PUBLICATION OF THE CALIFORNIA BAY-DELTA AUTHORITY

PHYSICAL PROCESSES & TIDAL MARSH RESTORATION

Management CUES

OCTOBER 2004

MARSH RESTORATION

BACKGROUND

Throughout the San Francisco Estuary, functional tidal marshes provide rare remnant habitat for special status species such as the California Clapper Rail in the Bay and juvenile Chinook salmon in the Delta. They also provide ecological goods and services for aquatic ecosystems, such as primary productivity that serves as food for species throughout the food chain. Very little of the Estuary's original tidal marsh habitat remains today, and CALFED goals include restoration of thousands of acres of these marshes. Restoration projects have the potential to provide benefits similar to undisturbed habitat, but the value of restored marshes may depend more on the quality than the quantity of the habitat.

The concept that species will benefit from restoration assumes that impaired marshes or non-marsh areas can be transformed from their current condition to fully functional marshes. However, scientists warn that restoration projects will not produce sustainable marshes without consideration of natural processes.

Scientists say that viable restoration projects need to be viewed as evolving systems, rather than as construction projects targeted towards particular habitat types. Although improving ecological conditions provides a central motivation for investing in marsh restoration, restoring physical processes form the foundation. In order to reach biological goals, restoration professionals need to understand and integrate the physical processes that can sustain the right conditions for biological activity.

DEFINING GOALS IN TIDAL WETLAND RESTORATION

Dynamic ecological processes in tidal marshes provide ecological goods and services such as food supply, breeding and spawning habitat, and buffering of flood pulses and storm tides. Such services, rather than any particular habitat type, should be the goal of restoration projects. While many of us envision restoring a lush habitat of native grasses for species of concern, the endpoint of a wetland restoration project is actually more difficult to define. No tidal marshes, not even "mature" ones, are static systems. Tidal marshes result from flows of energy and material, inputs and outputs that change each day (like the tides), over decades (like sediment supply) and over centuries (like sea level). In addition, habitat like that in naturally occurring undisturbed marshes might only be restored after many decades of evolution. Some features of tidal marshes, such as natural marsh soils, need to undergo lengthy developmental processes that cannot be skipped without uncertain results.

Scientists caution that setting overly specific goals for what type of wetland to restore may be unrealistic - there are limits to our ability to restore sustainable dynamic systems. In spite of advances in science and technology, we can only set the stage for nature to do its work. This is especially true in an ecosystem were human development has dramatically altered physical parameters and disturbance regimes that underlie wetland development. In addition, we must recognize that the remnant marshes we hope to emulate developed as part of a larger system that has changed dramatically over the past century. Just as attempts to 'freeze' desired habitat can lead to losing it, failure to recognize that natural processes are dynamic can lead to frustration. Patience, on a generational scale, is a necessary ingredient in our successful restoration efforts.

