Bolinas Lagoon Ecosystem Restoration Feasibility Project

Final Public Reports

V Project Reformulation Advisory Committee Summary of Draft Public Report

PRAG Committee

MEMORANDUM

May 23, 2006

TO: Bolinas Lagoon Technical Advisory Committee

FROM: Project Reformulation Advisory Committee:
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SUBJECT: Summary of Examination of Report Entitled: "Projecting the Future Evolution of Bolinas Lagoon" and Supporting Documents

RECOMMENDATION:
The Project Reformulation Advisory Group (PRAG) recommends that the report entitled "Projecting the Future Evolution of Bolinas Lagoon" and its supporting documents be recommended by the Bolinas Lagoon Technical Advisory Committee (BLTAC) for acceptance by the Marin County Open Space District Board of Directors.

SUMMARY:
The PRAG has examined the report entitled "Projecting the Future Evolution of Bolinas Lagoon", its supporting documents, and the questions concerning the Report's analyses and conclusions. The PRAG finds that the report fulfills its purpose as a scientific projection of past, present, and future conditions of Bolinas Lagoon, given the uncertainties inherent in assessing past and future conditions in a complex natural ecosystem.

FINDINGS:
The remainder of this memorandum summarizes the PRAG's key findings concerning the following elements of the report: A) the Conceptual Model, B) Tectonics, Dynamic Equilibrium(s), the 1854 Map, and the "Pristine Condition", C) Sediment Accumulation and Tidal Prism Loss, D) Inlet Closure, E) Habitat and Wildlife Changes, and F) Anthropogenic Changes.

For the remainder of this memorandum, the subject report will be referred to as the "PWA (Philip Williams Associates) Report" or "the report".

A. Conceptual Model

Viewed over the long term, the lagoon responds to cycles of: 1) instant deepening caused by large earthquakes on the San Andreas Fault (at average intervals of about 350 years during the last 1600 years), 2) followed by periods of rapid sediment accumulation and reduction of tidal prism because of increased transport of littoral sediment through the inlet and its deposition in the deepened recesses of the lagoon and 3) followed by periods of quasi equilibrium with more gradual habitat or tidal prism change.

During the rapid filling phase the littoral sediment is composed of beach sands and silt eroded from the Bolinas bluffs. Lagoon currents are strong enough to carry the fine sand and silt to the northernmost reaches of the lagoon where it is deposited. Alluvial sediment from the watershed comes into the lagoon mostly during severe storm events and averages 20-25% of the total from all sources (alluvial/total): 4500/19000 CY/yr (pre1850), 10,000/43,000 (1906-present). This percentage is expected to increase over the next 50 years as the lagoon becomes shallower and less littoral sediment is carried in to the lagoon as the strength of tidal currents diminish, although bluff-eroded silt will continue to be transported efficiently in suspension.

The rapid filling phase gradually slows until a quasi equilibrium state is reached where sedimentation is offset by sea level rise and the tidal prism is relatively stable. Waves caused by the wind become an important stabilizing force as they erode and re-suspend sediment on tidal flats thus increasing the opportunity for ebb tides to move accumulated sediment out through the inlet. It is this force in particular that promotes the longevity of unvegetated tidal flats in the quasi equilibrium period. The system remains in a state of quasi equilibrium until it is suddenly disrupted by another major earthquake.

This sequence of events has occurred five times during the past 1600 years -- presumably many more times over the past 7000 years during which Bolinas Lagoon has persisted as an intertidal lagoon. During the past 1600 years there has been one period of over 600 years and another with as few as 140 years between significant intervening earthquakes.

B. Tectonics, Dynamic Equilibrium(s), the 1854 Map, and the "Pristine Condition"

The conceptual model indicates that earthquakes that deepen the lagoon are followed by a period of rapid sediment accumulation as littoral sediments are transported throughout the lagoon by strong tidal currents. As the lagoon becomes shallower, tidal dispersion weakens and there is (more or less) a balance between sediment delivery and erosional processes (largely wind wave action that prevents shallow mudflat from becoming tidal marsh). The last earthquake that substantially affected Bolinas Lagoon occurred in 1906. Our empirical perception of the lagoon is based on observations during the last 50 years when the lagoon has been in a period of rapid sediment accumulation as it tends toward a more shallow quasi-equilibrium state.

How can we apportion the observed and predicted changes in the lagoon among natural vs. anthropogenic causes? Does the 1854 map represent pristine conditions? Was the lagoon in a quasi equilibrium state in 1854?

The 1854 map shows a very shallow lagoon with well developed tidal channels in the north basin suggesting that it had been shallow for an extensive period of time. Prior to 1906, the previous earthquake occurred in 1520 (386 years previously); although we do not know how long it takes for the lagoon to proceed from a deeper water to a shallow water condition (the rapid filling phase), by 1854 it had apparently been shallow for some time. The 1854 map is our best (and only) idea of the lagoon in a relatively pristine state and apparently in a quasi-equilibrium state.

Can we use the 1854 condition to evaluate anthropogenic impacts?

