An Overview of the Expected Physical Relationships Between the Intertidal and Shallow Bay Zones of the SF Estuary

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Introduction

For the purpose of environmental management and scientific inquiry, the SF Estuary ecosystem of the Bay Area has conventionally been subdivided into three major landscapes: the bay, the baylands surrounding the bay, and the local watersheds.

> Going from deep to shallow water, the bay has been subdivided into three parts, the deep bay below the 3-fathom contour, the shallow bay between the 3-fathom contour and zero depth (i.e., the mean lower-low water datum), and the intertidal zone between zero depth and the maximum height of the Estuary.
>
> The term “baylands” is part of a regional lexicon for the Estuary. They are commonly considered to include the tidal flats (which comprise the lower intertidal zone), the tidal marshes (which occupy the middle and upper intertidal zones), and the diked baylands, which include all the areas that would be tidal if not for levees, tide gates, etc.
>
> There are many lesser categories of the bays and baylands, according to salinity regime, tidal hydroperiod, age, and type of substrate.
>
> The regional community of environmental managers and scientists has not adopted or developed a classification system for our local watersheds, although a variety of systems are available.

Scientific study of the SF Estuary ecosystem has been focused on the deep bays. The shallow bays and the baylands have received much less attention by scientists. Even less is known about the nature of the local watersheds. They are the least understood of the three major landscapes, although watersheds largely control the conditions of the baylands and the bay.

The relationships between the Estuary and its watersheds are gaining attention. The “bay scientists” and the “wetlands scientists” and the “watershed scientists” are starting to look to each other for help to explain conditions that they observe in the field. Successful large-scale efforts to restore any of these major parts of the system will require collaborative input from all three of these groups of scientists.

But the dialogue is new and there are many basic questions still unanswered. For example, we have pretty good maps of the bathymetry of the bay and of its tidal flats and marshes, but we lack maps of the substrates of all the deep bay and we lack comparable maps of all of our watersheds. We know more about the movements of sediment within the bay than where the sediment comes from. We know from other regions that tidal marshes are important as habitat for estuarine and anadromous fishes, and that tidal marshes serve as filters that remove sediment and pollutants from the water. But we are just beginning to try to measure these marsh functions in this region.

Against a backdrop of uncertainty, I have agreed to provide a brief overview of some of the expected basic physical relationships between the deep and shallow parts of the estuary and its local watersheds, with a focus on relationships between the intertidal zone and shallow bays.

My two take-home messages are as follows.

1. **The bays, baylands, and local watersheds have been disengaged from each other because the connecting channels have been destroyed.** The sum total of what is now known about the three landscapes of the region is that they have been disconnected from each other by the deterioration of the creeks and sloughs and subtidal channels that used to run between them, such that each of these three landscapes is not well supported by the others and the system as a whole is therefore failing.

   For example, the natural ecology of the shallow bays and deep bays depends on tidal marshes as sources of nutrients and carbon, and the marshes served as habitats for bay fishes and other wildlife. The tidal marshes depend on inputs of nutrients and sediment from local watersheds. But most of the tidal marshes have been isolated from the tides by reclamation. Furthermore, the remaining marshes have become disconnected from their watersheds because the creeks that used to drain to the marshes have been diverted or consumed, or they are choked with sediment upstream of bridges and culverts that are too small in cross-section to convey the sediment that comes directly from the watersheds. Simply stated, our railroads, highways, and buried utilities that surround the Estuary have at least partially dammed our creeks for fish and water and sediment, and thus separated the tidal marshes from their local watersheds. At the same time, the tidal parts of the creeks and the tidal sloughs have severely shoaled and narrowed in response to the loss of tidal prism due to tidal marsh reclamation. All of the channels that used to connect the tidal marshes and the tidal flats to the shallow bays and deep bays have become foreshortened and many of them have become filled with sediment that comes directly from the bays.

2. **The restoration of the shallow bay landscape depends on the restoration of the intertidal zone.** A restored intertidal zone, including the tidal reaches of the local watersheds as well as the tidal marshes, is required to restore and naturally maintain the channels that connect the shallow bays and deep bays to the intertidal zone and the local watersheds. Furthermore, the restoration of large areas of tidal marsh will create shallow bay habitat in the form of very large channels that innervate the marshlands but do not completely drain during low tide.

