Wind Waves and Wetlands Workshop:

Assessing the Need for and Approaches to Attenuate Wind-Wave Energy in Tidal Wetland Systems

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Sponsors:

San Francisco Bay Conservation and Development Commission
San Francisco Bay National Estuarine Research Reserve
San Francisco Estuary Project's Wetland Monitoring Group
California Coastal Conservancy

Facilitator: Center for Collaborative Policy

SUMMARY

Workshop Purpose and Goals

Steve Goldbeck, San Francisco Bay Conservation and Development Commission

The San Francisco Bay Conservation and Development Commission (BCDC) organized this workshop to discuss the management of wind-wave energy in wetlands. Given the importance of wetland restoration in the Bay Area and the millions of dollars being invested in it, it is important to understand the physical and biological processes that affect whether wetland restoration projects will achieve their objectives. Looking toward the future, sea level rise means the Bay will get bigger, possibly at the cost of the wetlands. Therefore, we also need to understand how wind-wave energy management may play a role in protecting existing wetlands.

Factors Affecting Sediment Accretion

Dave Cacchione, U.S. Geological Survey, Emeritus

This talk focused on the physical processes of sediment transport in shallow water. Along with physical factors, geological and biological factors should also be considered.

Figure 1. Factors Affecting Sediment Dynamics on Mudflats

Physical	Geological	Biological
Wind Waves Fetch & Relative Orientation, Wind Speed, Wind Duration	**Sediment Properties** Grain Sizes and Densities Bulk Density, Cohesion, Strength	**Types of Organisms** Population density, Seasonality
Tidal Range & Currents	**Bed History** Compaction & Dewatering	**Vegetation**
Wind-Driven & Residual Currents	**Morphology** Bed slope, Length Scales, Bed Features (Physical Roughness)	**Bioturbation & Mucoidal Binding**

Tidal range is an important physical factor. The longer the tidal range, the stronger the currents. The tidal range also affects wetting and drying of the mudflat. Drying can lead to bed compaction, which affects erodibility. Aside from wind waves, the next most important factor affecting sediment dynamics is grain size. Biological processes are also important. For example, algal films can build up and retard erosion of mudflats and burrowing clams can make sediment more vulnerable to erosion.

The sediment accretion or erosion rate at a given site is dependent on several variables: fluid stress, fluid shear velocity, turbulent velocity, and suspended sediment concentration. Fluid stress in the water creates bed stress that entrains material from the bed. Particles tend to settle because of gravity, and that process is dependent on the concentration of suspended material. Fluid stress prevents settling, and this process is related to turbulent velocities. If particles are falling faster than mixing, you get sediment accretion. Deposition and erosion can be going on at the same time. If deposition is greater than bed stress, there is net deposition.

The stress needed to erode bed material increases with depth due to compaction. If you have cohesive sediment, it can erode in clumps instead of particle by particle. Depositional stresses for bay mud were calculated by Krone in 1962. Recent estimates of critical erosion stress were done using SEDFLUME to support the development of the proposed Aquatic Transfer Facility[1] in San Pablo Bay. SEDLFUME is a method using a flume in a narrow channel. It allows analysis of the erodibility of sediment at different depths, using sediment taken from a core sample.

Recent Estimates for Bulk Density and Critical Erosion Stress Based on Core Taken in 4.7 m Depth in SPB (SEDFLUME results) by Craig Jones, Sea Engineering Inc.

Depth (cm)	**D_{50} (μm)**	**r_b (g/cm^3)**	**τ_{cr} (N/m^2)**
0	13.26	1.37	0.26
5.7	10.11	1.37	0.91
10	12.21	1.46	1.92
16	10.61	1.35	1.74
21	10.92	1.38	2.56
Mean	**11.42**	**1.39**	**1.48**

On intertidal mudflats, wetting and drying affects erodibility. We can estimate the bottom stress generated by waves, but we also have to consider currents, not just waves. Longshore currents can carry sediment along the shore. Boat wakes can be similar to wind waves in terms of order of magnitude.

Factors Affecting Marsh Plant Colonization

John Callaway, University of San Francisco

Seeds and propagules and appropriate conditions are needed for marsh formation. A nearby seed source is needed for large-scale input of seeds. The landscape context is important, i.e.,

[1] The Aquatic Transfer Facility is being studied as an alternative to the use of an offloader for the transfer of sediment from dredging sites to the Hamilton Wetland Restoration Project in the City of Novato in Marin County.

the site's position within the estuary will affect its seed sources. In addition to seeds coming by water (and a lesser amount by air), there may be seed banks in the sediment. Seed banks are more common in natural wetlands than in restored sites, unless the sites were only recently diked off.

There is spatial variability of vegetation in the Bay. For marsh species, there are generally a greater number of species and total number of plants recruiting as you move from saltwater to freshwater sites.

