Engineering for Climate Change in San Diego
With reference to Sea level Rise on NCC

San Diego Floodplain Management Association Presentation 11-14-2013
Introduction

- **Bruce Smith, MBA, PE – SANDAG**
  - Study Overview

- **Chris Webb, MS – M&N**
  - Sea Level Rise Science & Guidance

- **David Cannon, MCE, PE – Everest**
  - Flooding & Design Water Level Rise Guidance

- **Bruce Smith, MBA, PE - SANDAG**
  - Adaptive Management, Regulatory Requirements and Conclusions
SANDAG’s Climate Action Strategy

Objective 4b: Protect Transportation Infrastructure from Sea Level Rise and Higher Storm Surges.

- This led SANDAG to prepare the draft LOSSAN Coastal Sea Level Rise Analysis for the Northern San Diego Coast in 2012.
- Caltrans requested that we include Interstate 5 in the study in mid 2012 and append the report to the North Coast Corridor Public Works Plan.
North Coast Corridor Program

A $6.5 billion program over 40 years including:

- Double tracking LOSSAN Coastal Rail Corridor
- Adding express lanes to Interstate 5
- Expansion of bike and pedestrian trails
- Environmental Mitigation Program for lagoon enhancements
- Other community enhancements
### Existing Infrastructure

<table>
<thead>
<tr>
<th>Existing Rail Bridge (Year Built)</th>
<th>HWY 101 Soffit Elevation (NGVD 29) (1920’S-30’S)</th>
<th>Rail Top of Sub-Grade (NGVD 29) (1885-1984)</th>
<th>Interstate 5 Soffit Elevation (NGVD 29) (1960’s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buena Vista Lagoon</td>
<td>8.2 ft</td>
<td>11.1 ft</td>
<td>21.1 ft</td>
</tr>
<tr>
<td>Batiquitos Lagoon</td>
<td>9.2 ft</td>
<td>19.6 ft</td>
<td>16.1 ft</td>
</tr>
<tr>
<td>San Elijo Lagoon</td>
<td>10.0 ft</td>
<td>17.0 ft</td>
<td>31.5 ft</td>
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<tr>
<td>San Dieguito Lagoon</td>
<td>6.1 ft</td>
<td>10.0 ft</td>
<td>21.6 ft</td>
</tr>
<tr>
<td>Los Penasquitos</td>
<td>16 ft</td>
<td>13.7 ft</td>
<td>21.7 ft</td>
</tr>
</tbody>
</table>

*Spring higher high tide is +4’, EOWL is 5.3’ NGVD29
**Current global SLR predictions range from 1.5 to 5.5 feet

**Future Extreme Ocean Water Level May Reach 10.8 feet**
Highway 101 Washed Away 1927
Past Predictions of Sea Level Rise

Using 1975 as a starting point, by 2013, or after 38 years, the range of predicted SLR was from 0.1 to 0.3 meters or 4 inches to a foot.

Actual was 2”, or half the lowest prediction!
Sea Level Rise Study Objectives

- Summarize current climate science & public guidance on climate change and SLR
- Recommend which sea level rise scenarios to use
- Provide design water level guidance considering; sea level rise, extreme tides, storm surge, storm waves, fluvial floods, and combinations of these
- Identify potential adaptive management strategies
Chris Webb – Climate Science
Climate Change & Sea Level Rise

- Climate change attributed to build-up of Greenhouse gases
  - Mainly Carbon Dioxide (CO$_2$) and
  - Methane (CH$_4$)
  - CO$_2$ now at 400ppm or 400/1,000,000 or 1/2500 or (1/25)% or 0.04% of atmosphere composition

- SLR projections primarily based on global climate change models for GHG.
Global CO2 now 400 ppm – 0.04%
Mean Global Temperature 1880-Date

Jan-Dec Global Mean Temperature over Land & Ocean

Anomaly (°C) relative to 1901-2000

NCDC/NESDIS/NOAA
Figure 2.2: Historic global sea-level observations (red) and future projections (dashed lines). The blue shaded area is from Meehle et al. 2007 analysis and the higher grey projections are from Rahmstorf, S. 2007 analysis.
Global Sea Level Rise

