Evaluation of Tidal Hydraulics and Geomorphic Change under different Restoration Alternatives

February 6, 2008
Topics for Today’s Discussion

- Summary of Work to Date
- Restoration Alternatives and their Major Elements/Assumptions
- Hydrodynamic Modeling
- Implications for Marsh Morphology
Work Completed

- Task A: Literature Review of Observed Marsh Loss Elsewhere and Management Responses
- Task B: Restoration Concepts
- Task C: Inlet Stability
- Task E: Geomorphology. Reviewed historical change and sediment delivery and developed Year 10 and Year 50 morphological predictions
Work in Progress

- **Task D: Hydrodynamic Modeling**
  - 95% complete, scheduled completion 2/28/08

- **Task F: Future Habitat Predictions**
  - 15% complete, scheduled completion 3/20/08

- **Task G: Conceptual Designs of Two Alternatives**
  - 5% complete, scheduled completion 3/20/08

- **Completion of Draft 100% Project Report**
  - 70% complete, scheduled completion 3/20/08
Restoration Concepts

- Alternative 1: No Action
- Alternative 2: New Ocean Inlet
- Alternative 3: Highway 1 Sill
  - 3a. Low Sill (1.4 m below MLLW)
  - 3b. High Sill (0.1 m below MLLW)
- Alternative 4: Parsons Slough
Alternative 1: No Action

- Assumes No Action is taken to arrest tidal erosion and marsh loss
- Provides a benchmark for evaluating the effectiveness of the proposed “restoration” actions
Alternative 2: New Ocean Inlet

- New ocean inlet created near the 1943 location of the Salinas River mouth
- Flood-tide shoal located near the 1943 location – known today as Lower Bennett Slough
- New connecting channel
- Highway 1 barrier
- New Highway 1 bridge
Likely Major Mechanisms of Tidal Habitat Loss and Changes

Loss of tidal marsh (edges)
- Plants physically removed by bank erosion
- Erosion of channel & tidal creeks
- Extended tidal creek network
- Erosion of soft sediments from mudflats & marsh plain

Loss of tidal marsh (interior)
- Plants physically removed by sediment erosion on the marsh plain
- Marsh elevation not keeping pace with water levels exceeding plants physiological constraints (drowning)
- Plant death likely caused by anoxic soil conditions
- Plants more susceptible to disease, etc.

Increased tidal volume, range, & velocities

Increased tidal flooding (inundation)

Decreased marsh elevations

Increased macroalgae abundance
- Smothers plants
- Reduced light availability

Decreased (organic) sediment production

Decreased (mineral) sediment & freshwater supply

Groundwater overdraft (agricultural & urban dev.)

Sea level rise

Tectonic events

Creation of Moss Landing Harbor
- Deeper estuarine mouth

Increased tidal flooding (inundation)

Diversion of the Salinas River (agricultural dev.)

Elevated nutrient levels (agricultural & urban dev.)

Decreased root biomass
Eliminate Connection to Moss Landing Harbor

Create New Inlet (smaller mouth)

Create New Inlet (smaller mouth)

Excavate Sinuous Channel

Restore self-shoaling inlet

Increase friction losses

DECREASE tidal volume, range & velocities

DECREASE tidal flooding (inundation)

Increase marsh elevations

Slow Loss of tidal marsh (interior)
- Will plants be physically removed by sediment erosion on the marsh plain

Slow loss of tidal marsh (edges)
- Will erosion of channel & tidal creeks slow?

Slow loss of tidal marsh (interior)
- Do water levels exceed drowning elevations?
Alternative 3: Highway 1 Sill

- Partial tidal barrier (a.k.a. sill) under the Highway 1 bridge
- Two sill heights were evaluated
  - 1.4 m (4.7 ft) below MLLW, selected to allow continued up-slough navigation for small craft (e.g., kayaks)
  - 0.1 m (0.4 ft) below MLLW, selected to reduce tidal prism comparable to Alternative 2
- Multiple sill configuration also possible
Likely Major Mechanisms of Tidal Habitat
Loss and Changes affected by Alternative 3

Reduce Tidal Connection to Moss Landing Harbor

- **DECREASE** tidal volume, range & velocities

- **Loss of tidal marsh** (interior)
  - Will plants be physically removed by sediment erosion on the marsh plain

- **Slow loss of tidal marsh** (edges)
  - Will erosion of channel & tidal creeks slow?

- **Slow loss of tidal marsh** (interior)
  - Do water levels exceed drowning elevations?