Zooey Diggory and Tom Parker (at SFSU) compared seed banks and seed rain (abundance of seeds transported to the site) at four sites on the Petaluma River. Two were natural sites and two were restoration sites. Seed banks at Pond 3, a restoration site, were small. Natural sites like Coon Island and Bull Island have greater seed rain, but most of the seeds are cattail (*Typha* spp.). Some seeds are coming in at high rates but do not establish. Seeds must be transported to a site, accumulate and establish. Wind waves could have a substantial effect on seed accumulation.

The most significant factors for marsh plant establishment are salinity and inundation. Once established, plants are fairly resistant to wind waves, inundation and salinity variation, but the crucial point is germination and early establishment. Low salinity conditions are needed for germination. Increased inundation resulted in lower germination rates in a Louisiana marsh. Lower diversity was found at lower elevation (greater inundation) in a freshwater marsh in the Chesapeake Bay. Also, competition affects plant diversity.

Sites with high wind wave energy will have lower rates of seed accumulation, higher inundation rates, and wind waves may reduce seedling survival.

A Methodology for Determining Whether Wind Wave Management is Necessary for a Given Restoration Site, or "Why Worry about Wind Waves?"

Phil Williams, Philip Williams & Associates

We now have the opportunity to significantly advance our methodology for predicting how wind-wave energy will affect wetland restoration sites.

There are two main types of wind-wave effects: (1) the effects of bay-generated waves on the bayfront edge of a restoring marsh, and (2) the effects of internally generated wind waves on the internal margin of a restoration site.

In the case of bay-generated waves, fetches can be several miles. An example is the Muzzi Marsh restoration in 1982. By 2004, the bayfront levee had eroded, but having it in place during the early years of the restoration project allowed the formation of the marsh during the period of colonization. Shoreline erosion caused by bay-generated wind waves at the Tolay Creek wetland restoration site necessitated putting in riprap along Hwy 37.

Large restoration projects now can have fetches of up to 2 miles within the site. For example, in the Napa Salt Pond restoration site, there are fetches of 3000-8000 feet. Internally generated wind waves can retard sediment deposition and erode and export deposited sediment.

We need to distinguish between how wind waves affected marshes that formed naturally and how wind waves affect restored marshes. China Camp is an example of natural marsh formation in a transgressive estuary. The marsh kept pace with gradual sea level rise and was sustained by "rolling over" the upland landscape. Marsh restoration is usually undertaken on a subsided site. Carl's Marsh is an example of a restoration site that relied on natural estuarine sedimentation to bring the mudflat up to the level that would allow spontaneous marsh plant colonization.

Physical variables affecting marsh formation

There are six main physical variables affecting marsh formation on a restoration site: initial elevation, tidal prism, suspended sediment concentration, colonization elevation, wind waves affecting deposition and erosion, and sea level rise rates.

We can influence three of these variables:

- Raise the initial elevation by placing dredged material on the site;
- Limit the tidal prism by controlling the size and elevation of the levee breach; and
- Attenuate wind wave effects by limiting fetch.

PWA has developed a conceptual model of the evolution of a site over time as sedimentation occurs. Once the mudflat elevation builds up, you can get spontaneous colonization by *Spartina* from the bay side, as opposed to vegetation spreading from the landward side.

Suspended sediment concentration is one the most important factors affecting the evolution of a site. Carl's Marsh is evolving rapidly because it is in a high total suspended sediment (TSS) environment. White Slough is evolving slowly; after 30 years, vegetation is still not established. Rising sea level will have much less effect than TSS on evolutionary trajectories.

Wind waves also affect marsh formation. Low wave energy leads to fast marshplain development and high wave energy delays marsh formation. If there is very high wave energy, a marsh will never form, and the site will always be a mudflat. We used to discount mudflats. Now we realize importance of mudflats, as transitional habitat and potentially as final habitat, since we are losing mudflats around the Bay.

Two tools to help predict sediment accretion: the hydrodynamic/analytic approach vs. geomorphic/empirical analysis

The hydrodynamic/analytic approach gives us a framework for our conceptual model and informs management solutions. It provides a systematic methodology based on linear wave theory and cohesive sediment dynamics that can incorporate stochastic processes like wind, waves and tides. We can use computer models to generate time sequences for seasonal differences in TSS and tides. The problem is that modeling and calibration are expensive, and the resulting uncertainties are too large for deterministic analysis. For example, PWA used a morphodynamic site evolution model for sedimentation with wave berms on the Hamilton Wetland Restoration Project site. It was very expensive and the model output gave a range of 1500-6000 feet as the maximum allowable fetch needed for sedimentation to occur.