- From 1900-2000 = 0.07”/year
- Approximately 8 inches since 1929 globally

Regional MSL trends from Oct–1992 to Jul–2009 (mm/year)
Sea Level Rise By 2100

5 meters

Ice-sheet melt Greenland/Antarctica

IPCC = Intergovernmental Panel on Climate Change

(Source: Houston & Dean 2011)
Various 2100 Global SLR Projections

(Source: California Coastal Commission)
SLR in San Diego – Tide Gauges & Satellites

Tide Gauge at La Jolla on Scripps Pier records SLR of 2mm per year or 8” per century from 1928.

Using Satellite Tide Gages from 1990 shows reduced sea level.
La Jolla Mean Sea Level Tide Gauge Data and Future Projections from the USACE (2011)

(MLLW is 2.29 feet below NGVD29 vertical datum)
Regional and Global Sea-Level Rise Projections

Being used by California for interim planning
CO-CAT (OPC) March 2013 SLR Guidance

- **2000 – 2030**: Regional* SLR of 0.1 ft to 1.0 ft
- **2000 – 2050**: Regional* SLR of 0.4 ft to 2.0 ft
- **2000 – 2100**: Regional* SLR of 1.4 ft to 5.5 ft

*Regional = California Coast south of Cape Mendocino
Tsunami Propagation Plot
Tohoku Japan  2011 M9.0 Event
La Jolla Tsunami waves from Japan M9.0 Quake
March 11, 2011

La Jolla Tsunami Related Water Level Differences

Date PST

Water Level Difference (ft)
Tsunami Inundation Maps

Maximum inundation area from tsunami runup for emergency planning (conservative)

http://www.conservation.ca.gov/cgs/geologic_hazards/Tsunami/Inundation_Maps/SanDiego
San Dieguito River Rail Bridge 243 at high spring tide.
1858 Category 1 Hurricane dissipated on Santa Catalina Island – San Diego had 85mph winds (200 yr storm)
1862/01 - 7” rain in San Diego
1916 Jan - 7.6” rain in San Diego (5” in 12 hours) SMRB and SLRRB washed away
1927 Jan - 6.3” San Diego, 21.9” in Cuyamaca. SDRBR raised
1938-39 El Nino there were 4 tropical storms
  ▪ 3 Storms made landfall in Baja Calif - 7”, 4” & 3” rain SD
  ▪ Cat 1 Storm 4 made landfall in San Pedro with 50mph winds
    ▪ 5” rain in Los Angeles
    ▪ 12” rain in surrounding mountains
1976 Hurricane Kathleen – 57 mph winds, 6 to 12 “ rain in South Calif. (160 year event)
1997 Hurricane Linda Cat 5 off shore - 2.5” rain & 18 ft waves
1997 Hurricane Nora 4.5” rain at Mt Laguna
Design Water Level Schematic
Coastal Storms Vs. Fluvial Storms

Based on Coastal Storms

- Wave crest above design water level
- Design water level
- Wave setup
- Sea level rise
- Design ocean water level (Extreme high water)

Based on Fluvial Storms

- Final design water level
- 100-yr storm water level
- Design ocean water level with sea level rise
- Sea level rise
- Design ocean water level (MHHW or MHL, etc.)

Bridge Soffit Elevation
Vertical Datum (NAVD88 or NGVD29)
Ocean Water Level Analysis Components

- **Still Water Level**
  - Estimated as MSL
  - Increases with increase in local MSL (Local SLR)

- **Astronomical Tide**

- **Cyclic Climate Patterns**
  - ENSO
  - PDO

- **Storm Surge**
  - Barometric pressure
  - Wind stress

- **Wave Set Up**

- **Tsunamis**
Vertical Datums & Tidal Benchmarks (La Jolla)
# Extreme Ocean Water Levels (La Jolla) (Over Gauge Life, NOAA 2012b)