**DECREASE** tidal flooding (inundation)

Sediment Placement

Increase marsh elevations

- Increase marsh elevations
Alternative 4: Parsons Slough

- Reduce tidal prism from Parsons Slough and South Marsh
- Assumes fill placed to raise bed elevations of Parsons Slough and South Marsh by 1.2 m (3.9 ft)
- A water control structure could accomplish similar results without requiring fill
Likely Major Mechanisms of Tidal Habitat Loss and Changes affected by Alternative 4

Reduce Effective Tidal Prism of Parsons Slough Control Structures or Sediment Placement

DECREASE tidal volume & velocities

Sediment Placement

DECREASE tidal flooding (inundation)

Inundation

Increase marsh elevations

Slow Loss of tidal marsh (interior)
- Will plants be physically removed by sediment erosion on the marsh plain

Slow loss of tidal marsh (edges)
- Will erosion of channel & tidal creeks slow?

Slow loss of tidal marsh (interior)
- Do water levels exceed drowning elevations?

Increase marsh elevations
1943 (Pre-Harbor) Conditions

- Used as an additional basis of comparison
- 1943 represents a more “stable” condition
  - Post-large scale Slough changes resulting from human settlement and Slough alterations
  - More “stable” Slough morphology – the main channel was not actively eroding
- Does not imply that 1943 conditions are, or should be, a goal of the restoration efforts
Hydrodynamic Modeling and Geomorphic Assessment

- Year 0: Immediately after implementation
- Year 10: Short-term morphological response expected to be evident
- Year 50: Long-term morphological response – likely at the limit for which meaningful predictions can be made

Note: Short- and long-term morphological predictions contain a high degree of uncertainty
How Do We Address Uncertainty

- Qualitatively discuss the major assumptions and associated uncertainty (e.g., relative scale and importance)
- Recognize how the different uncertainties affect management decisions
- Identify data gaps where possible that could be filled to reduce uncertainties
Hydrodynamic Comparisons

- Water level vs. Velocity
- Water level vs. Percent Exceeded
- Bed Shear Stress vs. Percent Exceeded
- Projected Slough Thalweg Depths
Water Level vs. Velocity Phase Diagram

Combine two time series plots…
Water Level vs. Velocity Phase Diagram

...into a single phase diagram
Water Level vs. Velocity – Year 0

![Graph showing the relationship between water level and velocity for Year 0. The graph includes a line curve indicating EBB and FLOOD conditions, with MSL, Existing marked on the graph.](image-url)
Water Level vs. Velocity – Year 0

![Graph showing water level vs. velocity for Year 0. The graph illustrates the relationship between water level (in meters, NAVD) and velocity (in meters per second) with two lines representing different years and actions. The graph is segmented into EBB and FLOOD categories.](image)

- EBB
- FLOOD
- MSL, Existing
- 1943
- Alt. 1 No Action
Water Level vs. Velocity – Year 0

![Graph showing water level vs. velocity for different scenarios and years.](image)

- EBB
- FLOOD
- MSL, Existing

- Alt. 1 No Action
- Alt. 2 New Inlet
- Alt. 3a Low Sill
- Alt. 3b High Sill
- Alt. 4 Parsons

Years and MSLs:
- 1943 Alt. 1 No Action
- Existing MSL
Water Level vs. Velocity – Year 50

- EBB
- FLOOD
- MSL, Existing
- Alt. 1 No Action
- Alt. 2 New Inlet
- Alt. 3a Low Sill
- Alt. 3b High Sill
- Alt. 4 Parsons

- Water Level (m, NAVD)
- Velocity (m/s)
Water Level vs. Velocity

Alt. 1 No Action  Alt. 2 New Inlet  Alt. 3a Low Sill  Alt. 3b High Sill  Alt. 4 Parsons

Year 0

Alt. 1 No Action

Alt. 2 New Inlet

Alt. 3a Low Sill

Alt. 3b High Sill

Alt. 4 Parsons

Year 10

velocity (m/s)  velocity (m/s)  velocity (m/s)  velocity (m/s)  velocity (m/s)

Year 50

Alt. 1 No Action

Alt. 2 New Inlet

Alt. 3a Low Sill

Alt. 3b High Sill

Alt. 4 Parsons

velocity (m/s)  velocity (m/s)  velocity (m/s)  velocity (m/s)  velocity (m/s)
Water Level vs. Percent Exceeded – Year 0

Water level (m NAVD) vs. % time exceeded. The graph shows two lines labeled 1943 and Alt. 1 No Action. The 1943 line is green, and the Alt. 1 No Action line is blue. The marsh plain is indicated by a label on the graph.
Water Level vs. Percent Exceeded – Year 0

