Sea Level Rise Adaptation: From Climate Chaos to Climate Resilience

Human Dimensions and Ocean Health In a Changing Climate

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Coastal Engineer
USC & California Coastal Commission
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Main Discussion Points

• How do we incorporate Sea-Level Rise into planning and regulatory actions?

• What Does the new NRC Report on Sea-Level Rise mean to Decision-makers?

• How does Sea-Level Rise fit into Resilience and Sustainability?
Consequences of Climate Change?

Flooding along Highway 1; rescue at Malibu Creek (unrelated events)

Structural damage, foundation failure, projectile impacts
Sea Level Rise is not NEW

Section 30006.5 Legislative findings and declarations; technical advice and recommendations
The Legislature further finds and declares that sound and timely scientific recommendations are necessary for many coastal planning, conservation, and development decisions and that the commission should, in addition to developing its own expertise in significant applicable fields of science, interact with members of the scientific and academic communities in the social, physical, and natural sciences so that the commission may receive technical advice and recommendations with regard to its decisionmaking, especially with regard to issues such as coastal erosion and geology, marine biodiversity, wetland restoration, the question of sea level rise, desalination plants, and the cumulative impact of coastal zone developments.
(Added by Ch. 965, Stats. 1992.)
Plot of historic sea level rise measured by tide gauges and satellites

Source: S. Rahmsdorf, Plenary Presentation, 10 March 2009; www.ozean-klima.de
Best Available Science
Sea Level Rise is not a new phenomenon, nor is it a new concern.
Historic Sea Level Rise and future projections from 2007 IPCC

Future sea level (rel. to 1990) based on IPCC AR4 global temperature projections

Full range: 75 – 190 cm by 2100

Source: S. Rahmsdorf, Plenary Presentation, 10 March 2009; www.ozean-klima.de
Future Sea Level Rise Projections from reports published after 2007 IPCC cut-off date

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S. Rahmsdorf, Plenary Presentation, 10 March 2009
 OPC Interim Sea-Level Rise Rise Projections
using 2000 as the Baseline

<table>
<thead>
<tr>
<th>Year</th>
<th>Average of Models</th>
<th>Range of Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030</td>
<td>7 in (18 cm)</td>
<td>5-8 in (13-21 cm)</td>
</tr>
<tr>
<td>2050</td>
<td>14 in (36 cm)</td>
<td>10-17 in (26-43 cm)</td>
</tr>
<tr>
<td>2070</td>
<td>Low: 23 in (59 cm)</td>
<td>17-27 in (43-70 cm)</td>
</tr>
<tr>
<td></td>
<td>Medium: 24 in (62 cm)</td>
<td>18-29 in (46-74 cm)</td>
</tr>
<tr>
<td></td>
<td>High: 27 in (69 cm)</td>
<td>20-32 in (51-81 cm)</td>
</tr>
<tr>
<td>2100</td>
<td>Low: 40 in (101 cm)</td>
<td>31-50 in (78-128 cm)</td>
</tr>
<tr>
<td></td>
<td>Medium: 47 in (121 cm)</td>
<td>37-60 in (95-152 cm)</td>
</tr>
<tr>
<td></td>
<td>High: 55 in (140 cm)</td>
<td>43-69 in (110-176 cm)</td>
</tr>
</tbody>
</table>

Note: These projections do not account for catastrophic ice melting, so they may underestimate actual SLR. The SLR projections included in this table do not include a safety factor to ensure against underestimating future SLR. For dates after 2050, three different values for SLR are shown - based on low, medium, and high future greenhouse gas emission scenarios. These values are based on the IPCC emission scenarios as follows: B1 for the low projections, A2 for the medium projections, and A1FI for the high projections.
NRC Sea-Level Rise Report

Graphs from Report In Brief
Figure 2. A Tale of Two Coasts: Projected cumulative sea-level rise (in cm) shows a steep change at Cape Mendocino (labeled MTJ). The descent of the ocean plate along the Cascadia Subduction Zone has caused much of the land along the coasts of Washington, Oregon, and northernmost California to rise at about 1.5-3 mm per year, decreasing relative sea-level rise. South of Cape Mendocino, where the coast is slowly sinking at about 1 mm per year, projections are close to global projections. The slight slope in the projection curves from north to south reflects the sea-level fingerprint of melting Alaska glaciers, which lower relative sea level, especially in northern Washington.
### Regional Sea-Level Rise Projections (in cm) Relative to Year 2000