<table>
<thead>
<tr>
<th>Event</th>
<th>Elevation (ft, NGVD 29)</th>
<th>Elevation (ft, NAVD 88)</th>
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</thead>
<tbody>
<tr>
<td>100-Year</td>
<td>5.32</td>
<td>7.43</td>
</tr>
<tr>
<td>75-Year</td>
<td>5.29</td>
<td>7.40</td>
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<tr>
<td>50-Year</td>
<td>5.27</td>
<td>7.38</td>
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<tr>
<td>10-Year</td>
<td>5.10</td>
<td>7.21</td>
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<tr>
<td>2-Year</td>
<td>4.83</td>
<td>6.94</td>
</tr>
<tr>
<td>1-Year</td>
<td>4.41</td>
<td>6.52</td>
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</table>
Greatest Vulnerability - Fluvial Flooding

San Dieguito River in Flood - Del Mar 1980
Los Penasquitos Lagoon – 20-Year Storm Flow
Fluvial Water Level Analysis Components

- **Model Type**
  - Dimensional Resolution (1D, 2D, or 3D)
  - Steady State vs. Unsteady State
  - Fixed Bed vs. Erodible Bed

- **Boundary Conditions**
  - Upstream
  - Downstream

- **Model Application**
  - Method to find maximum water level
  - Method to find maximum water velocity
Modeling Floods

- **Model Types**
  - Dimensional Resolution (1D, 2D, or 3D)
  - Steady State vs. Unsteady State
  - Fixed Bed vs. Erodible Bed

- **Model Application**
  - High tide & SLR to find maximum flooding water level
  - Low Tide & no SLR to find maximum water velocity

- **Realistic Approach: Fluvial Flood use Unsteady State Model with Erodible Bed**
  - Incorporate SLR Into Downstream Boundary Condition
  - $WL_{100}$ With SLR of 1.5’, 3.0’, 4.6’, 5.5’ as requested by CCC
Fluvial Water Level Analysis Guidance

- **Less Conservative Approach: Fluvial Flood Modeling With An Unsteady State Model**
  - $W_{L100}$ Under Existing Sea Level (per FEMA)
  - Add SLR Allowance of 1.5’, 3.0’, 5.5’ to $W_{L100}$

- **More Conservative Approach: Fluvial Flood Modeling With A Steady State Model**
  - $W_{L100}$ Under Existing Sea Level (per FEMA)
  - Add SLR Allowance of 1.5’, 3.0’, 5.5’ to $W_{L100}$

- **More Realistic Approach: Fluvial Flood Modeling With An Unsteady State Model Using Base Level With SLR**
  - Incorporate SLR Into Downstream Boundary Condition
  - $W_{L100}$ With SLR of 1.5’, 3.0’, 5.5’
### Flood & SLR - Existing Railroad Bridges

100-Year Water Surface Elevation & Freeboard without & with 3’ Sea Level Rise For Existing Bridges

<table>
<thead>
<tr>
<th>Bridge Information</th>
<th>100 Yr Flood without Sea Level Rise</th>
<th>With 36-Inch SLR Added To WSE</th>
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</thead>
<tbody>
<tr>
<td>Bridge Floodplain</td>
<td>Year Built/Improved</td>
<td>Sub Grade Elevation</td>
</tr>
<tr>
<td>San Luis Rey River</td>
<td>1916/1925</td>
<td>24.0</td>
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<tr>
<td>Loma Alta Creek</td>
<td>2008</td>
<td>22.0</td>
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<tr>
<td>Buena Vista Lagoon</td>
<td>1984</td>
<td>11.1</td>
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<tr>
<td>Agua Hedionda Lagoon</td>
<td>2007</td>
<td>26.0</td>
</tr>
<tr>
<td>Batiquitos Lagoon</td>
<td>1942/1980</td>
<td>19.6</td>
</tr>
<tr>
<td>San Elijo Lagoon</td>
<td>1942</td>
<td>17.0</td>
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<tr>
<td>San Dieguito River South</td>
<td>1916</td>
<td>10.0</td>
</tr>
<tr>
<td>Los Penasquitos Lagoon</td>
<td>1911</td>
<td>14.1</td>
</tr>
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<td>Los Penasquitos Lagoon</td>
<td>1932</td>
<td>14.1</td>
</tr>
<tr>
<td>Los Penasquitos Embankment</td>
<td>1925</td>
<td>8.8</td>
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</table>
# Railroad Bridges With 100 Year High Water Above Ballast Subgrade

