers, docks and berths. Anchorage Ln. and Canon St, parking areas, unpaved open space, and the Red Sails Inn.</td>
<td>P04, P05, P07, G14-6, G18-13, G14, CP2, CP3</td>
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<td></td>
<td>Sportfishing Corridor (Subarea 15): 11 piers, docks and boat berths. Vagabond Sportfishing, Mitch’s Seafood, H&amp;M Landing, Sun Harbor Marina and Pier 32 Marina.</td>
<td>P01, P03-5, P07, G11, G12, G18-13, G14, CP2, CP3</td>
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<td></td>
<td>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.</td>
<td>P02, P05, P07, G16, G18, G18-11, G13, G14, G19, CP2, CP3</td>
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<td></td>
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<td></td>
<td></td>
<td>Naval Training School (Subarea 17): 3 buildings of Naval Fleet Anti-Submarine Warfare Training Center and parking areas along Torpepo Point.</td>
<td>P01, P03, P06, P07, G16, G18-11, G15, G18</td>
<td></td>
</tr>
<tr>
<td>Safe Port</td>
<td>2</td>
<td>5</td>
<td>High</td>
<td>3.5%</td>
<td>0.8%</td>
<td>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.</td>
<td>Entrance Corridor (Subarea 14): Anchorage Ln. and Canon St.</td>
<td>P07, G14-6, G18-11, G14, WS1-5, HH2, HH4</td>
</tr>
<tr>
<td>Green Port</td>
<td>4</td>
<td>5</td>
<td>Very High</td>
<td>Beach dune 89.5%</td>
<td>Beach dune 8.4%</td>
<td>Over 1/3 of beach dune within Port jurisdiction may be lost. Little to no capacity for landward migration of eelgrass exists.</td>
<td>Beach Corridor (Subarea 11): Beach Dune</td>
<td>EC3-5, EC7, EC9, CP5, CP8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shelter Island Point (Subarea 12): Eelgrass</td>
<td>EC3-5, EC7, EC9, CP5, CP8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
<td>Very High</td>
<td>Eelgrass</td>
<td>Eelgrass</td>
<td>Beach Corridor (Subarea 11): La Playa and Kellogg Beaches, Beechmont Park, Shelter Island Shoreline Park</td>
<td>G18-11, EC1, EC3-5, EC5, CP2, CP3, CP5</td>
<td></td>
</tr>
<tr>
<td>Public Port</td>
<td>3</td>
<td>3</td>
<td>Medium</td>
<td>11.1%</td>
<td>1.6%</td>
<td>Impacts to commercial recreation and open space. Land uses are heavily commercial/industrial with storm water infrastructure that may assist in limiting impact duration.</td>
<td>Beach Corridor (Subarea 11): La Playa and Kellogg Beaches, Beechmont Park, Shelter Island Shoreline Park</td>
<td>G18-11, EC1, EC3-5, EC5, CP2, CP3, CP5</td>
</tr>
</tbody>
</table>
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
Step 3. Select Metrics for Evaluating Baseline; Alternatives

- Financial metrics key importance
- Also environmental metrics
- Non-market community metrics also matter
- Examples:

<table>
<thead>
<tr>
<th>Port Function</th>
<th>Potential Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working Port</td>
<td>Annual Revenue; Jobs Supported; Occupancy; TEUs IM/EX</td>
</tr>
<tr>
<td>Safe Port</td>
<td>Annual Injuries; Illnesses; Fatalities</td>
</tr>
<tr>
<td>Green Port</td>
<td>Habitat; Fish Populations; Air Quality</td>
</tr>
<tr>
<td>Public Port</td>
<td>Annual Visitors; Recreational Trips</td>
</tr>
</tbody>
</table>
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:
  \[ \text{NPV} = \sum_{i=1}^{n} \frac{(B_i - C_i)}{(1+r)^i} \]
  \( i = 1, 2, ..., n \)
- \((B_i - C_i)\) = 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:**

<table>
<thead>
<tr>
<th>Adaptation Strategy</th>
<th>Option Description</th>
<th>Working Port</th>
<th>Safe Port</th>
<th>Green Port</th>
<th>Public Port</th>
<th>Example Monetary Value of Green and Public</th>
<th>Midpoint Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>G16</td>
<td>Gather elevation data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI14</td>
<td>Prioritize LID for impaired storm sewers</td>
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<td>EC3</td>
<td>Restore wetlands</td>
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</tr>
<tr>
<td>CP3</td>
<td>Construct breakwaters</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>WS2</td>
<td>Review operations to minimize saltwater intrusion</td>
<td></td>
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</tr>
</tbody>
</table>

1. Discounted service acre-years (DSAYs)
2. Discounted visitor days (DVDs)
Example

% Difference of Alternatives

-100 -80 -60 -40 -20 0 20 40 60 80 100

Alternative A  Conservation  Alternative B

Ecological  Recreational  Economics
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
Laura Moran | Senior Manager | Senior Biologist
ENVIRON International Corporation
773 San Marin Drive | Suite 2115
Novato, California 94998
T: +1 415 899 0731 | F: +1 415 899 0707 | M: +1 415 246 7397
lmoran@environcorp.com