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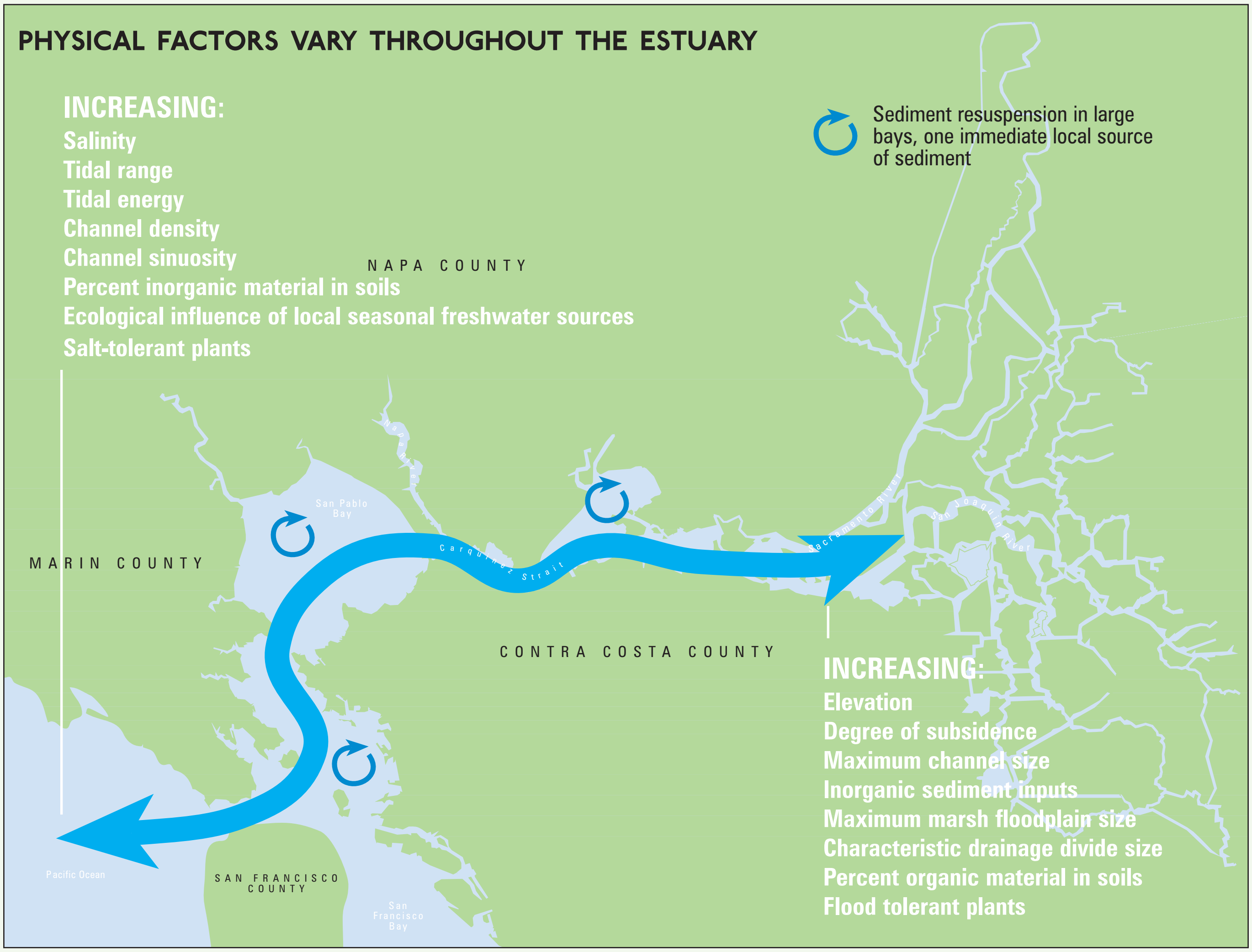

Tidal marshes respond to physical factors that vary from site to site in the Estuary. The trends shown on the following figure are not meant to indicate literal, steadily increasing gradients. Indeed, aspects of this figure change seasonally with inflow, and daily with the tides. Rather, they are meant to put some general tendencies into perspective. For example, we know that local tributaries and complex hydrodynamics change the salinity at different points in the Estuary. Nonetheless, salinity in the Delta is generally lower than in San Francisco Bay. The South Bay has its own patterns that are not depicted here, but in general it has a similar physical environment to San Pablo Bay. Circles indicate sediment re-suspension in the large Bays, which can serve as local sediment sources for tidal marshes.

One implication of changes in physical processes is that different parts of the estuary may respond differently to large-scale changes. One example of this is found in sediment cores and shallow sediment profiles in brackish Suisun Marsh. In the past 70 years, changes in vegetation are visible, possibly reflecting changes in salinity in the Estuary. Scientists say that ecological communities in brackish areas may be more sensitive to sea level rise, drought, or inflow changes than areas at either end of the salinity gradient. Source: Steve Culberson and Michael Kiparsky. Illustration: Darren Campeau.