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Existing Rail Bridges</th>
<th>Proposed Rail Bridges</th>
</tr>
</thead>
</table>
| **100-Year Flood - Bridges with water above the Subgrade** | San Dieguito River (243.2)  
Penasquitos Lagoon (246.1)  
Penasquitos Creek (248.7)  | Penasquitos Lagoon (246.1)  
Penasquitos Creek (248.7)  |
| **100-Year Flood & 3’ SLR - Bridges with water above the Subgrade** | Buena Vista Lagoon (228.6)  
San Elijo Lagoon (240.4) – Steady State Model Result  
San Dieguito Lagoon (243.2)  
Penasquitos Lagoon (246.1)  
Penasquitos Lagoon (246.9)  
Penasquitos Lagoon (247.1)  
Sorrento Valley (247.7)  | Buena Vista Lagoon (TBD)  
San Elijo Lagoon (240.4) – Steady State Model Result  
Los Penasquitos Lagoon (246.1)  
Los Penasquitos Lagoon (246.9)  
Los Penasquitos Lagoon (247.1)  
Sorrento Valley (247.7)  |
## Bridge Project Description

<table>
<thead>
<tr>
<th>Bridge Project Description</th>
<th>Bridge Location</th>
<th>Construction Timeframe</th>
<th>0” SLR</th>
<th>18” SLR</th>
<th>36” SLR</th>
<th>66” SLR</th>
<th>66” SLR Without Flood</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Luis Rey River</td>
<td>MP 225.4</td>
<td>2010-2020</td>
<td></td>
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<tr>
<td>Buena Vista Lagoon Bridge Replacement &amp; Double-Track</td>
<td>MP 228.6</td>
<td>2010-2020</td>
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<td>Agua Hedionda Lagoon Bridge Replacement (West)</td>
<td>MP 230.6</td>
<td>2011</td>
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<tr>
<td>Agua Hedionda Lagoon Bridge Replacement (East)</td>
<td>MP 230.6</td>
<td>2011</td>
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<tr>
<td>Batiquitos Lagoon Bridge Replacement &amp; Double-Track</td>
<td>MP 234.8</td>
<td>2020-2030</td>
<td></td>
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<tr>
<td>San Elijo Lagoon Bridge Replacement &amp; Double-Track</td>
<td>MP 240.4</td>
<td>2010-2020</td>
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<td>✓</td>
<td>✓</td>
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<td>✓</td>
<td>Risk will be managed via storm monitoring and operational restrictions.</td>
</tr>
<tr>
<td>San Elijo Lagoon Bridge Replacement &amp; Double-Track (New Inlet Location)</td>
<td>MP 240.6</td>
<td>2010-2020</td>
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<td>✓</td>
<td>✓</td>
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<td>Risk will be managed via storm monitoring and operational restrictions.</td>
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<td>San Dieguito River Bridge Replacement &amp; Double-Track (North Abutment)</td>
<td>MP 243.0</td>
<td>2030-2040</td>
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<tr>
<td>San Dieguito River Bridge Replacement &amp; Double-Track (South Abutment)</td>
<td>MP 243.2</td>
<td>2030-2040</td>
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<tr>
<td>Los Penasquitos Lagoon Bridge Replacement</td>
<td>MP 246.1</td>
<td>2010-2020</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
<td>Risk will be managed via storm monitoring and operational restrictions.</td>
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<tr>
<td>Los Penasquitos Lagoon Bridge Replacement</td>
<td>MP 246.9</td>
<td>2010-2020</td>
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<td>✓</td>
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<td>Risk will be managed via storm monitoring and operational restrictions.</td>
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<tr>
<td>Los Penasquitos Lagoon Bridge Replacement</td>
<td>MP 247.1</td>
<td>2010-2020</td>
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<td>Risk will be managed via storm monitoring and operational restrictions.</td>
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<tr>
<td>Los Penasquitos Creek Sorrento Valley Bridge Replacement</td>
<td>MP 247.7</td>
<td>2010-2020</td>
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<td>✓</td>
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<td>Risk will be managed via storm monitoring and operational restrictions.</td>
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<tr>
<td>Los Penasquitos Creek Merge Bridge Replacement</td>
<td>MP 248.7</td>
<td>2010-2020</td>
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<td>✓</td>
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<td>Risk will be managed via storm monitoring and operational restrictions.</td>
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<tr>
<td>Carroll Creek Bridge Replacement</td>
<td>MP 249.9</td>
<td>2010-2020</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

