Design of Levee Breaches in Sheltered Water for Flood Risk Reduction & Marsh Restoration

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Alameda County Flood Control District

- Flood Control District established in 1949
- 10 zones based loosely on watersheds
- Western Alameda County: hills to Bay
Integrated Flood Plain Management and Restoration

• We are working jointly with a number of State, Federal and local agencies including FEMA Region-9, NOAA, California Coastal Conservancy, Fish and Wild Life and many more.
Bay Hydrodynamics
South Bay Marsh/Ponds Embankment Systems
EXTENSIVE MARSH/POND/EMBANKMENT SYSTEM
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 salt pond compounds

• As a partner with the restoration projects Flood Control goal is to reduce coastal flooding potentials

• Flood Control in charge of design alternatives
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 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 the tides hydrodynamics?

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

4. Will these breaches be sustainable?
Study Purpose

- Perform a reconnaissance level investigation of existing restoration breaches
- Establish realistic range of existing breach sizes within SF Bay region
- Develop an understanding of basic levee breach characteristics and geometry
- Gain insight into breach performance over time
- Verify / refine empirical equations for tidal channel hydraulic geometry
- Apply to future flood control and restoration projects within ACFCD (Eden Landing)
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 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 and Current)
  ▫ Literature Review
  ▫ Interviews
  ▫ Site Visits
Available Historic Data - U.S. Coast Survey T-Sheets

- Historic maps of coastal marsh features prior to Euro-American modification (c. 1850s)
- Detailed mapping of SF Bay marsh extents and tidal channels
- Important for understanding physical and ecological characteristics of SF Bay shoreline
### 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>
</tbody>
</table>

**Total** 67 1972-2011
Levee Breach Armoring
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
Observations

Typical Breach Erosion Features:

- Slumping and caving of the exposed levee soils
- Breach sidewalls typically have vertical to near-vertical slopes
- Erosion and undercutting along the saturated levee base initiates slumping and caving, widening the breach
- Armoring appears very effective at stabilizing breach width (minimal breach erosion and/or progression)
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
  - Expected to begin within next 5 years
  - Multi purpose project including coastal flood reduction
Comparable Eden Landing Breaches

- Study Locations refined to include comparable breach sites
  - Develop refined data set applicable to Eden Landing area
  - 24 out of 67 site selected
- Selection Criteria – Breaches excluded
  - Multiple initial breach locations and extreme wind-wave erosion
  - Erosion occurring only in the tidal channel or surrounding mudflat areas
  - Training levees or other man-made features
  - High ground or relatively non-erodible features
  - Recent breaches locations (2010 or later)

<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>External</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>Tidal-Fluvial</td>
<td>6</td>
<td>A21 Southwest, A21 South, A20 South, A19 Southwest, A19 Southeast, Slaughterhouse Point 3</td>
</tr>
<tr>
<td>Internal</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>
Findings

Current 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 Current Breach Width (ft)</th>
<th>Minimum Current Breach Width (ft)</th>
<th>Maximum Current 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 Levee Breach Widening:**
- Highest average: External breaches
- Lowest Average: Internal breaches
- Average rates up to two times higher where initial width data was measured within 1-2 years following breach date
- Rates generally higher shortly after levee breaching and decrease with time from the breach date

<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 Included</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>
External Levee Breaches

Average Annual Rate of Breach Widening - Eden Landing Comparable External Levee Breaches

- Faber Tract: 3.1 ft/yr
- Outer Muzzi 1: 3.0 ft/yr
- Outer Muzzi 2: 1.8 ft/yr
- Outer Bair Island Northwest: 2.4 ft/yr
- Outer Bair Island Southwest: 18.3 ft/yr
- Outer Bair Island West: 10.0 ft/yr
Average Annual Rate of Breach Widening - Eden Landing Comparable Tidal-Fluvial Levee Breaches