![Graph showing water level vs. percent exceeded for Year 0. The graph includes a line for 1943 and a line for Alternate 1 No Action. The graph indicates the water level in meters NAVD (% time exceeded). The graph also highlights the marsh plain.](image-url)
Water Level vs. Percent Exceeded – Year 0

Marsh plain

Water level (m NAVD)

% time exceeded
Water Level vs. Percent Exceeded – Year 0

The graph shows the water level (in meters NAVD) vs. the percentage of time exceeded for different alternatives in Year 0. The alternatives are:
- Alt. 1 No Action
- Alt 2. New Inlet
- Alt 3a. Low Sill
- Alt. 3b High Sill
- Alt. 4 Parsons

The graph indicates that the water level is significantly higher for alternatives with a new inlet or a high sill compared to the 1943 baseline. The marsh plain is indicated by a shaded area on the graph.
Water Level vs. Percent Exceeded – Year 50

- 1943
- Alt. 1 No Action
- Alt 2. New Inlet
- Alt 3a. Low Sill
- Alt. 3b High Sill
- Alt. 4 Parsons
## Annual erosion rates

<table>
<thead>
<tr>
<th></th>
<th>(thousands m³/yr)</th>
<th>Years 0-10</th>
<th>Years 10-50</th>
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<tbody>
<tr>
<td>Alternative 1 – No action</td>
<td></td>
<td>98</td>
<td>48</td>
</tr>
<tr>
<td>Alternative 2 – New inlet</td>
<td></td>
<td>15</td>
<td>11</td>
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<tr>
<td>Alternative 3a – Low sill</td>
<td></td>
<td>43</td>
<td>28</td>
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<tr>
<td>Alternative 3b – High sill</td>
<td></td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Alternative 4 – Parsons Slough</td>
<td></td>
<td>61</td>
<td>35</td>
</tr>
</tbody>
</table>
Restoration Implications

- Restoration actions can reduce the erosive forces in the Slough to 1943 (pre-harbor) conditions.
- Alternatives could be further refined to increase restoration potential:
  - Modify sill height or add multiple sills in order to manipulate the tidal range to meet desired marsh inundation characteristics (at current sea level).
  - Place fill in the Slough channel upstream of the sill to potentially achieve flood dominance.
  - Place fill on the marsh plain to bring subsided and degraded marshes to a more sustainable elevation.
Phasing and Adaptive Management

- Phasing the restoration would an adaptive approach and help reduce the uncertainties
- Phase 1: Parsons Slough restoration
- Phase 2: Highway 1 Sill (low or high) and sediment placement on a few degraded marsh areas
- Phase 3: TBD, perhaps sediment placement in the Slough channel, increasing the height of the sill, or constructing the new ocean inlet
Preliminary evaluation of the watersheds does not reveal any easily available, self-maintaining source of sediment for restoring sediment delivery.

Most nearby fluvial sources (e.g., Salinas and Pajaro Rivers) contain contaminated sediments.

Sediment is required to maintain marshes in the face of sea level rise.
Implications for Marsh Morphology
Geomorphic Context

- Interpretation of the model results
- Can we stem the loss of sediment?
- Do we need to find a source of sediment?
- How much sea level should we expect?
- What will be the fate of the marshes?
Management Alternatives: Flow Characteristics

![Graph showing flow characteristics with different management alternatives and water levels.](image)
Threshold in intertidal wetland evolution

Defina et al., 2007 Self-organization of shallow basins in tidal flats and salt marshes. Journal of Geophysical Research 112, F03001
Future Sea Level Rise

- Monterey Bay SLR 1.86 mm / yr (1973-1999)
- Eustatic SLR 1.8 mm/yr 1900-1990
- Eustatic SLR 3.3 mm/yr 1993-2004
- IPCC 2100 range 180 – 580 mm (mid 200-430)
- Ice melt contribution:
  - 78 (±21) -160 (±65) mm by 2050
  - 167 (±65) – 560 (±230) mm by 2100

Natural Marshplain Elevation in 2100
(relative to rising tidal waters)

- Initial marsh elevation: MHHW
- Dry density of carbon: 500 kg m$^3$

Orr, Crooks and Williams 2003 Will Restored Tidal Marshes Be Sustainable?
Restored Marshplain Elevation in 2100 (relative to rising tidal waters)

Initial marsh elevation: -0.5m MHHW  Dry density of carbon: 500 kg m$^3$

Sediment Requirements

- **Salinas River discharge:** 1.7 – 3.3 million t/yr
  (Farnsworth and Milliman, 2003; Inman et al., 1998)

- **Pajaro River discharge:** 56 thousand t/yr
  (Inman et al., 1998)

- **Carneros Creek discharge:** 10 thousand t/yr
  (Watson, personal communication)