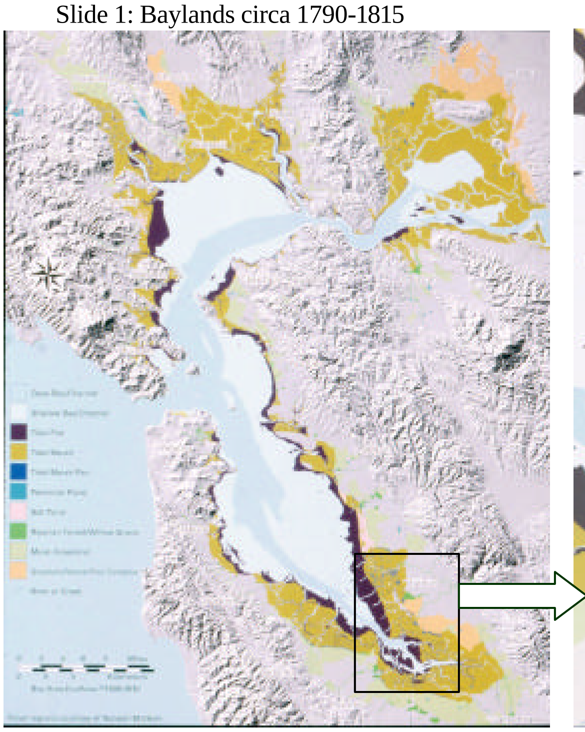
   For example, the ribbons of marsh that wind their way among the salt ponds and other diked baylands of South Bay and North Bay used to be shallow bay channels hundreds of feet wide and miles long. The main channel of Coyote Creek included more than 400 acres of shallow bay habitat. The larger tributary sloughs comprised another 100-200 acres of shallow bay. In addition, all of these channels also included tidal flat. When the marshes were reclaimed, the channels naturally adjusted to the loss of tidal prism by shoaling and narrowing. As they filled with sediment, they evolved from shallow bay to tidal flat, and then from tidal flat to tidal marsh. We now have narrow corridors of tidal marsh where we used to have shallow bay channels. To restore the channels, the adjacent areas of diked baylands must be returned to the tides.

Definitions

SLIDE SET 1: Regional and South Bay EcoAtlas Historical Views

The historical view of the ecosystem provides a useful template for starting a discussion of the connections between the bays, wetlands, and watersheds because it shows where the connections tend to exist, due to climate and topography that have not changed since historical times.

Slide 1: Baylands circa 1790-1815



Map Credit: SFEI

Slide 2: South Bay detail of Slide 1

Map Credit: SFEI

Here we see the spatial relationships among the three major landscapes and their major habitat components of the historical bay ecosystem. The map on the left shows the region prior to European contact. The map on the right is a close up of part of South Bay. The upper watersheds that surround the Estuary lead downslope to broad alluvial plains that lead to tidal marshes (shown in mustard yellow), which lead to tidal flats (shown in brown) and then shallow bay habitats that surround the deep bay (shown in lighter blue and darker blue, respectively).

The intertidal zone extends between maximum high water and minimum low water, and includes the tidal marshes and tidal flats. Note that we are not talking about the tides alone, but all the factors, such as wind and rain and runoff and air pressure and the shape of the bay that contribute to water "level" or water "height", relative to the land. The shallow bay zone extends between minimum low water and the 3-fathom (i.e., minus 18 ft) deep contour. Zero depth corresponds to the average height of the lower low tides. The deep bay zone extends below the 3-fathom contour.

<u>Basic Characteristics</u>
SLIDE SET 2: South Bay EcoAtlas Historical and Modern Views

Slide 3: Detail of South Bay Historical Baylands

Map Credit: SFEI

Slide 4: Detail of South Bay modern baylands, circa 1998

Map Credit: SFEI

The grain size of the alluvial sediments on the plain around the bay decreased with distance downslope from the hillsides to the bayshore. The alluvial sediments that accumulated away from the creeks near the edge of the tidal marshland were so fine that they did not drain well and therefore supported seasonal wetlands including vernal pools in some locales.

Most of the marshes consist of fine silt and clay plus plant material. But there are some sandy marshes near local sources of sand in Central Bay, North Bay, and the Delta. Tidal marshes and tidal flats have backshores and foreshores. The backshore of a marsh is where the marsh transitions to the upland. The foreshore of the marsh and backshore of the tidal flat are the same, and correspond to the transition from tidal flat to marsh. The foreshore of the tidal flat corresponds to the transition from tidal flat to shallow bay. All of these transitions are physical zones rather than discrete lines, and they are ecologically fuzzy.