<table>
<thead>
<tr>
<th>Component</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steric and dynamic ocean&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$3.6 \pm 2.5$</td>
<td>$7.8 \pm 3.7$</td>
<td>$20.9 \pm 7.7$</td>
</tr>
<tr>
<td>Non-Alaska glaciers and ice caps&lt;sup&gt;b&lt;/sup&gt;</td>
<td>$2.4 \pm 0.2$</td>
<td>$4.4 \pm 0.3$</td>
<td>$11.4 \pm 1.0$</td>
</tr>
<tr>
<td>Alaska, Greenland, and Antarctica with sea-level fingerprint effect&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seattle, WA</td>
<td>$7.1$</td>
<td>$16.0$</td>
<td>$52.7$</td>
</tr>
<tr>
<td>Newport, OR</td>
<td>$7.4$</td>
<td>$16.6$</td>
<td>$54.5$</td>
</tr>
<tr>
<td>San Francisco, CA</td>
<td>$7.8$</td>
<td>$17.6$</td>
<td>$57.6$</td>
</tr>
<tr>
<td>Los Angeles, CA</td>
<td>$8.0$</td>
<td>$17.9$</td>
<td>$58.5$</td>
</tr>
<tr>
<td>Vertical land motion&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North of Cape Mendocino</td>
<td>$-3.0$</td>
<td>$-5.0$</td>
<td>$-10.0$</td>
</tr>
<tr>
<td>South of Cape Mendocino</td>
<td>$4.5$</td>
<td>$7.5$</td>
<td>$15.0$</td>
</tr>
<tr>
<td>Sum of all contributions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seattle</td>
<td>$6.6 \pm 5.6$</td>
<td>$16.6 \pm 10.5$</td>
<td>$61.8 \pm 29.3$</td>
</tr>
<tr>
<td>Newport</td>
<td>$6.8 \pm 5.6$</td>
<td>$17.2 \pm 10.3$</td>
<td>$63.3 \pm 28.3$</td>
</tr>
<tr>
<td>San Francisco</td>
<td>$14.4 \pm 5.0$</td>
<td>$28.0 \pm 9.2$</td>
<td>$91.9 \pm 25.5$</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>$14.7 \pm 5.0$</td>
<td>$28.4 \pm 9.0$</td>
<td>$93.1 \pm 24.9$</td>
</tr>
</tbody>
</table>

<sup>a</sup> Projection indicates the mean and ± standard deviation computed for the Pacific coast from the gridded data presented in Pardaens et al. (2010) for the A1B scenario. Ranges are the means for B1 and A1FI using the scaling in Table 10.7 of IPCC (2007; see also Table 5.1 of this report): (B1/A1B) = (0.1/0.13); (A1FI/A1B) = (0.17/0.13).

<sup>b</sup> Extrapolated based on ice loss rates for glaciers and ice caps except Alaska, Greenland, and Antarctica. No ranges are given because these sources are assumed to have a small or uniform effect on the gradient in sea-level change along the U.S. west coast (see “Sea-Level Fingerprints of Modern Land Ice Change” in Chapter 4).

<sup>c</sup> Extrapolation based on ice loss rates and gravitational attraction effects for Alaska, Greenland, and Antarctica. Ranges reflect uncertainty in ice loss rates.

<sup>d</sup> Assumes constant rates of vertical land motion of $1.0 \pm 1.5$ mm yr$^{-1}$ for Cascadia and $-1.5 \pm 1.3$ mm yr$^{-1}$ for the San Andreas region. The signs were reversed to calculate relative sea level. Uncertainties are 1 standard deviation.
NRC Sea-Level Rise Projections using 2000 as the Baseline

<table>
<thead>
<tr>
<th>Time Period</th>
<th>North of Cape Mendocino</th>
<th>South of Cape Mendocino</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 - 2030</td>
<td>-4 - +23 cm (0.13 -- 0.75 ft)</td>
<td>4 – 30 cm (0.13 -- 0.98 ft)</td>
</tr>
<tr>
<td>2000 – 2050</td>
<td>-3 - + 48 cm (0.1 -- +1.57 ft)</td>
<td>12 – 61 cm (0.39 -- 2.0 ft)</td>
</tr>
<tr>
<td>2000 – 2100</td>
<td>10 – 143 cm (0.3 -- 4.69 ft)</td>
<td>42 – 167 cm (1.38 – 5.48 ft)</td>
</tr>
</tbody>
</table>

Ranges are the means for B1 and A1FI using the scaling in Table 10.7 of IPCC (2007). See also Table 5.1 of this report): B1/A1B = (0.1/0.13); (A1FI/A1B) = (0.17/1.13)

Non-Alaska glaciers and ice caps extrapolated based on ice loss rates for glaciers and ice caps except Alaska, Greenland, and Antarctica. No ranges are given because these sources are assumed to have a small or uniform effect on the gradient in sea-level change along the US west coast.