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WHICH COMES FIRST, THE PHYSICAL OR THE BIOLOGICAL?

Physical processes, such as hydrology, and biological processes, such as organic soil development, dominate function at different times in the life of a restored marsh. Physical processes are often most important at the beginning of a project when elevation is too low for vegetation to colonize. Only after plants begin to grow do biological processes become central. At many potential restoration sites, the depth of the water must be decreased through sediment inputs as a first step. Thus, wetland restoration planners must pay close attention to water circulation, tidal action, sediment supply, and the geomorphology of the area to be restored in the initial phases of a restoration project. Only over time, as sediment builds elevation, can plants colonize and begin to grow. When this happens, however, biology takes over in importance. Plants grow roots and rhizomes that contribute organic matter to soils, and further raise elevation. Management goals are usually driven by biological goals. Nonetheless, managers need to become familiar with physical processes first, even if they are only a means to a biological end.

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SEDIMENT SUPPLY WILL LIMIT WETLAND RESTORATION IN THE ESTUARY

Dollars are not the only limiting resource in the Estuary. Tidal wetland restoration depends on sediment supply. Many areas in the Delta and the Bay that were historically tidal marshes have long been diked off. Subsidence has lowered the land behind the levees, and this lowering has been exacerbated by sea level rise. Because a marsh's elevation relative to tidal elevation helps determine whether vegetation can flourish, many potential sites for restoration of tidal marshes (particularly in the Delta) are now too low for plants to take root if levees were simply breached. Restoring these areas to tidal marsh habitat will require an initial increase in their elevation through a large input of sediment. In addition, marshes in the Bay will require continued inputs of sediment to keep up with elevation gains as sea level continues to rise.

Hydraulic mining during the gold rush flushed millions of tons of sand, silt and gravel from the watersheds above the Estuary. Rivers have been moving this "sediment wave" downstream ever since. However, recent analyses show that sediment load in the Sacramento River watershed has decreased by about 50% since 1957. This is because much of the hydraulic mining debris has already moved towards the ocean, and because large upstream dams trap huge volumes of sediment in their reservoirs. This exacerbates a problem for managers trying to proceed with wetland restoration throughout the Estuary in the face of subsidence. Insufficient supply of sediment will be a major challenge in our wetland restoration efforts.

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ELEVATION IS ESSENTIAL FOR ECOLOGY

In the Bay, the elevation of a marsh's surface relative to the tidal range strongly determines the physical conditions in a marsh. These conditions combine with sediment characteristics to influence tidal marsh habitat. Hydroperiod (how deep, for how long, and how often water inundates a site) depends on elevation and the ability of tidal water to access an area. Vegetated marsh plain exists in only one to two feet of the tidal range in the Bay, so a difference in tidal elevation of a few inches can dramatically change the ecological community that exists there. In addition, tidal action is damped moving upwards through sloughs. This means that locations farther from the tidal water source have an even smaller range of elevations in which plants can thrive. Thus, designing projects with accurate elevation data is critical. These initial elevation designs can determine whether a project will follow a trajectory towards sustainable intertidal marshes, and also the amount of habitat that can develop within a project site.

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FRESHWATER INFLUENCES MARSH PLANT COMMUNITIES

Looking below the surface may be important in marsh ecology. Studies in Suisun Marsh show that salinity in the rooting zone influences regional vegetation patterns. This work suggests soil salinity conditions provide an important environmental framework for other ecological interactions. Sub-surface salinity is influenced by changes in local groundwater as well as fresh surface water inflow. Should managers consider stewardship of local streams as part of the management of tidal marshes?