The geomorphic/empirical uses monitoring data of evolution from restored projects around SF Bay, but there has been no systematic data collection and little data or restoration experience for large, deeply subsided sites. It requires the use of judgment and is open to different interpretations. For example, the design for Sonoma Baylands initially called for fetch lengths of 4000 feet. Back in 1989, the restoration objective was to get a vegetated marsh as quickly as possible. PWA did a quick survey of sites around the Bay that didn't have wind waves impeding marsh formation and came up with 1000-ft design criteria. There has been monitoring to see how well we did in achieving design objectives.

The Hamilton restoration project was the first time significant resources were dedicated to evaluation of potential wind waves. The design objective was a habitat mosaic of mudflats and marshes. PWA surveyed 18 other restoration sites, analyzed wave power and evidence of colonization, and came up with a 3000-ft fetch criteria.

What have we learned about wind waves?

- Setting objectives means deciding on how we want site to evolve. It requires specifying a planning horizon.
- Sites higher than marsh plant colonization elevation are acceptable, but filling a site too high limits tidal channel formation.
- Wind waves are of least concern on small sites with high sediment concentrations and full connection to the Bay.
- Wind waves are of most concern on large, deeply subsided sites with low sediment concentrations and constricted access to Bay.
- The worst-case scenario is that wind waves will erode and export sediment from a restoration site leading to permanent shallow subtidal habitat.

We need to develop a practical predictive tool, based on existing accretion algorithms (e.g. Mehda 1996, Fagherazzi 2007) that projects net accretion/erosion rates for different wave climates and suspended sediment concentrations in subsided restoration sites. Because of the large uncertainties and assumptions in these algorithms, this tool will only be credible and useful if calibrated with long term field data from large windy, deeply subsided restoration sites. This tool can then be used to determine the design wave climate parameters and whether and how wave action should be managed in restoration site design.

Monitoring shows that in a more wave-exposed location in Sonoma Baylands, you have a two-year lag in marsh formation compared to a more protected area. It fits the conceptual model perfectly. In the South Bay, sites evolve rapidly even with long wave fetches because TSS is very high. If we can monitor deeply subsided sites like Napa Salt Ponds, we can collect sufficient data to better calibrate models. If we can bring in new data and develop better curves, we can produce a Wetland Design Guidelines 2.0.[2]

Wetland Restoration Design: A Project Manager's Perspective

Amy Hutzel, California Coastal Conservancy

More than 35,000 acres of wetland restoration are planned for the Bay Area. Significant costs, which vary due to existing conditions and design, are associated with these projects. There are a large number of issues to be considered in planning, many of which are more contentious than wind-wave energy attenuation.

Wetland Design Challenges

- Site conditions (hazardous materials, deteriorating infrastructure)
- Tidal and fluvial flood management
- Subsidence and sediment supply
- Mercury methylation
- Existing infrastructure, e.g. PG&E towers

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[2] Philip Williams & Associates and Phyllis M. Faber prepared *Design Guidelines for Tidal Wetland Restoration in San Francisco Bay* for The Bay Institute with funding from the Coastal Conservancy in 2004.

- Neighboring properties, e.g. airports
- Vector concerns
- Invasive species, e.g. *Spartina*
- Conflicts regarding public use
- Conflicting habitat needs of wildlife

Managers and funders want to know what they are "buying", but may be more flexible than restoration designers, engineers, regulators, etc. They want to create self-sustaining systems and processes. This is different from a mitigation project with specific marsh habitat objectives.

Costs of Large Tidal Wetland Restoration Projects

"Large" tidal projects	**Acres**	**Rough Cost**
Napa-Sonoma Marsh	3,000	$5m
Hamilton/Bel Marin Keys	2,400	$175m
Eden Landing	722	$5m
Napa Plant Site	1,400	$7m
Bair Island	1,400	$11m
Bahia	418	$4.2m
South Bay Salt Ponds	13,000	$980m
Sears Point	970	$21m
Dutch Slough	1,166	$35m
Cullinan Ranch	1,564	$22m

A Tale of Two Projects

	Napa Salt Ponds $2k/acre	**Hamilton $75k/acre**
Site Characteristics	Former Salt Ponds Within 3′ of Marsh Plain Elevation Historical Channels Remote Location	Former Airfield Subsided up to 10′ below Marsh Plain No Antecedent Topography Adjacent to Development
Restoration Design Features	✓ Minor Earthmoving ✓ Natural Sedimentation ✓ Historical Template	✓ Haz Mat Removal ✓ Dredge Material Reuse ✓ "New" Template ✓ Flood Control Levee

There is a very dramatic range of costs per acre among restoration sites. The difference is in the site characteristics. Sources of significant project costs include flood management levees;

public access amenities; restoration design features (e.g., fetch berms); site clean-up; protection of existing infrastructure (power lines, etc.); monitoring, applied studies, and adaptive management; and operations and maintenance. Major costs at Hamilton are in the placement of dredged material and building the marsh template and the flood control levees. Sixty percent of the South Bay Salt Ponds project cost is building a perimeter levee to protect Silicon Valley from flooding.