### PWP Phase 1 Bridges
- Green: Projected water surface elevation below Top of Subgrade
- Yellow: Projected water surface elevation above Top of Subgrade by as much as 2.0 feet.
- Red: Projected water surface elevation above Top of Subgrade by over 2.0 feet.

### Notes
- Risk will be managed via storm monitoring and operational restrictions.
Tsunami Design Considerations

- Tsunami waves of 2 to 3 feet (from Tide Gauges)
- Believed uncoupled with:
  - Tides
  - El Nino Southern Oscillation
  - Storm surge
  - Fluvial flooding
- Treat as a separate event
- High velocities are greatest threat to bridges and embankments
Tsunami Design Guidance

- Provide lateral support for impact loading
- Protect bridge abutments and piers from scour
  - Deep pile foundations
  - Scour protection
- Protect transportation embankments from scour
  - Armor embankments
- Secure pre-cast elements to protect against uplift
  - Tie downs/bolting
  - Open vents (e.g., sidewalks)
Combined High Water Analysis Summary

- **Railroad & I-5 Bridges**
  - Fluvial storms result in highest water levels

- **Highway 101 Bridges**
  - Fluvial or coastal storms result in highest water levels
  - Site-specific assessment required

- **Tsunamis**
  - Separate, independent events
  - Increases water levels by several feet over MHW
  - Water elevation increases are below fluvial levels
  - Generate high, lateral forces and water velocities
Resilient Design Guidance

Alternative Analysis - Consider full range of SLR (1.5 to 5.5 feet)

- Where feasible and practicable, design for the greater of:
  - 100-year ocean water level with 5.5 feet SLR plus waves for HWY 101
  - 100-year fluvial flood water level with 5.5 feet SLR for Railway & Freeway

- Conduct unsteady state modeling to assess service interruptions
  - Compare results to ballast elevations for rail bridges
  - Compare results to travel lane elevations for I-5 bridges

- Treat tsunamis as separate events
  - Scour the most significant threat

Consider Adaptation Strategies for the higher SLR projections

- Consider operational interruptions during storms as an adaptation strategy
- Consider adaptation strategies to accommodate higher predictions of up to 5.5 feet by 2100 or when it occurs due to uncertainty in future predictions
- Design bridges that can be raised in future
Bruce Smith – Adaptation & Conclusions
Adaptable Precast Concrete Bridge Spans

- If infeasible to design to the highest projected SLR
  - Design piles to support higher bridge in future.
  - Use precast bridge spans that can be raised if higher SLR occurs in future.
Adaptable Precast Concrete Bridge Spans
Other Considerations

Balance science, engineering, & environmental issues:

- **Science – how good are the SLR projections?**
  - No probabilities are associated with projections
  - Evolving science and predictions
- **Engineering – cost to accommodate SLR**
  - Different design criteria in different corridors
    - 50-year for local infrastructure
    - 75-year for interstate freeway
    - 100-year for interstate railroad
  - Adaption may be more effective than designing for highest projections
- **Environmental Review – need to consider the LEDPA**
  - Wetlands impacts
  - View impacts
- **Permits – regulatory requirements evolve**
  - Coastal Commission
  - FHWA (now recommending design for scour under 200-year storm)
  - FEMA (currently studying incorporation of SLR into floodplain mapping)
Questions

San Clemente Pier 1983

Source: Jim Dahl, City of San Clemente