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FILL MATERIAL AND NATURAL MARSH DEVELOPMENT

Using dredged or fill material to quickly raise marsh elevations can be a useful tool, but may involve a biological tradeoff. The more we allow natural processes to create a "biological veneer" on marsh restoration projects, the better success we will have sustaining viable habitat. Marsh plants and invertebrates live within the top one-meter of soil. They can more effectively take root and survive within naturally deposited mineral and organic material than in dense, compacted fill material. For this reason, marsh restoration projects are best initially constructed below the ideal equilibrium marsh elevation (this also helps induce channel formation in the nascent marsh). Since elevation takes time to build naturally, there can be a tradeoff between the speed with which a project will reach the desired condition, and the eventual quality of the resulting habitat. Fill material is often subject to rapid compaction in the first years of a restoration project. Engineers can estimate consolidation rates for these sediments – such estimates, combined with more precise elevation data, might more quickly bring constructed marsh surfaces to their target elevations.

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SEDIMENT SUPPLY FROM LOCAL TRIBUTARIES TO THE BAY VARIES GREATLY

Sediment deposition in the middle of the Bay mostly reflects the supply from the Sacramento River. But much transported sediment is deposited at the edge of the Bay, likely originating from local streams. These local Bay tributaries might be a source for more of the sediment inputs to Bay marshes than is commonly assumed. Recent estimates suggest that about 40% of the sediment inputs to the Bay may come from local tributaries, and that their importance may be increasing as river sediment decreases. However, projecting the potential of these tributaries to contribute to wetland restoration projects is difficult, in part because local sediment supply varies tremendously between watersheds around the Bay. Recent estimates of sediment supply in various local tributaries range over two orders of magnitude, and these estimates may be compounded by even higher variability between years. Thus, there will be productive years and erosive years over time and at different marshes throughout the Estuary. Could more thorough measurements of sediment supply from local tributaries present an opportunity to more accurately gage the sediment supply for marshes?

QUESTIONS ABOUT THE SCIENCE?

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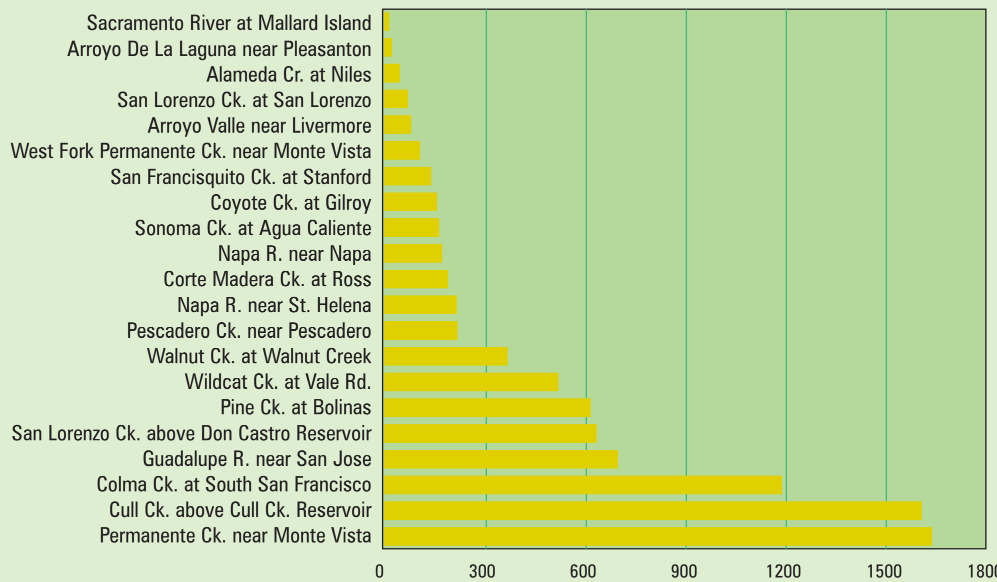
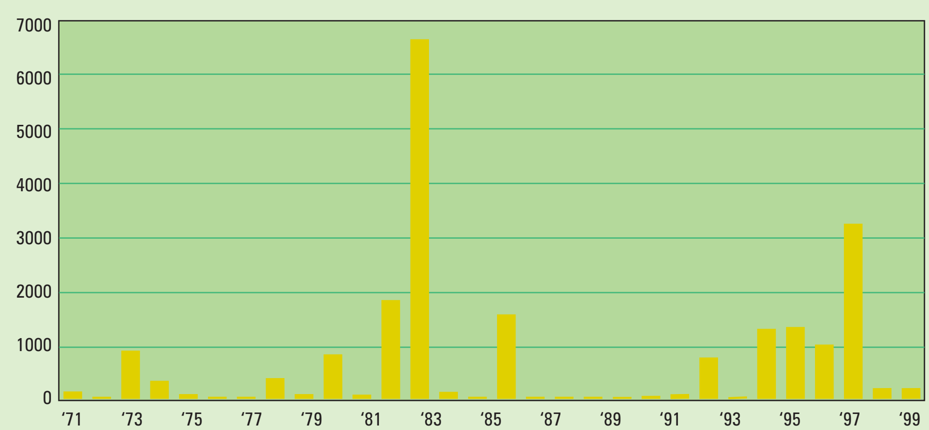
SEDIMENT EXPORT
MEASURED IN TRIBUTARIES OF SAN FRANCISCO BAY - IN TONNES/SQ.KM/YEAR