The shallow bays have many types of substrate, including silt and clay ("bay mud") sand, shell hash, and bedrock. The tidal flats have the same bed types as the shallow bays, except they lack bedrock. Artificial shorelines, such as riprap and seawalls, usually exist where tidal flats would otherwise transition to tidal marshes.

SLIDE SET 3: photos of tidal marsh showing its physiography

Slide 5: IR photo of Petaluma Marsh plain detail

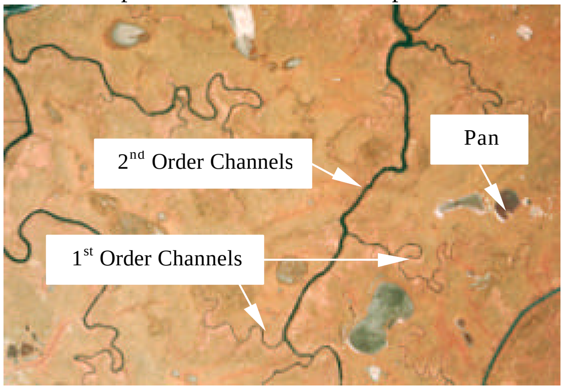


Photo Credit: Laurel Collins

Slide 6: IR photo Montezuma Slough Marsh detail

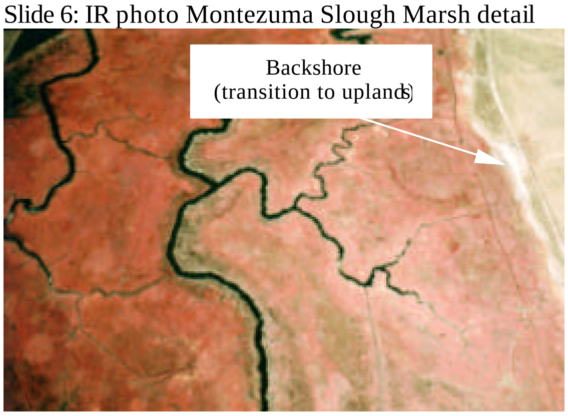


Photo Credit: Josh Collins

There are many types of tidal marsh: low marsh that gets wet on almost every high tide; middle marsh that gets wet on most high tides; high marsh that gets wet during only the highest tides each month; young marsh and old marsh; natural marsh and restored marsh; broad marshes between creeks and narrow fringe marshes along creeks and shorelines; and there are marshes of different salinity regimes. But the basic features of tidal marshes are the foreshore, backshore, marsh plain, tidal pans, and tidal channels large and small. Tidal marsh channels get larger with distance toward their connections to the bay.

SLIDE SET 4: photo of tidal flat

Slide 7: East Bay mudflat

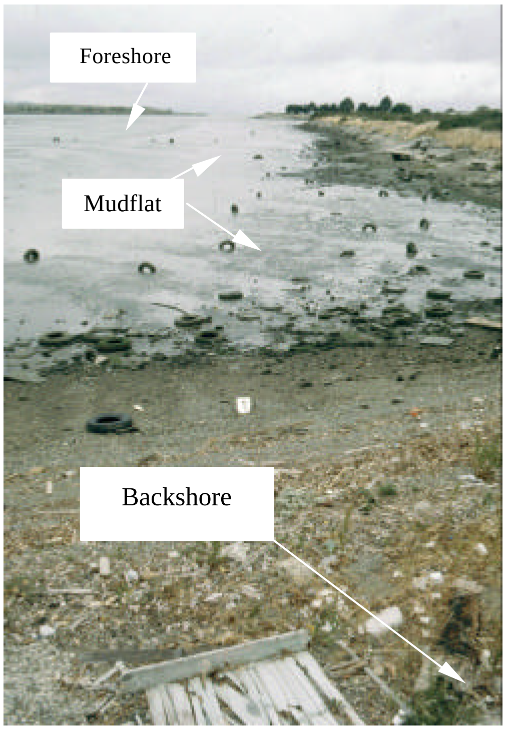


Photo Credit: Josh Collins

We know much less about tidal flats than about tidal marshes. We know that they slope toward the shallow bay zone. Narrower flats slope more steeply. There is less tidal flat under less saline conditions because tidal marsh plants grow lower in the intertidal zone under fresher conditions. Under freshwater conditions, there is marsh where there would otherwise be tidal flat. This is part of the explanation for less tidal flat in Suisun than in North Bay, and less in North Bay than in South Bay.

Tidal flats have channels, and the larger of these can have natural levees. But most of the channels do not completely cross the tidal flat. They begin near the transition to marsh and end before they reach shallow bay.