- **Elkhorn marshes (healthy) need:** 30-40 thousand t/yr
  (SLR of 3 mm/yr)
Change observed in Elkhorn Slough are characteristic of sediment starvation

No Action Alternative

Drivers of Change
- Sea level rise
- Non-positive sediment budget

Metric of State
- Extensive vegetated marshes
- Extensive mudflats

Time
Management Alternative without Restored Sediment Source

- Extensive vegetated marshes
  - Delayed but eventual conversion to mudflat because of sea level rise

Metric of State vs. Time

Extensive mudflats
Alternative with Long-Term Sediment Management

Amount of sediment required depends on inlet management alternative and rate of sea level rise.
Comparison of Alternatives

- All action management alternatives reduce rate of sediment loss
- High sill and new inlet most effective alternatives for reducing rate of sediment loss
- Rate of sediment loss will diminish without management but may take 50 years before equilibrating (consequence extensive marsh loss)
- No modeled Alternative results in a supply of sediment
Next Steps
Conceptual Plans of Two Alternatives

- Plan Views (e.g., locations of structures or activities)
- Cross sections of the channel
- Longitudinal profile
- Preliminary cost estimates
Schedule

- **Task D: Hydrodynamic Modeling**
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Back-up Slides
Literature Review

- Summarized observed changes and plausible causes of change at Elkhorn Slough
- Reviewed applicable case studies of marsh loss and management actions elsewhere
  - Louisiana
  - Jamaica Bay (New York Harbor)
  - Southeast England
Case Study Key Findings

Restoration efforts have had mixed results:

- Marshes requiring substantive hydrologic control had diminished sediment accretion
- Spray dredging of thin sediment layers on degraded or subsided marsh had greatest short-term success
- Long-term marsh sustainability requires addressing sediment deficits
Case Study: Louisiana

Lack of sediment lowered marsh elevations and increased stress from tidal flooding and salinity.
Case Study: Louisiana

The Small Sediment Diversion Project was designed to mimic natural crevasses and associated marsh-building processes.
Case Study: Jamaica Bay

Reductions in sediment supply, altered hydraulics, and/or sea level rise are hypothesized to have contributed to marsh loss.

Elders Point, 1974 (97 acres)  
Elders Point, 1999 (21 acres)
Case Study: Jamaica Bay

A 1-acre pilot project at Big Egg Marsh consisted of spraying a thin layer of locally-borrowed sediment on the marsh.

First growing season after spraying

Spraying locally borrowed material on Big Egg Island
Analysis Approach

- Calibrated hydrodynamic model modified to represent Alternatives at Year 0
- Year 0 bed shear stress signatures, coupled with a comparison to 1943 (pre-harbor) shear stress signatures, used to develop Year 10 morphology
- Year 10 bed shear stress used to develop Year 50 morphology
Water Level vs. Velocity – Year 10

- EBB
- FLOOD

Water Level (m, NAVD)

Velocity (m/s)

EBB
FLOOD

MSL, Existing

Alt. 1 No Action
Alt. 2 New Inlet
Alt. 3a Low Sill
Alt. 3b High Sill
Alt. 4 Parsons

1943

Bed Shear Stress vs. Percent Exceeded – Year 0

![Graph showing Bed Shear Stress vs. Percent Exceeded for Year 0. The graph has two curves labeled 'Alt. 1 No Action'. The x-axis represents % time exceeded ranging from 0 to 60, while the y-axis represents Bed shear stress (N/m²) ranging from -0.5 to 0.5. The graph also includes labels for EBB and FLOOD.]
Bed Shear Stress vs. Percent Exceeded – Year 0

![Graph showing Bed Shear Stress vs. Percent Exceeded for the year 0. The graph compares two scenarios: Alt. 1 No Action and Flood. The x-axis represents the % time exceeded, and the y-axis represents the Bed shear stress (N/m²). The graph shows the percentage of time different shear stresses are exceeded under flood and ebb conditions.](image-url)
Bed Shear Stress vs. Percent Exceeded – Year 0

- Bed shear stress (N/m²)
- % time exceeded

1943
- Alt. 1 No Action
- Alt 2. New Inlet
- Alt 3a. Low Sill
- Alt. 3b High Sill
- Alt. 4 Parsons

EBB
- FLOOD
Bed Shear Stress vs. Percent Exceeded – Year 50

- 1943
- Alt. 1 No Action
- Alt. 2 New Inlet
- Alt. 3a Low Sill
- Alt. 3b High Sill
- Alt. 4 Parsons

Bed shear stress (N/m²) vs. % time exceeded.
Connection to Sediment Sink
Thresholds defining intertidal wetland evolution

Sediment Dynamics are Critical