Sediment export from tributaries to San Francisco Bay varies greatly from watershed to watershed...

ESTIMATED ANNUAL SEDIMENT LOAD
FROM BAY AREA SMALL TRIBUTARIES - IN 1000'S METRIC TONNES



... and from year to year. Figures courtesy of Lester McKee, SFEI.

"TRANSIENT SEDIMENT ZONES" COULD PROVIDE SEDIMENT SOURCES FOR RESTORATION PROJECTS

Not all potential restoration project locations have equal sediment supply – tapping into natural processes could help increase rates of sedimentation in marshes. Mobile plugs of sediment move with the tides at some river mouths. For example, on Sonoma Creek and the Petaluma River, sediment moves upriver with incoming tides and deposits as the tide slackens. On outgoing tides, the sediment re-suspends and flushes downriver, depositing at the river mouth. The cycle repeats with every tide, resulting in mobile deposits that are removed and replaced by tidal action. Research indicates that restoration projects sited near transient sediment zones can accrete sediment faster than similar projects farther from those zones. Sediment availability can limit restoration project viability in the Estuary, and managers should consider natural sources of sediment in decisions of where to site restoration projects.

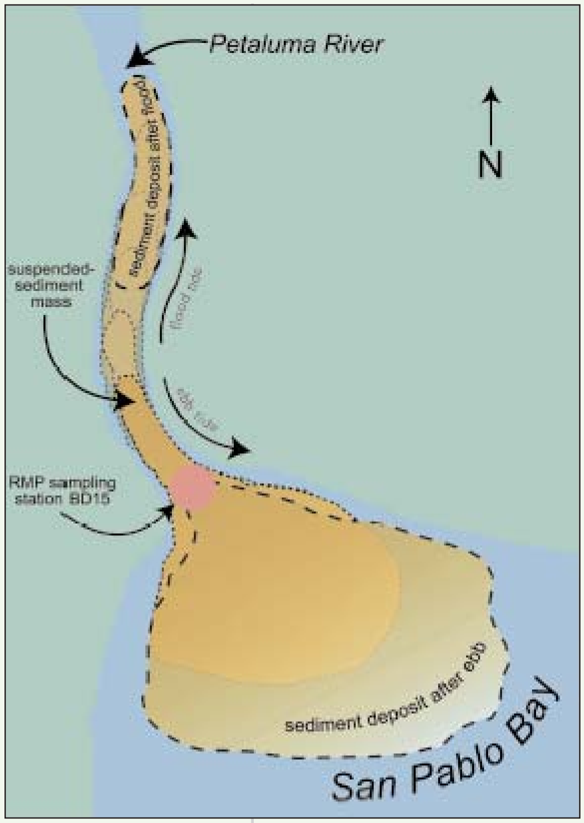


Illustration of transient sediment zone dynamics on the Petaluma River. Figure: Schoellhamer et al., 2003 Pulse of the Estuary, SFEI.

