Review of an historic coastal event reaching regression and impacts to coastal loading.

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Photo Credit: GEI Consultants
- Flood Control District established in 1949
- 10 zones based loosely on watersheds
- Western Alameda County: hills to Bay
Bay Hydrodynamics
South Bay Marsh/Ponds Embankment Systems
BACKGROUND

- Historic operation of the Salt Ponds since 1850 with no record of coastal flooding in Alameda County

- State of California acquisition of 41,000 acres of Salt ponds for restoration in 2003

- Goal of the restoration is to breach the dikes and restore the tidal action within the compounds

- As a partner with the restoration projects Flood Control goal is to reduce coast flooding potentials
Let’s understand the physics and check why we never experienced any coastal flooding up to date.

- Develop a 2-dimensional model of the 35-square-mile salt ponds network
- Evaluate flood protection with/without dikes
Simulation Results: Dikes In-Place

Salt ponds:
- Act as cascade of individual compartments for flood protection
- Large volume available between the dikes substantially reduces the peak tide due to the its dumping effect
Questions

1. What would be an appropriate size for the breaches?

2. What would be the expected rate of a breach widening once exposed to high tides?

3. Can we manage a coastal breach within a reasonable time frame?

4. Will these breaches be sustainable?
Study Purpose

- Perform reconnaissance level investigation of existing restoration breaches
- Establish understanding of existing breach sizes, geometry, characteristics - SF Bay
- Gain temporal insight into breach behavior
- Verify / refine empirical equations for tidal channel hydraulic geometry
- Apply to future flood control and restoration projects within ACFCD
Historic Tidal Marsh Diking and Restoration

- Tidal wetland areas diked for salt production or agriculture
- Material along levee alignments dredged for fill – created “borrow sloughs”
  - Maintained by salt/agriculture operations
  - Consolidated over time
  - Tidal exposure
  - Some locations protected with armoring
### Study Sites - 67 Breach Locations

Compiled from literature review, interviews, “satellite reconnaissance”

<table>
<thead>
<tr>
<th>Restoration Levee Breach Site</th>
<th>General Study Site Location</th>
<th>Number of Levee Breaches Evaluated in Study</th>
<th>Year of Levee Breach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Island Marsh</td>
<td>North Bay; near confluence with Napa River</td>
<td>4</td>
<td>2009-2011</td>
</tr>
<tr>
<td>Slaughterhouse Marsh</td>
<td>North Bay; American Canyon shoreline</td>
<td>5</td>
<td>1983, 2002-2008</td>
</tr>
<tr>
<td>Pond 2A</td>
<td>North Bay; north of Hwy 37</td>
<td>1</td>
<td>1995</td>
</tr>
<tr>
<td>Pond 3 (Midnight Breach)</td>
<td>North Bay; north of Hwy 37</td>
<td>1</td>
<td>2002</td>
</tr>
<tr>
<td>White Slough</td>
<td>North Bay; Vallejo shoreline at Hwy 37</td>
<td>1</td>
<td>1978</td>
</tr>
<tr>
<td>Bahia Marsh</td>
<td>North Bay; along Petaluma River</td>
<td>10</td>
<td>2008-2009</td>
</tr>
<tr>
<td>Carl's Marsh</td>
<td>North Bay; along Petaluma River</td>
<td>2</td>
<td>1994</td>
</tr>
<tr>
<td>Sonoma Baylands Marsh</td>
<td>North Bay; near confluence with Petaluma River</td>
<td>2</td>
<td>1996</td>
</tr>
<tr>
<td>Nevada-Shaped Marsh</td>
<td>North Bay; North Richmond shoreline</td>
<td>2</td>
<td>1979-1981</td>
</tr>
<tr>
<td>Muzzi Marsh</td>
<td>North Bay; Corte Madera Shoreline</td>
<td>4</td>
<td>1976</td>
</tr>
<tr>
<td>Oro Loma Marsh</td>
<td>South Bay; Hayward shoreline</td>
<td>2</td>
<td>1997</td>
</tr>
<tr>
<td>Cogswell Marsh</td>
<td>South Bay; Hayward shoreline</td>
<td>2</td>
<td>1980</td>
</tr>
<tr>
<td>Eden Landing Pond E8A</td>
<td>South Bay; Hayward shoreline</td>
<td>5</td>
<td>2011</td>
</tr>
<tr>
<td>Whales Tail Marsh</td>
<td>South Bay; Hayward shoreline</td>
<td>1</td>
<td>2000-2001</td>
</tr>
<tr>
<td>Bair Island</td>
<td>South Bay; Redwood City shoreline</td>
<td>10</td>
<td>1979-1983, 1993, 2009</td>
</tr>
<tr>
<td>Cooley Landing</td>
<td>South Bay; East Palo Alto shoreline</td>
<td>3</td>
<td>2002-2005</td>
</tr>
<tr>
<td>Faber Tract</td>
<td>South Bay; East Palo Alto shoreline</td>
<td>1</td>
<td>1972</td>
</tr>
<tr>
<td>Alviso Pond A6</td>
<td>South Bay; Mountain View/Sunnyvale shoreline</td>
<td>4</td>
<td>2010</td>
</tr>
<tr>
<td>Alviso Ponds A10, 20, 21</td>
<td>South Bay; Newark/Milpitas shoreline</td>
<td>5</td>
<td>2006</td>
</tr>
<tr>
<td>Warm Springs Marsh</td>
<td>South Bay; Newark/Milpitas shoreline</td>
<td>2</td>
<td>1986</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>67</strong></td>
<td><strong>1972-2011</strong></td>
</tr>
</tbody>
</table>
Study Methods and Data Sources