As we will see later, whether or not a channel extends from marsh across the tidal flat to bay probably has important consequences for the relationships among these places, and is controlled in large part by the conditions of the tidal marsh and local watersheds.

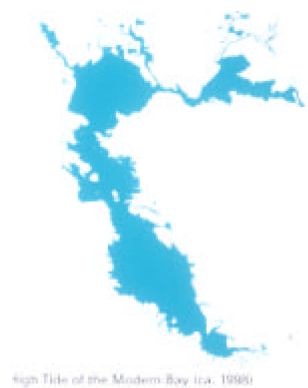
<u>Historical Changes in Distribution and Abundance</u>

SLIDE SET 5: Pairs of past and present maps of extent of high tide and baylands

Slide 8: High tide
circa 1790-1815

Map Credit: SFEI

Slide 9: High tide
circa 1998



Map Credit: SFEI

Slide 10: filled areas
circa 1998

Map Credit: SFEI

Slide 11: diked areas
circa 1998

Map Credit: SFEI

In the Estuary downstream of the Delta, there used to be about 240,000 acres of intertidal zone, with about 190,000 acres of tidal marsh and 50,000 acres of tidal flat. Now there are only about 40,000 acres of marsh and about 29,000 acres of tidal flat. There used to be about 174,000 acres of shallow bay, and 100,000 acres of deep bay. There is still about the same amount of shallow bay, but only about 82,000 acres of deep bay.

Land development and an increase in sedimentation in the intertidal zone due to an increase in watershed erosion have shifted the intertidal zone and the shallow bay zone toward the deep bay. Agriculture, salt production, and urbanization have replaced tidal marsh and some tidal flat. New tidal flat has formed at the edges of shallow bay, and some of this new tidal flat has evolved into tidal marsh, and new shallow bay has formed at the edges of deep bay. Simply stated, all around the bay, the upland grasslands, tidal marsh, tidal flat, and shallow bay habitats have shifted toward the deep bay.

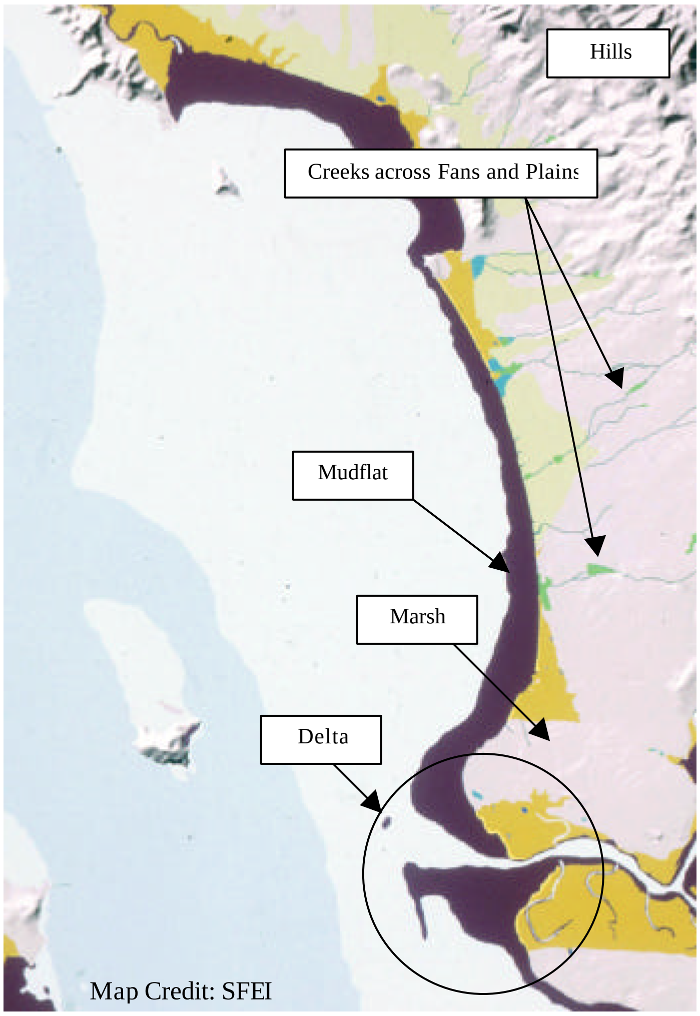
The Estuary has become smaller in aerial extent and volume but there is still about the same amount of shallow bay. The reduction in area <u>and</u> volume of the estuary is mostly represented by the loss of tidal marsh and tidal flat.