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HISTORICAL STUDIES SUGGEST NOT ALL BAY MARSHES REQUIRE LARGE MINERAL SEDIMENT SUPPLY

Just before European settlement San Francisco Bay region in the 1850's, tidal marshes in the Bay existed under conditions of lower sediment supply than today. Natural marshes are dynamic. They were created by slowly rising sea levels, and are maintained by a combination of sediment delivery from outside the marsh and accumulation of organic material generated by plants. Cores of sediment in South Bay marshes show that soil dating from before the 1800's is mostly peat, with very little inorganic sediment. This suggests these marshes did not require large amounts inorganic sediment to maintain their elevation. This conclusion is related to evidence that most creeks didn't reach the Bay as they do now. Rather, they tended go underground at alluvial fans, emerging as springs. This means that historically, sediment was delivered from tributaries at much lower rates than today. This evidence suggests that some types of marshes, in some Bay locations, might be sustainable with today's decreased sediment supplies once they are established. This is partly because the edges and sloughs of marshes likely trapped tidally borne sediment, while the internal parts of the marsh developed through organic deposition. If these processes still operate, they could inform estimates of how much sediment will be needed for marsh development in the Bay.

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MARSH CHANNEL NETWORK FUNCTION MAY BE MORE IMPORTANT THAN FORM

Data indicate that small tidal sloughs can provide refugia for native species, which may provide a reason for paying closer attention to these channels. Sinuous channels winding through a salt marsh can be an alluring visual image. But over-simplifying channel networks can hurt the success of restoration projects. *Dendritic* channels are those that branch in irregular, tree-like ways typical of natural marshes. *First-order channels* are the smallest marsh channels, farthest from the ocean. Below

Aerial view of dendritic channel networks, Petaluma marsh. Figure courtesy Stuart Siegel.

the point where two or more first-order channels join, the channel is defined as a *second-order channel,* and so forth. Lower-order channels are more affected by biological than tidal forces, while physical processes dominate the higher-order channels nearer to the ocean. Individual channels are interconnected to make *channel systems*, made up of a high-order channel, and all of the lower-order channels that flow into it.

Channel networks in marshes serve two functions. First, channels *serve as conduits* for water, nutrients, sediment and animals. Second, *channels provide habitat* for fish and birds, and including important edges between vegetated and unvegetated habitats.

Channel networks can be measured aerially for one estimate of marsh channel density, but such estimates can tell only part of the story. For example, two channels might appear identical in an aerial photograph, but a deeper channel could provide different function than a shallower one. Taking both depth and width into account is the most useful measure of channel density because it represents the amount of water that can flow through these conduits. However, whereas other density measurements can be made remotely, volumetric density requires fieldwork to quantify.

Channel density in natural marshes varies. For example, salt marshes have high density of smaller channels, while brackish systems tend to have a small number of large channels. Channels can sometimes be designed in low-tech ways, such as by encouraging their formation with furrows of soil, but high tidal energy may overwhelm soil structures. Where tidal energy is lower, such starter channels can aid channel formation. These methods can work, but are most often appropriate farther from a levee breach. Ultimately, channel morphology at all levels of a marsh responds more to the physical conditions present than to efforts to engineer their form.

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UNDERSTANDING ELEVATION DATUMS

One of the greatest challenges in planning tidal marsh restoration is measurement of elevation. Methods for measuring elevation are seemingly simple, but easy to confuse. It is critical to understand and use them properly in project design and planning.

- **Datums** are baseline elevations at particular points, against which other elevation measurements can be taken.
- **Tidal datums** mark elevation relative to the range of tides at a particular point. This can be the most ecologically relevant measurement as it tells us about the relationship between the surface of the marsh and the tide. Tidal datums are valid only in the vicinity of where they are measured.
- **Geodetic datums** are established relative to the idealized surface of the earth, which is approximately but not exactly sea-level. This is the datum most often used to gauge altitude or elevation.