Alaska, Greenland and Antarctica extrapolation based on the ice loss rates and gravitational attraction effects; Ranges included to reflect uncertainty in ice loss rates.

Vertical land movement assumed at a constant rate of 1.0 + 1.5 mm/yr for Cascadia and -1.5 + 1.3 mm/yr for the San Andreas region.
Sea-Level Rise Projections
Various Scientific Reports

Sources can be provided upon requested.
Sea-Level Rise Projections
Various Scientific Reports

Sources can be provided upon requested.
FIGURE 5.10  Committee’s projected sea-level rise for California, Oregon, and Washington compared with global projections. The dots are the projected values and the colored bars are the ranges. Washington and Oregon = coastal areas north of Cape Mendocino; California = coastal areas south of Cape Mendocino.
## NRC Sea-Level Rise Projections

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Projected, based on A1B Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 - 2030</td>
<td>~ 6 inches (0.5 feet)</td>
</tr>
<tr>
<td>2000 – 2050</td>
<td>~ 12 inches (1.0 feet)</td>
</tr>
<tr>
<td>2000 – 2100</td>
<td>South of Cape Mendocino: ~ 24 inches (2 feet)</td>
</tr>
<tr>
<td></td>
<td>North of Cape Mendocino: ~ 36 inches (3 feet)</td>
</tr>
</tbody>
</table>
### Table 5.3 Regional Sea-Level Rise Projections (in cm) Relative to Year 2000

<table>
<thead>
<tr>
<th>Component</th>
<th>2030 Projection</th>
<th>Range</th>
<th>2050 Projection</th>
<th>Range</th>
<th>2100 Projection</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of all contributions</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Seattle</td>
<td>6.6 ± 5.6</td>
<td>-3.7–22.5</td>
<td>16.6 ± 10.5</td>
<td>-2.5–47.8</td>
<td>61.8 ± 29.3</td>
<td>10.0–143.0</td>
</tr>
<tr>
<td>Newport</td>
<td>6.8 ± 5.6</td>
<td>-3.5–22.7</td>
<td>17.2 ± 10.3</td>
<td>-2.1–48.1</td>
<td>63.3 ± 28.3</td>
<td>11.7–142.4</td>
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<td>San Francisco</td>
<td>14.4 ± 5.0</td>
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### Time Period Projections

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Uses of SLR Projections

Siting New Development
Protection Existing Development

Goleta Flood Risks, at present and with 1.4 m rise in sea level.
Source, Pacific Institute The Impact of Sea Level Rise on the California Coast, Heberger et al. 2009
SLR Concerns for Planning

LCPs are Key to Addressing SLR

- Land Use Plans
  - Kinds of Development
  - Locations Development
  - Intensity of Development

- Resource Protection Policies
  - Hazards Element
  - Safety Element

- Implementing Ordinances

Source: San Diego Foundation, Focus 2050
New development should be safe from erosion, flooding or wave impacts over its life – without shore protection.

**Long-term Beach Change**
- Erosion for 75 or 100 years*
- **PLUS**
- Seasonal Beach Change

**Wave & Water Level Changes**
- Water level from high tide
- **PLUS**
- 75 or 100 years* of sea rise
- **PLUS**
- Waves from 100-year storm (1% probability of occurrence)
Waves from Significant Storm Events

The Coastal Data Information Program (CDIP)

Historic Data

This section of the website provides access to all of CDIP’s data, from the first observations made in 1975 to values just five minutes old, recorded by sensors in the water at this very moment. For a complete explanation of the organization of CDIP data, please refer to the Data Management section of our web documentation.

To locate data and products of interest, try one of the following:

- For a map including all stations, click below on ‘Maps’
- For a directory table of all stations, click below on ‘Directory’
- For a filtered table or regional selection, click on the menu bar to the left.
- For a custom search, use the search utility in the navigation bar atop this page.

For historic swell model output, please use the Swell Model Archives.

Maps - All Stations

Directory - All Stations

CDIP's major funding contributors are the US Army Corps of Engineers and the California Department of Boating and Waterways.

http://cdip.ucsd.edu/hav=historic&sub=datadiri&metric=data&UTC&pub=publics&map_stat=1,2,3
SLR Concerns for Permits

New development should be safe from erosion, flooding or wave impacts over its life – without shore protection.