<u>Basic Physical Processes</u>

Slide Set 6: Main Landscapes and their Elements

Tidal marsh is transitional from upland to tidal flat, and tidal flat is transitional from marsh to shallow bay, and shallow bay is transitional from tidal flat to deep bay. The line between deep bay and shallow bay is somewhat arbitrary, although these zones have different ecological and geomorphic characteristics. In fact, the lines between any of these landscapes or zones are fuzzy when viewed through ecological and physical processes.

Slide 12: Historical view of east side of Central Bay
circa 1795-1815



Looking bayward from the local watersheds, we can see active deltas at the mouths of most creeks, where they enter the intertidal zone, and at the lower limits of the tidal flats, where the creeks and sloughs leave the intertidal zone and enter the shallow bays. The creeks and sloughs were actively building the alluvial plain, tidal marsh, tidal flat, and shallow bay by deposited sediment from the local watersheds.

Looking landward from the deep bay, we can see that the tides and currents move fine material from shallow bay into tidal flats. The grain size of this material decreases with distance landward, or upslope, toward the backshore of the marsh.

Thus, the alluvial sediments decrease in size with distance downslope from the upper watersheds to the tidal marshes, and the estuarine sediments decrease in size with distance upslope from the deep bay to the tidal flats and tidal marshes.

The movements of sediment as well as water from the watersheds to the bay, and from the bay to the marshes, were essential processes that connected one landscape to another and maintained the physical system as a whole. The tidal marshes occupy the middle reaches of these processes. They truly are transitional landscapes between watersheds and the bay.

The lateral extent and slope of the flats change seasonally and perhaps more often than that. Sediment is re-suspended from shallow bay and tidal flat by wind-generated waves and some of this sediment is transported further shoreward, toward the tidal marshes. But the residence time of this material in either zone is not known. And its origin is not known, except that it is derived from watersheds that drain into the estuary.

Of increasing interest is how the contributions of sediment into the intertidal zone and shallow bay zone from local watersheds might increase with distance upstream along slough and creeks that drain those watersheds. Simply stated, the importance of a local watershed as a source of intertidal sediment and water increases with distance upstream into the watershed.

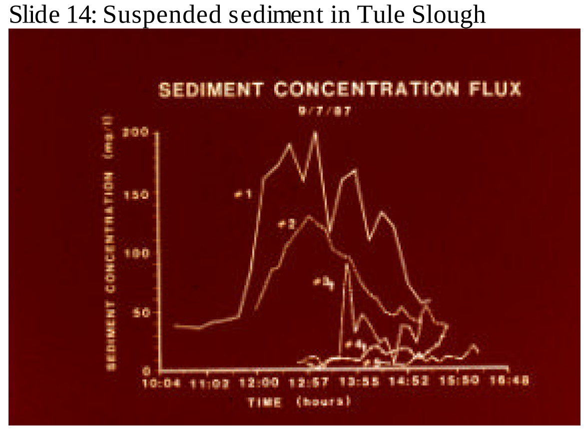
Some of the sediment that is re-suspended from the shallow bay and tidal flat is transported into the tidal marshlands, and most of that is retained there. Under conditions of stable or rising sea level, tidal marshes are for the most part permanent sediment sinks.

SLIDE SET 7: Marsh Processes

Slide 13: IR photo of Petaluma Marsh plain detail

Photo Credit: Laurel Collins

Slide 14: Suspended sediment in Tule Slough

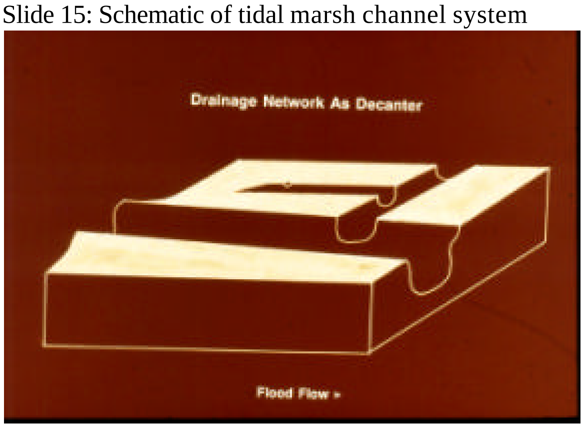


Data Source: Josh Collins

Let's look more closely at the "filtering" function of tidal marshes. On the left we see an aerial view of tidal marsh showing its structure as a filter, with channels large and small innervating the marsh plain. On the right we see a set of data for suspended sediment concentration during one rising tide that did not overtop the banks of the channel anywhere from its connection to the tidal flat to its terminus near the backshore of the marsh plain. Although this tide never got above the channel banks, the concentration of suspended sediment decreased as the tide moved upstream through the channel system.