Investments of government funds over the last decade have included ~ $200 for bayland acquisitions, ~ $50 million for restoration planning and ~ $50 million for restoration. We expect to spend another ~ $400 million in the coming decade.

Project managers want options at a variety of price points to analyze and design the project and to build it. We need cost/benefit analysis of acreage and timing of various habitats. We also need to know if marshes are going to persist in the face of sea level rise in order to answer the questions of those who wonder why we are spending money on them. We can be flexible -- the goal may not be "insta-marsh."

Regulatory, Project Manager and Climate Change Perspectives

Steve Goldbeck, BCDC

BCDC has three main perspectives on wind waves in tidal wetlands. First, as a regulatory agency, BCDC sometimes issues permits that require restoration projects as mitigation for salt marsh that will be destroyed by a development project. We need to be able to predict whether a mitigation project will achieve its goals, and we can't force every applicant to do expensive modeling. Permit enforcement is based on monitoring. Given limited budgets for monitoring what should BCDC require? How can we determine whether a project is on its trajectory to meet its design goals, and what are the error bars? We need tools that are useable but not simplistic.

Second, as a partner in project management on the Sonoma Baylands and Hamilton projects, BCDC needs better information to determine whether expensive structures like berms are needed.

Finally, in developing policies to help the Bay Area adapt to climate change, BCDC needs to consider whether it is appropriate to protect the face of levees to help them persist in the face of sea level rise. It is important for habitat to be resilient.

Wind-Wave Energy Management in Context: Geomorphic Perspective on Marsh Restoration

Steve Crooks, Philip Williams & Associates

Wind waves play a role in defining landscape layout in natural systems. We develop projects in the context of the landscape and its sediment supply. Waves bring a lot of habitat diversity, e.g., erosion of a mudflat feeds the marsh behind it. You get a wide mudflat with fringing marsh.

Dune fields and beaches behave dynamically to attenuate seasonal wave activity. The system is stable as long as the recovery time is less than the perturbation return interval. (The ability to accommodate change defines landform resilience.) Salt marshes also behave dynamically to attenuate wave activity, but more slowly and over greater time intervals.

San Francisco Bay to San Pablo Bay is tidally influenced; the South Bay is wind-wave influenced.

There are different thresholds in intertidal wetland evolution: vegetation thresholds and energy thresholds. Change can be gradual or there can be a step change between mudflat and vegetated marsh. Models developed in Europe could be developed for SF Bay.

The Warm Springs site experienced rapid sedimentation; the Parson's Slough site had impaired sedimentation. In Sonoma Baylands, from 1997 to 2002, there was limited tidal exchange and limited sedimentation. From 2002 to 2006, the blockage eroded, there was greater tidal exchange and greater sedimentation.

During a storm surge at Twitchell Island, the water level went up 2 feet, allowing waves to get stronger. At Liberty Island, there are two types of concerns related to wind-wave energy: habitat formation and flood management, i.e., protection of nearby levees. Wave energy appears to be limiting tule growth.

PWA is participating in a new CALFED-funded project called BREACH III that will be evaluating and predicting restoration thresholds in evolving marshes. They will be developing new numerical models of different possible trajectories.

Mudflat recharge is an option. Potential benefits include maintaining sediment in circulation, reducing the rate of wetland loss, feeding restoration sites, and creating edge habitat. However, there are concerns about overfilling, sediment quality and potential biological impacts.

Conclusions

- Intertidal morphology is a balance between hydrodynamics and sediment transport.
- A threshold exists which separate mudflat from vegetated marshes.
- It is important to be aware of landscape (source-sink) relationships.
- Restoration should maintain flood protection but incorporate disturbance to improve restoration habitat diversity.
- Expectations for success criteria should be in line with evolutionary trajectories.
- There are opportunities to use mudflat recharge to support marsh accretion and restore habitat diversity.

Marsh Vegetation and Substrate Interactions with Wind-Wave Energy in San Francisco Bay: Patterns, Processes of Erosion and Deposition in Natural Settings and Breached Diked Baylands

Peter Baye, Consulting Ecologist

We tend to look for equilibrium states, but things in SF Bay are based on variable thresholds that move back and forth. There are marsh vegetation and substrate interactions and cyclic process of sediment accretion and erosion.

According to Pethick's conceptual model (1992), natural tidal marsh and mudflat systems are parts of continuous dynamic shoreline profiles, like beaches and dunes. Wave erosion of marshes is episodic and is a short-term storm profile response to excess wave energy. Recovery (accretion, progradation) occurs during low energy phases and is a long term, gradual process. Vegetated marsh serves as a sediment reservoir and wave buffer.