Two types of geodetic datums are currently in use. NAVD-88 is federally maintained, and is substantially more accurate than NGVD-29. The two datums are based on different ways of estimating the shape of the surface of the Earth, but it is possible to convert from one to the other. Efforts are underway to update and synchronize tidal and geodetic datums in the Bay. This work involves re-surveying older locations to account for sea level rise, converting them to NAVD-88, and linking to tidal datums. Linking geodetic and tidal datums also requires precise resurveying, because there is no direct connection between the land-based and the tidal-based datums.

Without improved surveys relative to a common datum, we cannot even make an accurate map of what tidal marsh restoration could be possible. Because many of the benchmarks in the Estuary are out of date, they no longer provide reliable elevation information. With more accurate, regularly updated measurements of the topography of the Estuary, we can start to understand whether and where CALFED's wetland restoration goals can best be achieved.

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LOCAL ACTIONS IMPACT SEDIMENT SUPPLY

Historical and watershed-scale views show that sediment is a limiting factor for tidal marsh restoration in the Bay, but local conditions may also play a role. Some land use practices can increase sediment supply. For example, urban or residential development can expose soil from beneath protective vegetation cover, allowing rainfall and runoff to move it to streams and rivers. However, these activities generally measurably increase sediment only locally, and rarely create reliable sources for restoration projects. More importantly, this sort of sediment supply often creates its own problems in other parts of the watershed, such as clogging salmonid spawning gravels with fine particles, and decreasing the effectiveness of flood control channels. On the other hand;

- Other restoration projects compete for sediment. Reconnecting floodplains to create riparian habitat can create sediment sinks;
- Riprap put in place to stabilize banks prevents rivers from meandering, decreasing the natural movement of sediment from rivers to the Delta and the Bay. But removing riprap carries its own problems, such as erosion of valuable riparian property;
- Removing some dams could potentially allow rivers to return to their natural sediment transport regime, while providing great potential benefits to fisheries and aquatic ecosystems.

These examples illustrate ways in which factors outside of marshes can influence a project's success. Sediment supply presents a potential constraint on tidal wetland restoration projects, but managers can plan for it on local as well as estuary-wide scales.

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DELTA TULE MARSHES CAN EXPAND IF THEY START AT THE PROPER ELEVATION

Recent work demonstrates that tule marsh restoration projects can flourish in the Delta. Measurements on smaller flooded islands show that currently tules have not only established, but are extending in towards the deeper interior of the islands at rates of up to two meters per year. They can establish if provided a base elevation of about two feet below Mean Sea Level, and some restored areas are evolving towards an elevation similar to the few remnant natural marshes in the Delta. This indicates that enough sediment exists in the system now to allow growth of tule marshes in some regions of the Delta, given proper elevations and the maintenance of hydrologic processes.

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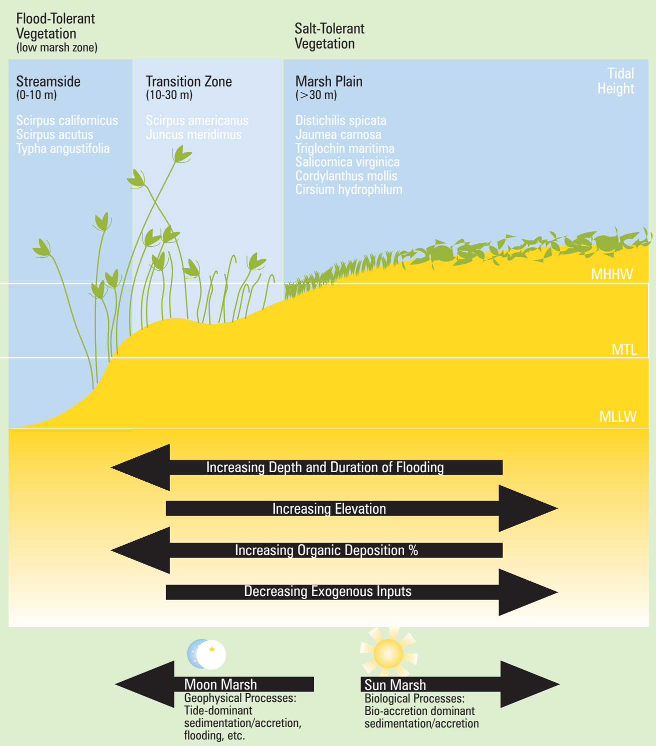
Management CUES