In this example, where the water level never rose above the channel banks, the loss of suspended sediment means that the sediment was being deposited along the channel bed. But repeated measurements of the length of this channel system and of its cross-section show that that the channel has not changed in dimension. This means that the sediment that is deposited on the bed during flood tide is re-suspended by the ebb tide. How often the sediment is exchanged between the tidal marsh channel and the adjacent tidal flat or shallow bay is unknown. But obviously some sediment, and presumable some water, is washing back and forth within the marsh channel system for some length of time.

Slide 15: Schematic of tidal marsh channel system

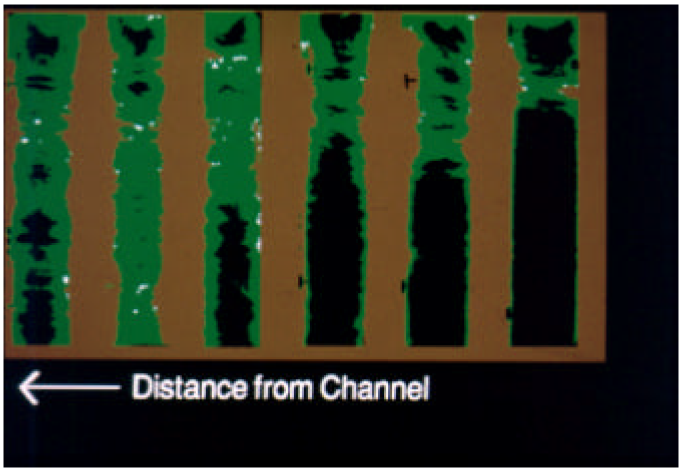


Source: Josh Collins

This schematic shows the channel system as sediment decanter. As the water rises into a channel, it slows due to the friction, and the flow becomes less turbulent. The suspended sediment begins to settle to lower parts of the water column. The lower layers of water move upstream through the channel slower than the upper layers because of friction at the channel bed. The clean upper layers of water stream forward into the tributaries before the sediment-laden water. In very long channels, the sediment-laden water may not reach the end of the system except on very high tides.

Channels achieve a "dynamic equilibrium" between their size, shape, and the average supplies of water and sediment. Unless these supplies change, the channel does not significantly change size, which means that the sediment and water that comes in during the flood tide and that does not go onto the marsh plain must go back out of the channel during the ebb tide.

Slide 16: Profile of sediment core transect



Data Source: Josh Collins

But some tides are high enough to carry sediment nto the marsh plain. Here we see a set of shallow cores of marsh sediment taken along a transect that extended onto the marsh plain from the edge of a channel. The amount of suspended inorganic sediment that is carried by the tides from the shallow bay and tidal flat onto the marsh is mostly trapped within 30 feet or less of the channel banks. As we move further away from the channel bank, the marsh sediment becomes increasingly organic, and this organic sediment is created in place by plant growth; it is not filtered from the tides.

This means that most of the filtering action of the marsh is conducted within the marsh channel system and its immediate margins.

The marsh also provides a way for the tides to dissipate their energy. As the rising tide moves across the tidal flat and into the tidal marsh channels, or out of the channels and onto the marsh plain, it is slowed by friction. The tidal flat and marsh can damp the tidal wave and reduce its energy. Marshes "soften" the shoreline of the estuary and thus we expect them to reduce the amount of shoreline reflection of the tidal wave. Recent findings suggest that large-scale tidal marsh restoration may reduce the size of the standing waves or seiches that occur at the mouths of our local rivers and streams and throughout the South Bay and elsewhere in the Estuary.

Let's summarize this part of the overview.