Long-term Beach Change
- Erosion for 75 or 100 years*

PLUS

Seasonal Beach Change

Wave & Water Level Changes
- Water level from high tide

PLUS

75 or 100 years* of sea rise

PLUS

Waves from 100-year storm
(1% probability of occurrence)

All shaded items will change with sea level rise.
SLR Concerns for Permits

New development should be safe from erosion, flooding or wave impacts over its life – without shore protection.

Long-term Bluff Changes

Slope Stability with a Factor of Safety ≥ 1.5

PLUS

Erosion for 75 or 100 years (life of structure)

Setback = FS (1.5) +

(Annual Erosion Rate × life of structure)
SLR Concerns for Permits

New development should be safe from erosion, flooding or wave impacts over its life – without shore protection.

Long-term Bluff Changes

Slope Stability with a Factor of Safety ≥ 1.5 PLUS

Erosion for 75 or 100 years (life of structure)

Setback = FS (1.5) + (Annual Erosion Rate x life of structure)

All shaded items will change with sea level rise.
What SLR Projection do we use?

Photos (Clockwise from top left)
Sunset Beach; El Segundo Power Plant; Port of LA;
Santa Monica Pier; Asilomar Beach; Seymour Center,
Santa Cruz; Pacifica.
SLR Adaptation Tools

Avoid Hazards
Land Acquisition
  Fee Simple Acquisition
  Conservation Easements
  Transfer of Development Credits
Managed Retreat
Rolling Easements
Setbacks
Elevation

Move Hazards Away from Development
Maintain or Restore Sediment Supply to Coast
  Remove dams or by-pass sand around dams
  Harbor dredging or by-passing
Improve or Augment Sand Supplies
  Interrupt Rip Currents
  Nourish with similar or coarser than native sand
  Canyon Interceptors
Nourishment from Offshore Sand, sand in debris basins
SLR Adaptation Tools

Move Hazards Away from Development (con’t)

Retention of Sand/Beach Material
- Beach Berms
- Dune Nourishment
- Groins with or without Nourishment
- Jetties with or without Nourishment
- Breakwaters, submerged or emergent

Innovative Retention Options
- Artificial Reefs
- Perched Beaches
- Artificial Headland
- Delta Augmentation
- Beach Dewatering

Improve or Augment Sand Supplies
- Nourish with similar or coarser than native sand
- Canyon Interceptors
- Nourishment from Offshore Sand, sand in debris basins
- Remove dams or by-pass sand around dams
- Harbor dredging or by-passing
SLR Adaptation Tools

Barriers between Hazards and Development

Revetments
- Rip Rap
- Concrete Armor Units
- Gabions
- Geotextile Bags

Seawalls
- Vertical Tie-back walls
- Gravity Walls
- Cantilever Walls

Miscellaneous
- Vegetation
- Dewatering
- Sea Cave fills

Flood Protection
- Buildings
- Electrical Equipment
- Tunnels
Adaptation to Sea-Level Rise

Solana Beach, north of Fletcher Cove, 2010. Source: California Coastal Records Project
Adaptation to Sea-Level Rise

Solana Beach, north of Fletcher Cove, 2010. Source: California Coastal Records Project
Adaptation to Sea-Level Rise – HOW?

Solana Beach, north of Fletcher Cove, 2010. Source: California Coastal Records Project
Solana Beach, further north, 2010. Source: California Coastal Records Project
Adaptation to Sea-Level Rise

Solana Beach, north of Fletcher Cove, 2010. Source: California Coastal Records Project
Relocation Away from Hazards

House Relocation in Freshwater Lagoon, Humboldt Co, CA

Cape Hatteras Lighthouse, photos from National Park Service

House Removal, Pacifica, CA 1998
Concerns about Shoreline Armor

Block beach access, encroach on beach, reduce sediment supply, halt new beach creation, change beach character and habitat, & end effects.
Gleason’s Beach
Adaptation Options?
Broad Beach
Adaptation Options?
Broad Beach Circa 2009
Coastal Commission Policy Guidance – coming soon

www.coastal.ca.gov
Summary and Questions

“There will be time to deal with climate change…… But there will not be a better time. There will only be worse times.”

David Remnick, No More Magical Thinking, New Yorker, 19Nov2012.
Infrastructure Interdependencies

Since roads often share right-of-way with utilities, efforts to establish routes may determine locations of multiple linear infrastructure elements. Issues of relocation should consider all right-of-way elements early in the planning process.

Image from California Coastal Records Project, 2008
Arrow shows location of photo taken 4 February 2010