Tidal marsh edge responds to the prevailing wave energy regime (episodic, infrequent storm events and annual or seasonal wind-wave climate) and sediment supply. The Emeryville Crescent shoreline is prograding despite being hit by waves with a 5-mile fetch because the wave energy is dissipated across a small section of sloped mudflat. This is a part of the profile that we can manage. The Hayward shoreline is retreating.

There are different processes of vegetation establishment at different sites:

- Direct establishment on a levee or its eroded bench;
- Bayward lateral spread (progradation) of shoreline fringing marsh, which can be as fast as one to two meters per year;
- Radial spread of discrete tidal flat colonies, with eventual coalescence; and
- Diffuse, frequent seedling colonization of tidal flats.

Colonization by seedlings is a sensitive stage for mechanical disturbance, e.g., by wind-wave energy. It is easier for plants to spread clonally than to establish by seeds. Rhizome growth itself anchors the sediment, and creates a feedback loop in which sediment accretion and plant growth reinforce each other.

- At China Camp, slump blocks became a substrate for colonization by *Spartina*. There is net progradation and wave fetch is not limiting progradation of the marsh. Despite strong erosional pulses, sediment accretes in between the pulses.
- At Mare Island, the fringing marsh prograded 3-5 m per year (1998-2000) at a site with greater than 20 mile fetch. There was annual displacement of cordgrass zones by pickleweed zones.
- At the Hamilton site in Novato, marsh vegetation and storm events mediate the erosion cycle on a high-energy transgressive marsh shoreline.

If you take wind waves out of context from nearshore profile, sediment supply, etc., you may overestimate the need for wind wave attenuation.

Marshes can build their own barriers, given the right materials, such as shell hash or sand. In these cases, high wave energy is constructive, building beach ridges that function much like flexible levees, responding with each storm event. Some beach ridges stabilize with high marsh vegetation and persist as natural marsh berms.

Bay barrier beaches can be up to 1 m high. They are mobile (transgressive), self-construct if sand/shell supply suffices, form a natural wave energy buffer at marsh edge, provide high tide roosting sites, and serve as an ecotone.

Sedimentary processes contrasted

Tidal breach – subsided diked bayland (conventional 1970s-1990s)	**Natural tidal marsh (Holocene)**
Vertical accretion of **bare mud** to threshold of emergence for subsequent vegetation Marsh vegetation is secondary, subsequent process following physical sedimentation and emergence of mid-intertidal flats	Vertical accretion of **vegetated marsh** (peat) with rising Holocene sea level Vegetation-sediment interactions are primary, contemporaneous mode of vertical marsh accretion

Diked baylands are restored bare, but they should be vegetated first. They are mostly sheltered from open bay wave energy by perimeter levees. Internal wind-wave energy is generated following the initial post-breach flooding. Sites often have steep, sparsely vegetated or bare interior levee slopes, a reflective shore profile, and a smooth bed. Water depth and minimal bottom friction results in wind wave propagation in the absence of bed roughness from submerged or intertidal vegetation.

In an East Anglia, United Kingdom study, marsh vegetation did most of the work of buffering wind-wave energy. The breakwater was only necessary in first 2-3 years.

An Army Corps of Engineers study from 1979 described stabilizing dredged material with *Spartina* plugs in an areas with wave fetch of over 7 km.

Conclusions

- Diked baylands are enclosed lagoons.
- Lagoons are relatively low wave energy environments compared with marsh shores exposed to open bay waves.
- Critical wave fetch for *Spartina foliosa* transplants on exposed shorelines of San Francisco Bay is over 7 km.
- Highly wave-exposed salt marsh shorelines in San Francisco Bay undergo cyclic erosion and progradation.
- San Francisco Bay marsh progradation occurs where wave energy is extremely high, but nearshore slopes are gentle.
- Coarse sediment (sand, shell) can be used to buffer wave energy.
- Native perennial terrestrial vegetation can be used to stabilize levees.
- Planted marsh vegetation on gentle slopes is among the most cost-effective engineering tools for wave energy attenuation, shoreline stabilization, and marsh creation.

Design Approaches to Address Wind Wave Attenuation in SF Bay Restoration Projects

Bob Battalio, Philip Williams & Associates

Shorter fetches and shallower depths reduce wave growth. A marsh plain of 30 to 60 feet can significantly reduce wave heights and energy. Design approaches to address wind wave attenuation include berms, benches, floodplains, and outboard levees.