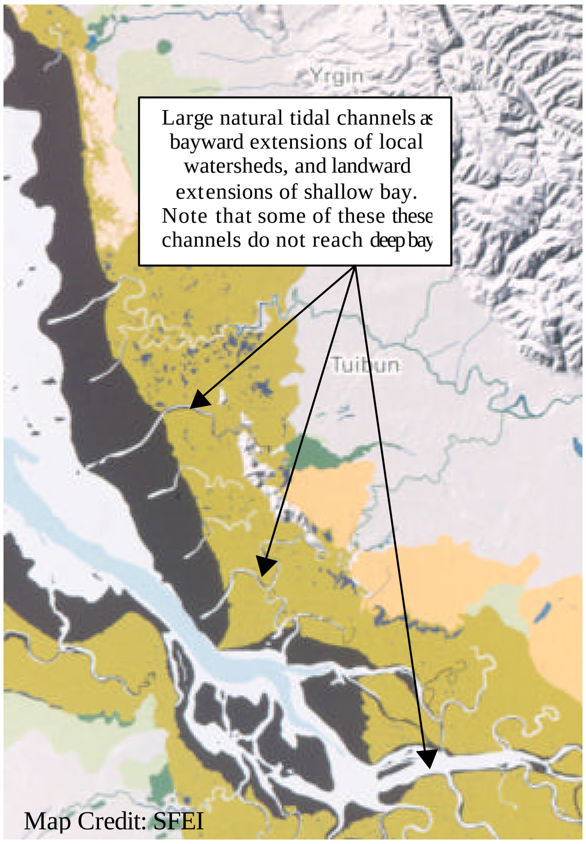
Watersheds convey water and sediment through rivers and streams and into tidal marshes, tidal flats, and shallow and deep parts of the bay.

Some of this sediment, especially the very fine-grain sediment that reaches the shallow bay, is transported by the tides and wind-generated waves from the shallow bay into tidal flats and from the flats into tidal marsh.

Channels facilitate this physical relationship between watersheds, wetlands, flats, and the bay.

Some of the channels extend throughout the system, from watersheds to deep bay, and other channels do not. The ones that go all the way from watersheds to deep bay wind through the intertidal zone, directly connecting all three of the major landscapes. Tidal marsh channels that do not extend completely across the tidal flat or through the shallow bay serve to connect the shallow bay to the intertidal zone, at least during high tide. Channels that extend from watersheds to the intertidal zone but not to the bay provide important connections between the intertidal zone and watersheds. In any case, channels are the dominant pathways of ecological and physical processes that link together the watersheds, wetlands, and bay landscapes.

Slide 17: Detail of historical view of South Bay



Map Credit: SFEI

There are many examples of habitats that depend upon these connections. For example, the largest expanses of tidal marsh, tidal flat, and shallow bay tend to develop in association with medium size watersheds having large sediment loads but inadequate discharge to maintain a channel all the way across the tidal flat and though the shallow bay into deep bay.

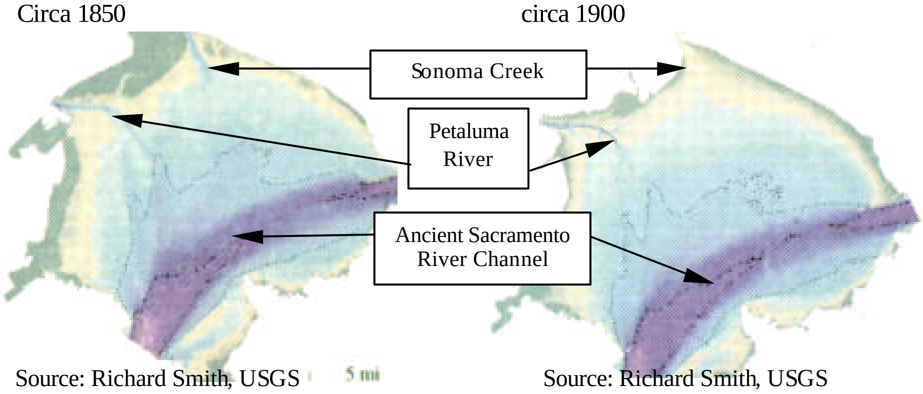
In this historical map, we see many channels that lead from medium size watersheds through tidal marsh and into tidal flat. We can see that the tidal flat is building outward, or bayward, into the shallow bay at the ends of the channels. What we are looking at is the process of natural creation and self-maintenance of tidal flat and shallow bay as critical habitat for many species of shorebirds and fishes and other wildlife. This process depends upon the channel connections between the intertidal zone and the shallow bay, and between the watershed and intertidal zone.

Close study of this estuary and others clearly shows that under natural conditions the larger tidal channels are very stable. There is apparently, and as expected, a balance between water supply and sediment supply that determines the extent of channel connection between the estuarine zones. Again, if the average supplies of sediment and water do not change, then the larger channels remain about the same. But an increase in sediment or a decrease in water tends to cause channels to shoal and shorten. Again, the loss of channel connections can disengage one major landscape from another, and thus significantly and negatively affect the ecosystem as a whole.

SLIDE SET 6: USGS bathymetric study of San Pablo Bay changes.