SUN - MOON MARSH ZONATION



Physical processes vary not only across the Estuary, but also within marshes. This conceptual cross-section shows how physical factors and vegetation tend to vary in the example of an idealized marsh. Plant species at each elevation are different throughout the Estuary — the species listed here are typical of Suisun Marsh. Source: Steve Culberson. Illustration: Darren Campeau.

ACCELERATED SEA LEVEL RISE WILL IMPACT RESTORATION PROJECTS...

Because almost all restoration sites have subsided, we rely on natural estuarine sedimentation to build the surface elevation of mudflats to a level where plants can colonize. With accelerated sea level rise, the rate of sediment build up will need to be faster. In some cases, sedimentation may not be fast enough to keep pace. In addition, rising sea level creates larger sediment "sinks" within the estuary, leading to a greater overall sediment demand and lower sediment concentrations in tidal waters.

...BUT, ONCE ESTABLISHED, VEGETATED TIDAL MARSHES ARE RESILIENT TO ACCELERATED RISE

Once vegetation has colonized emerging mudflats, the resulting marsh can keep pace vertically with high rates of sea level rise through accumulation of organic material. Sea level has fluctuated widely throughout the past _ million years, and marsh communities have adapted to respond to this. However, as sea level rises, marshes will be more frequently inundated by tides, and the vegetation will change to favor more flood-tolerant plants. Mudflats provide a buffer from wave energy, as well as the direct source for much of the sediment that maintains marsh morphology. Ultimately, the sustainability of marshes over the coming decades and centuries may be threatened by increased erosion of mudflats offshore due to sea level rise and reduction of sediment supply. As these mudflats lower in elevation, the erosion of fringing marshes at the bayfront edge will accelerate. Under natural conditions, the marsh would expand inland as sea level rises, compensating for the loss at the bayfront edge. Today, roads or levees border most marshes, creating a hard edge that prevents this inland migration.

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TERMS

Mean High Water – the average of all high waters over a long period

Mean Low Water – the average of all low waters over a long period

Mean Lower Low Water – the average of the lower of the two low water heights of each tidal day

Mean Sea Level – the average height of the sea surface over a long period

Mudflats- areas on the seaward side of tidal wetlands that remain under water even at the lowest tides.

NGVD-29 – National Geodetic Vertical Datum, an older system for determining elevation, based on surveys conducted in 1929. Regarded as less accurate than NAVD-88.

NAVD-88 – North American Vertical Datum. A federally-maintained system for determining elevation, based on 1988 surveys.

Sediment – rock and mineral particles transported by water. Sediment relevant to wetlands tends to be relatively fine because the low gradients involved do not transport larger particles.

Subtidal – always covered by water, even at low tide

Tidal elevation – the height of a tide with respect to a fixed point (datum) on land

Tidal range – Mean High Water minus Mean Low Water. This can be used as an average movement of the water level during a typical tidal cycle.

Uplands – the area on the landward side of the tidal marsh, where the land surface is not inundated by even the highest tides.

These Cues are intended to increase communication between resource managers and CALFED-funded scientists, not as an exhaustive technical review. Source material is published reports as well as preliminary results and working hypotheses from conferences and public workshops – please contact those listed above if you would like supporting documents, or are interested in exploring the primary literature. These Cues have been reviewed for accuracy in our reporting. Other Management Cues are available at http://science.calwater.ca.gov

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