- **Collected Study Data**
  - Breach Widths – Current and Historic
  - Average Annual Rate of Breach Widening
  - Breach Width Progression Trends
  - Channel Invert Elevations
  - Breach Geometry
  - Levee Fill Soil Types

- **Data Sources**
  - Aerial Imagery (Historic / Current)
  - Literature Review
  - Interviews
  - Site Visits
Breach Type Categories

- Breach sites categorized based on location and influences
  - Location relative to bay
  - Location relative to fluvial sources
  - Location within restoration site

- Five separate categories developed for levee breach type:
  - External
  - Tidal-Fluvial
  - Internal
  - Unplanned
  - Armored
Breach Type Categories

- Tidal-Fluvial Breach – Warm Springs
- External Breach – Oro Loma
- Internal Breach – Eden Landing
- Armored Breach – Oro Loma
Observations

Typical Breach Erosion Features:

- Vertical to near-vertical slopes
- Erosion and undercutting along the levee base
- Slumping and caving - widening
- Armoring appears very effective at stabilizing breach
Satellite Image Data Collection

Outer Bair Island Southwest;
September 2008
(not yet breached)
Satellite Image Data Collection

Outer Bair Island Southwest;
May 2009
Breach Width – 40’
Satellite Image Data Collection

Outer Bair Island Southwest;
October 2009
Breach Width – 65’
Satellite Image Data Collection

Outer Bair Island Southwest;
November 2010
Breach Width – 110’
Eden Landing

• Future SBSPRP Phase 2 Restoration Work
  ▫ EIS/R process underway
  ▫ Multi purpose project including coastal flood reduction
Comparable Eden Landing Breaches

- Study Locations refined to include comparable breach sites
  - Refined data set applicable to Eden Landing area
  - 24 of 67 sites selected
- Selection Criteria – Breaches excluded
  - Multiple breach locations, extreme wind-wave erosion
  - Erosion of mudflat only
  - Training levees, high ground, armored
  - Recent breaches

<table>
<thead>
<tr>
<th>Breach Type Category</th>
<th>Number of Comparable Breaches Included</th>
<th>Breach Study Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External</strong></td>
<td>6</td>
<td>Faber Tract, Outer Muzzi 1, Outer Muzzi 2, Outer Bair Island Northwest, Outer Bair Island Southwest, Outer Bair Island West</td>
</tr>
<tr>
<td><strong>Tidal-Fluvial</strong></td>
<td>6</td>
<td>A21 Southwest, A21 South, A20 South, A19 Southwest, A19 Southeast, Slaughterhouse Point 3</td>
</tr>
<tr>
<td><strong>Internal</strong></td>
<td>12</td>
<td>Slaughterhouse Point 1 and 2*, Outer Bair Interior 1-5, Whale’s Tail Marsh Breach, Pond 2A, Bahia interior 4-6</td>
</tr>
</tbody>
</table>
Excluded Examples