Tidal-Fluvial Levee Breaches

<table>
<thead>
<tr>
<th>Location</th>
<th>Average Annual Rate of Breach Widening (ft/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A21 Southwest</td>
<td>8.3</td>
</tr>
<tr>
<td>A21 South</td>
<td>5.0</td>
</tr>
<tr>
<td>A20 South</td>
<td>4.2</td>
</tr>
<tr>
<td>A19 Southwest</td>
<td>4.2</td>
</tr>
<tr>
<td>A19 Southeast</td>
<td>15.0</td>
</tr>
<tr>
<td>Slaughterhouse Point 3</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Average Annual Rate of Breach Widening - Eden Landing Comparable Internal Levee Breaches

*Note - Unplanned breach location considered as internal breach type

Internal Levee Breaches

- Slaughterhouse Point 1: 0.8 ft/yr
- Slaughterhouse Point 2: 1.1 ft/yr
- Outer Bair Interior 1: 1.0 ft/yr
- Outer Bair Interior 2: 1.8 ft/yr
- Outer Bair Interior 3: 1.8 ft/yr
- Outer Bair Interior 4: 3.2 ft/yr
- Outer Bair Interior 5: 3.3 ft/yr
- Whale's Tail Marsh Breach: 2.0 ft/yr
- Pond 2A: 0.6 ft/yr
- Bahia Interior 4: 5.0 ft/yr
- Bahia Interior 5: 3.3 ft/yr
- Bahia Interior 6: 5.0 ft/yr
Breach Width Progression - Comparable Internal Levee Breaches

Internal Levee Breaches

Estimated Breach Width (ft)

- 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

Dates:
- 12/19/1985
- 12/19/1986
- 12/19/1987
- 12/19/1988
- 12/19/1989
- 12/19/1990
- 12/17/1991
- 12/17/1992
- 12/17/1993
- 12/17/1994
- 12/17/1995
- 12/16/1996
- 12/15/1997
- 12/15/1998
- 12/15/1999
- 12/15/2000
- 12/15/2001
- 12/15/2002
- 12/14/2003
- 12/14/2004
- 12/14/2005
- 12/13/2006
- 12/13/2007
- 12/13/2008
- 12/13/2009
- 12/13/2010
- 12/13/2011
- 12/13/2012
Findings

Breach Width Progression Trend:

• Breach width progression plots show an asymptotic trend of widening.

• Width progression rates are higher immediately following levee breaching and decrease with time from breach.

• Data supports trends suggested by empirical relationships
  ▫ Channel hydraulic geometry reaches equilibrium state over time
  ▫ Hydraulic geometry a function of size and tidal prism within 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)
Verification of Empirical Relationships

Developing Relationships based on Eden Landing Historic Marsh

- Evaluate relationship between marsh watershed and tidal channel width in Eden Landing study area
- Refine previously developed regional equation for Eden Landing site
Findings

- Verify a strong correlation between historic channel width and marsh area
- Good agreement with previously developed equations for SF Bay
- 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
- Equation coefficients refined for Eden Landing
Application to Eden Landing

- Current pond areas range from 70-175 ha
- Considering two main external breaches
  - Using refined equation for Eden Landing: Each breach approximately 180’ wide
  - Smaller internal breaches: Range from 95-105’ wide
Conclusions

- Existing data compiled from restoration projects around SF Bay
  - Suggests equilibrium state for breach and channel width between 50-150’ depending on location and influences (breach type categories)
  - Breach widening rates varies from approximately 5-15 ft./yr. (manageable from maintenance standpoint)
- Empirical equations developed for historic SF Bay marshes suggest strong correlation between channel width and marsh area
  - However, we recommend these equations be refined for local application
  - Once refined for local restoration project, equations will help guide design of sustainable breach geometry.
- Empirically derived breach and channel geometry coincide well with the optimized geometry used in coastal flood modelling for Eden Landing restoration project.
- Study indicates that marsh restoration projects compliment goals of coastal flood protection