Berms: Intertidal Site

Objectives of intertidal berms include facilitating sedimentation and vegetation, creating habitat in the early years of site evolution, and influencing channel formation. Berms are constructed along historic channels, borrowing material adjacent to the historic channel. Weak soils in historic channels are expected to scour. The berm crest should be lower than or equal to 1’ above MHHW. Berms are irregular with flat slopes.

Waves spread into shadows behind berms. The waves active in diked, subsided baylands are locally generated, with short periods (short wave lengths) and short crests and are directionally spread. These conditions limit berm effectiveness because the waves propagate into the lee of the berms. Diffraction and directional spreading govern, not refraction. Gaps in berms are needed for channels and diversity; they increase wave transmission, due to wave propagation through gaps. Waves diffract around islands; wave heights are not reduced much by islands.

In Napa Ponds 4 and 5, a clamshell dredge was used to excavate sinuous channels, and then a berm was built along the edge of the channel. This is an example of intertidal berms used to limit wind-wave action. The approach was developed to be consistent with construction equipment and methods traditionally used in the SF Bay Area, and it was extremely cost effective. The approach was also developed to be consistent with natural marsh geomorphology. This methodology is the most cost-effective approach employed to date, and can be considered the "latest generation" approach to wind wave control in restoration. (In contrast, the "peninsulas" constructed in Sonoma Baylands might be considered a "first generation" approach.)

Berms: Subtidal Site

On subtidal sites, berms are constructed at drainage divides with imported fill. Fill can also be used to construct intertidal shoals or flats.

At Sonoma Baylands (1996), the first generation of berms, called "peninsulas", were built in a low site filled with dredged material. Berms were spaced and built at a height to dissipate 70% of the wave energy. At Hamilton, berms were designed to dissipate 30% of the wave energy (wider spacing, lower crests). Linear features dissipate more wave energy than islands.

Berms can be used for both wave dissipation and channel training. Berms can be arranged to direct water currents into sinuous channels.

Intertidal Benches

Intertidal benches are built as extensions of existing levees to achieve several objectives:

- Lower the total water level by attenuating waves and wave run-up;
- Provide a "habitat-friendly" alternative to traditional armoring;
- Reduce potential for failure of the levee subgrade; and
- Provide material for sacrificial erosion.

In the Petaluma Marsh Restoration Project, an intertidal bench served as alternative to armoring a levee with riprap. The bench converted a slope of 1:5 to a slope of 1:20. PWA used hindcasting to calculate wave conditions, and statistically combined tidal elevations to calculate wave power at different elevations. This provides guidance on the desired bench location, and the relative effect of berm and bench geometries in limiting wave-induced erosion. This methodology was applied to the Warm Springs site and the results were correlated with measured erosion. The results were used to design benches under construction at the Hamilton site levees. At Warm Springs, the benches have vegetation established on them, indicating that this approach is valid.

Allow Overtopping to Wetland Floodplain

At Eden Landing, the levee is designed to allow overtopping to a wetland floodplain. The overtopped water is stored in a managed seasonal wetland. This approach provides an alternative to building huge levees with lots of armoring.

Reducing Depths

At Napa Pond 3, the restoration design included a large starter channel to enhance site drainage, thereby reducing the depths available for wind wave generation. The site is above mean tide level, and the project managers were concerned that it might not drain at lower tides. Poor drainage would (1) increase wind-wave action (2) reduce sedimentation and (3) inhibit vegetation establishment. The channel was constructed to address these concerns and appears to have been a successful approach.

Outboard Levee

At Muzzi Marsh, the outboard levee was left in place as a sacrificial erosion buffer. This is an especially important consideration for bayfront sites, where the storm surge and storm waves in the Bay can readily inundate the site with much greater erosion potential than wind waves generated within the site.

Alternative Design Approaches to Address Wind-Wave Attenuation in San Francisco Bay Restoration Projects

Peter Baye, Coastal Plant Ecologist, and Roger Leventhal, FarWest Engineering, with Stuart Siegel and Christina Toms, Wetlands and Water Resources

There are several design concerns for wind-wave energy in the context of tidal marsh restoration.

- Excessive wind-wave energy can erode the shoreline or levee, inhibit mudflat accretion, and inhibit marsh growth.
- Sufficient or tolerable wind-wave energy can have constructive effects, including sediment transport, distribution of plant propagules and plant litter, and constructive disturbance regimes.
- Deficient wind-wave energy possibly may limit dispersion of sediment and litter, e.g., wrack, coarse woody debris that aids in sedimentation and vegetation establishment.

The main controversy is regarding the degree to which wind waves threaten to erode shoreline levees.