Multiple Breach – Outer Bair Island

Armored Breach – Warm Springs

Recent Breach – Eden Landing

Mudflat Erosion – Sonoma Baylands
## Findings

### Average Breach Width
- Highest: External breaches
- Lowest: Internal breaches

<table>
<thead>
<tr>
<th>Breach Type Category</th>
<th>Average Breach Age (yrs)</th>
<th>Average Breach Width (ft)</th>
<th>Minimum Breach Width (ft)</th>
<th>Maximum Breach Width (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External</td>
<td>25</td>
<td>125</td>
<td>100</td>
<td>175</td>
</tr>
<tr>
<td>Tidal-Fluvial</td>
<td>7</td>
<td>86</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>Internal</td>
<td>14</td>
<td>66</td>
<td>25</td>
<td>160</td>
</tr>
</tbody>
</table>
Findings

**Average Annual Rate of Breach Widening:**
- Highest: External breaches
- Lowest: Internal breaches
- Average rates up to two times higher where initial width data was measured within 1-2 years following breach date
- Suggests higher rate just after breaching, decreases with time

<table>
<thead>
<tr>
<th>Breach Category</th>
<th>All Breaches Where Widening Occurred</th>
<th>Only Breaches Where Initial Width Measured Shortly After Breach (1-2 yrs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Annual Rate of Widening (ft/yr)</td>
<td>Number of Breaches</td>
</tr>
<tr>
<td>External</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Tidal-Fluvial</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Internal</td>
<td>2</td>
<td>12</td>
</tr>
</tbody>
</table>
Breach Width Progression - Comparable Internal Levee Breaches

- Whale's Tale
- Pond 2A
- Outer Bair Island Interior 1
- Outer Bair Island Interior 2
- Outer Bair Island Interior 3
- Outer Bair Island Interior 4
- Outer Bair Island Interior 5
- Bahia Interior 4
- Bahia Interior 5
- Bahia Interior 6

Estimated Breach Width (ft)

Dates:
- 12/19/1986
- 12/19/1987
- 12/18/1989
- 12/17/1991
- 12/17/1993
- 12/17/1996
- 12/16/1998
- 12/15/2000
- 12/15/2002
- 12/14/2004
- 12/13/2006
- 12/12/2008
- 12/11/2010
- 12/13/2012
Findings

**Breach Width Progression Trend:**
- Breach width progression - asymptotic trend of widening.
- Breach progression rates higher just after breaching - decrease with time from breach.

**QUESTION:** How does this compare to geometry suggested by empirical relationships?

- Channel hydraulic geometry reaches equilibrium state
- Hydraulic geometry is function of tidal prism of restoration area
Verification of Empirical Relationships

- Historic observations linking channel hydraulic geometry and tidal prism
- Empirical relationships previously developed for SF Bay region (Williams et al., 2002)

Diurnal tidal prism vs. marsh watershed area for mature ancient marshes in SF Bay
(Williams et al., 2002)

Channel top width vs. marsh watershed area for mature ancient marshes in SF Bay
(Williams et al., 2002)
Available Historic Data - U.S. Coast Survey T-Sheets

- Historic maps of coastal features prior to Euro-American modification (c. 1850s)
- Detailed mapping of SF Bay marsh extents and tidal channels
- Important for understanding physical characteristics of SF Bay shoreline
Verification of Empirical Relationships

Developing Relationships based on Eden Landing Historic Marsh

- Refine previously developed regional equation for Eden Landing site
  - Relationship between marsh watershed and channel width
Findings

- Equation coefficients refined for Eden Landing
- Verify strong correlation between historic channel width and marsh area
- General agreement with previously developed regional equation
- However, trends diverge for larger marsh areas
  - SF Bay study included several large marshes (1,000-10,000 hectares)
  - Range of Eden Landing marsh area between 15 - 1,500 hectares

\[
y = 3.44x^{0.552}
\]

\[
y = 4.67x^{0.43}
\]

\[R^2 = 0.88\]
Application to Eden Landing

- Using refined Eden Landing equation; pond areas ranging from 75-275 ha
  - Equilibrium levee breach width ~100-175’ wide (for single breach)
  - For same area, equilibrium reach width decreases for multiple breaches
  - For final breach/pond design, optimization needed for max. allowable flood levels
Conclusions

- **San Francisco Bay restoration dataset:**
  - Suggests equilibrium state for breach/channel width: 50-175’
  - Widening rates $\sim$5-15 ft./yr.
- **Empirical equations developed for historic SF Bay marshes:**
  - Strong correlation between channel width and marsh area
  - Used to guide breach design – suggest local refinement
- **Empirically derived geometries:**
  - Coincide well with optimized geometry used in Eden Landing coastal flood modelling
- **Marsh restoration projects can compliment goals of coastal flood protection**