Slide 18: San Pablo bay bathymetry Circa 1850

Slide 19: San Pablo Bay bathymetry circa 1900



Source: Richard Smith, USGS

Source: Richard Smith, USGS

For example, in this set of slides we see the historical loss of shallow bay channels that connected Sonoma and Petaluma watersheds to the deep part of San Pablo Bay. Reclamation of tidal marsh greatly lessened the tidal prism for Petaluma, Sonoma, and Napa streams and thus reduced their ability to maintain the portions of their channels that lead across the tidal flats and shallow bay to the deep bay. At the same time, a flood of sediment from hydraulic mining in the central Sierra choked the filter. The Sonoma channel is completely gone and the other channels are maintained by routine dredging.

Slide Set 7: Interpretation of Salt Ponds

Slide 20: Oblique aerial photo of South Bay salt ponds

Slide 21: Orthogonal aerial photo of salt ponds

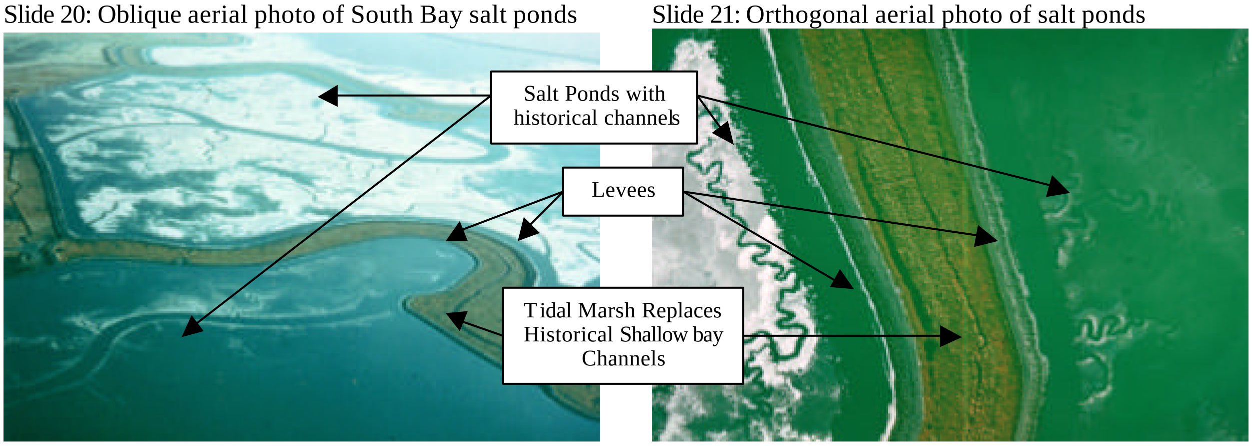


Photo Credit: Mike Monroe, USEPA

Photo Credit: Mike Monroe, USEPA

Here we see two aerial views of salt ponds in South Bay. Notice that the levees around the ponds also demarcate the historical banks of the largest tidal marsh channels. When the marshes were reclaimed, the channels shoaled and narrowed, such that there is now marsh between the levees, were there used to be shallow bay channel and mudflat.

The volume of tidal water that is represented by large amounts of tidal marsh clearly affects the length and width and depth of channels that connect watersheds to deep bay, and tidal marsh to tidal flat, and tidal flat to shallow bay. Restoring tidal marsh means restoring the tidal prism that is necessary to maintain these connections.

It is important to emphasize that the largest of the tidal marsh channels, such as the ones that used to exist between the large areas of diked marsh is South Bay and that have since evolved into marsh, were deep enough that they did not de-water during low tide. They actually functioned as landward extensions of shallow bay. Tidal marsh restoration, if undertaken at a large enough scale, will also restore shallow bay, and the critically important physical and ecological interactions between the shallow bay and intertidal zone.

Conclusions

In this brief talk, I have emphasized the importance of restoring the lower reaches of local creeks to protect tidal marshes, and the importance of restoring tidal marshes to protect shallow bays. I have not talked about diked baylands because they lack direct and continuous connections to the intertidal zone or shallow bay zone. Diked baylands can be managed to store flood waters, retain or release salt, or to reduce the tidal prism, but they do not serve to maintain the physical system of channels that connect together the watersheds, tidal baylands, and the bays. It should be noted, however, that diked baylands have important ecological functions as seasonal wetlands that also need to be protected. Ideally, large amounts of seasonal wetlands could be restored as diked baylands in the context of large amounts of tidal marsh. This is the basic vision put forth by the Bay Area Wetlands Ecosystem Goals Project.