EFFECT OF MARSH VEGETATION ON RESISTANCE TO EROSION
Comparison of sediment shear strength of tidal flat and vegetated marsh, San Francisco Bay

	Shear strength (psf)	Penetrative resistance (lbs)	Erodibility Index
Tidal flat (bay mud)	**107** (56-151)	0.4	2.81
Cordgrass	**156** (106-181)	1.4	0.39
Pickleweed	**299** (209 -345)	2.8	0.14

Source: Pestrong, Ray. 1965. The Development of Drainage Patterns in Salt Marshes (Palo Alto: Stanford).

Slope and vegetation, not berms, have been used to dissipate wind-wave energy on the East Coast. A U.S. Army Corps of Engineers study of shoreline stabilization and tidal restoration projects conducted from 1970-1990 recommended the following design emphasis:

- Low-cost, large-scale, simple technology;
- Soft engineering (nonstructural);
- Slope and vegetation as the primary tools;
- Temporary (1-3 yr), small wavebreaks during early establishment of marsh;
- Recommended slopes of < 1:15 (to dissipate wave energy); and

- Marsh width of 20-30 feet dissipates > 80-100% incident wave energy.

The East Coast experience is more applicable than some people think because Atlantic *Spartina alterniflora* in sand substrate has been found to have similar mean height and mean density to Pacific *Spartina foliosa* in bay mud substrate. Thus, the two species can be expected to have similar wind-wave damping effects.

Fetch Thresholds

PWA estimated a fetch threshold for marsh establishment and growth in San Francisco Bay as less than 1000 feet, based on a restoration project retrospective in 1992. This was a preliminary design estimate and experimental tests were lacking. The nearshore slope was not treated as variable and they did not appear to compare passive colonization to spread of established marsh vegetation. Newcombe and Knutson of the U.S. Army Corps of Engineers used experimental test transplants. They estimated cordgrass sod transplant survival and growth at fetches of greater 7 km in the open bay. They concluded that lagoons had “low energy” and naked sprigs of cordgrass had high rates of survival.

At Sonoma Baylands, the presence or absence of vegetation does not correlate with fetch. Instead of using the single variable of fetch, you need to use a multivariate approach, looking at slope and width of bench, drainage on the site, etc. Clonal perennial terrestrial vegetation (creeping wild rye) has been observed protecting levees from erosion at Sonoma Baylands.

The original question was “How can you design wave breaks to enable sediment accretion in order to reach the elevations at which marsh plant colonization can occur?” A better question is “How can we achieve the most marsh plant colonization for the amount of earth moved while protecting flood control levees?”

Alternative Approaches

Intertidal Mounds. At Sears Point, intertidal mounds (marsh nuclei) were used to jumpstart marsh plant colonization. The concept is based on chronological sequence of aerial photos in natural marshes. The initial vegetation was a mix of remnant vegetation and new colonization. Vegetation was able to colonize the mound before the mudflat reached the threshold elevation for seedlings.

Gentle Backshore Gradients (Levee Benches). An alternative means of dissipating wave energy is to build very flat backshore gradients, e.g., levee benches, with vegetation roughness as the goal. Restoration sites could be managed in a way that is similar to Suisun Marsh, where the marsh is managed for alkali bulrush.

Sidecast Ridges. Sidecasting sediment ridges on the outside bends of tidal channels creates landforms that are equivalent to natural features. Sidecast ridges next to channels are now being used in Napa Salt Ponds. The ridge crests support high marsh vegetation, such as pickleweed and gumplant. Counter-levee mounds are built along the rest of the channel and tidal channels naturally erode in the gaps between the mounds and ridges.

Alluvial Fans. At Sonoma Baylands, hydraulic deposition of dredged material, although not planned that way, mimicked natural features like marsh ponds and alluvial fans. An alluvial fan can support rapid initiation of marsh progradation even where mudflat colonization is slow. It also creates a high marsh–terrestrial ecotone. This naturalistic marsh edge gradient and process have wave damping potential.

Vegetative Stabilization. At the Petaluma Marsh Expansion Project in Novato, the Marin Audubon Society, Peter Baye and Philip Williams & Associates are experimenting with vegetative stabilization of a diked bayland bed that will then become a mudflat. This "pre-vegetation" approach will involve flooding and draining a pickleweed/brackish marsh or growing sacrificial terrestrial vegetation to create residual bed roughness. Flood/drain management has additional wildlife benefits, such as creating white pelican habitat.

Alternative Design Approaches: Additional Engineering Thoughts

Roger Leventhal

Wind-wave energy management is a complex problem and is not amenable to numerical/analytical solutions. The geomorphic approach involves looking at areas of stable vegetation growth and back-calculating the wave climate.

Wave Hindcasting

The wave hindcasting method uses a wind rose to generate wind speeds and directions. It is possible to calculate the percent of time each wave occurred based on the percentage of time a given wind speed occurred from each wind direction. Wave heights are then summed for all wind directions, giving the total number of occurrences for each wave height and the percentage of time each height was exceeded. This is a tool somewhere between the rule of thumb and the expensive modeling.

Roland (2005) calculated critical wave erosion heights to be approximately 1 foot, but it is the frequency of the wave distribution matters. Shaefer (2003) looked at coastal wetland sites and found that erosion occurred when incident wave heights were greater than 1 foot for the 20th percentile of wave heights.

Therefore, designs need only to bring specific wave heights below the threshold, not block all waves, to be effective. With reflective methods such as linear wave berms, wave energy is reflected as well as absorbed, possibly leading to unpredictable sedimentation patterns.

Cost Comparisons

The Hamilton Wetland Restoration Project design includes seven berms for 380 acres of tidal wetlands. Total length of the berms is 7,300 feet and will cost approximately $1.2 million. The site was significantly lowered due to fill borrow, increasing wave energy.

The cost of levee construction ($10/cy) is much higher than the alternatives. There is a sunk cost for placing material with a dredge pipe fan, plus minor additional cost to move the pipe around to different parts of the site. The cost of mound construction is minimal, estimated at $250 per mound at Sears Point. Mound density can be modified as needed by design. Sidecast ridges have minimal cost because there is no major transport and compaction of soils. Pre-vegetation makes sense since we are already managing water on sites for many years.

Issues Raised in Group Discussions

(Note: The comments below do not represent group consensus.)

- **Alternatives to Berms.** The group debated the use of alternatives to bare soil berms to achieve wind-wave energy attenuation. Choosing an approach to adopt depends upon restoration objectives and site–specific opportunities and constraints, such as flood protection needs, site topography, availability of sediment, and capacity for adaptive management.
- **Plants as Tools for Creating the Site.** The group discussed the idea that, in addition to looking at plants as a response variable, wetland restoration site designers can look at plants as forcing elements. Establishing vegetation on restoration sites may be appropriate

under certain conditions, even if that vegetation is sacrificial, i.e., it may be lost to inundation following levee breaching. This is because plants provide physical roughness for a couple years even if they are dead. It is important to evaluate the effects of friction-based approaches, such as the use of vegetation and viscosity of the bed, as an input to the calculation of wave dissipation.

- **Parallels to Stream Restoration.** It may be useful to adapt for use in wetland restoration the range of engineering approaches that are used in stream bank stabilization, i.e., from bioengineering, using plants such as willows, to harder engineering approaches, such as riprap. Similarly, in wetland design, different levels of engineering can be used for different levels of wave energy.
- **Working in the Landscape Context.** Discussion took place of examples of friction-based approaches that were of minimal success in achieving adequate sedimentation because the wider system was erosional. The effectiveness of various bioengineering approaches depends upon sensitivity of the system and long terms evolutionary trends. In some settings, minimal efforts can be taken to improve habitat diversity, while in others, efforts are wasted. Actions should be taken to encourage natural site self-design.
- **Monitoring requirements.** The group discussed the need for post-construction monitoring to guide future design. Discussion took place on the importance of not drawing conclusions about design effectiveness based upon short-term data sets that may not capture larger defining events.
- **Long-Term Trends.** The group discussed the issue of wind-wave energy at two levels: (1) site specific design, i.e., how to achieve objectives and (2) looking at estuary as a whole and how the shoreline will be responding to sea level rise.

Tools Needed by Project Managers

- Project managers want options at a variety of price points to analyze and design the project and to build it. They need cost/benefit analysis of acreage and timing of various habitats.
- Project managers could benefit from having a framework to help them evaluate the level of engineering required on different sites, e.g., if an agency buys a certain 30-acre site, is it buying $300,000 worth of levees?
- Project managers need to know whether marshes are going to persist in the face of sea level rise in order to be able to respond to those who wonder why we are spending money on tidal marsh restoration.

Topics for Future Research

- Different approaches to wind-wave energy management should be evaluated through well-posed experiments, including the measurement of the wind, waves, suspended sediment, and erodibility of sediments in different parts of the restoration site.
- It would be interesting to look at plant recruitment variability at sites with different wind exposure.
- Tide berms and mound structures provide low velocity edges that accelerate sediment deposition. What is the greatest factor as sediment is deposited, low velocities or low wave energy? To provide a low velocity edge of 5,000 feet, what is most economical to construct, mounds or berms?

- The zone of erodible sediment in the Bay is decreasing and insufficient sediment supply is going to be a problem in the long term for site restoration. It might be helpful to map out the Bay, breaking it into regions, to do a first level screening of what major processes are, e.g., areas of sediment supply, where the large mud flats are, where erosion is occurring, where marsh edges are retreating or advancing.

Next Steps

The San Francisco Bay Conservation and Development Commission will be holding a workshop with the U.S. Geological Survey on San Francisco Bay sediment dynamics later in 2008.