One problem is that each earthquake results in a different 1) overall subsidence, 2) west-east subsidence, and 3) north –south lateral movement. Even with no anthropogenic effects, each earthquake will result in the lagoon moving toward a unique quasi-equilibrium form because geomorphic units and channel morphologies will change. Hence, not all changes that we observe (or predict) in the lagoon based on comparisons with 1854 can be attributed to anthropogenic impacts. For example, in 1906 there was apparently differential east-west subsidence such that the west side of the fault line did not drop as far as the east side (and in some areas may have actually uplifted). Between earthquakes, the west side is creeping North, and perhaps slowly rising, relative to the east side. This, in part, may explain the rapid diminishing of Bolinas Channel and perhaps contribute to the expansion of salt marsh north of Kent Island.

A second problem is the reliability of the 1854 map and PWA's ability to derive quantitative data from it. The map appears to be reliable in depicting habitat type, distribution, and extent. It also indicates that in 1854 the lagoon was quite shallow. Estimating tidal prism is more difficult. The PWA report provides an estimate of tidal prism of 3.7 MYC (+/- 0.7 assuming +/- 0.5 ft in historic tidal range), revised from an earlier estimate of 4.5 MCY (details of estimates are provided in Appendix B of the Report). Given the numerous assumptions and estimates (historic tidal range, slope of mudflats in 1854, conical equations for estimating volume in the lagoon), the tidal prism estimate for 1854 should be viewed as crude and approximate.

<u>Conclusion</u>:

The 1854 map provides our only picture of a relatively pristine condition of the lagoon in a quasi-equilibrium state. However, because each earthquake is unique and sets the lagoon on a different trajectory toward a quasi-equilibrium state, we cannot ascribe all changes we see in the lagoon from 1854 to the present and beyond to anthropogenic impacts.

C. Sediment Accumulation and Tidal Prism Loss

<u>Sediment Accumulation</u>

The Report discusses both sediment accumulation and tidal prism loss. Estimates of sediment accumulation are from coring data (primarily from the north basin) measured in mm/year, then extrapolated over the lagoon and corroborated with bathymetry data.

<u>Pre1854 Total Sediment Accumulation</u> = 19,000 CY /year

<u>Alluvial delivery = 4,500 CY/year</u> (extrapolated from Holocene erosion rates in Tennessee Valley)

<u>Littoral sources = 19,000-4,500 = 14,500 (assumes all watershed sediment stays in lagoon)</u>

<u>1854-1906 Sediment Accumulation</u> = 39,000 CY/year
Note: The Report uses a value of 13,000 CY /year as an estimate for the north basin only based on coring data. If the coring data estimate is extrapolated for the lagoon as a whole, the value is 39,000 CY/year. This would lower the pre1906 estimate of tidal prism (see Figure 3-14) and make the displacement from the earthquake larger.

<u>Alluvial delivery = 39,000 – 14,500 = 24,500 CY/yr</u> (Change is due to watershed delivery as littoral sediment delivery was not expected to change as the lagoon was already shallow)

<u>Littoral sources = 14,500 CY/year</u>

<u>1906-2004 Sediment Accumulation</u> = 43,000 CY/year

<u>Alluvial delivery = 10,000 CY/year</u> (Tetra-tech estimate for 1951-2001 period confirmed by PWA).

<u>Littoral Sources = 43,000-10,000 = 33,000 CY/year</u> (derived by subtracting watershed estimate from total accumulation; the latter from core data. Hence, all watershed sediment delivered is assumed to stay in the lagoon. Higher littoral sediments are expected due to much higher tide current velocities following deepening of the lagoon. As the lagoon becomes progressively shallower, watershed sediments will become a higher percentage of overall sediment accumulation).

Tidal Prism Loss

The table below reflects how the tidal prism changed during various periods since 1854 (data from Report Figure 3-14).

TIDAL PRISM LOSS (estimates without error bars)

Date	Tidal Volume (MCY)	Change from previous value	Number Years since previous value	Loss of Tidal Prism/year (CY) over interval
1854	3.7			
1906				
Pre-earthquake	3.2	- 0.5	52	9,615[1]
Post-earthquake	6.7	+ 3.5	NA	
1929	5.6	- 1.1	23	47,836
1968	4.3	- 1.3	39	33,333
1998	3.5	- 0.8	30	26,666
2050	2.5	- 1.0	52	19,230
2125[2]	2.0	- 0.5	75	6,666

[1] This value may be significantly higher if the estimated sediment accumulation from the north basin cores is extrapolated over the entire lagoon (Report confines estimate to north basin only).

[2] The future quasi-equilibrium period

It should be understood that sediment accumulation does not necessarily correspond directly to tidal prism loss. First, the net effect of sediment accumulation is offset by sea level rise (adding 13,500 CY/year of tidal prism). Also, sediments deposited above MHHW or below MLLW do not affect tidal prism

Conclusion:

As noted, the estimated Tidal Prism loss from 1854 to 1906 may be significantly higher than the value of 9,615 CY/year in the Table. Following the earthquake, there was rapid sediment accumulation and tidal prism loss. The rate of tidal prism loss has been declining and is expected to decline further. This is due to the lagoon becoming progressively shallower as it recovers from the earthquake and tends toward a quasi-equilibrium. As the lagoon becomes shallower, tidal dispersion of littoral sediments will decrease. Wind-waves will erode and re-suspend shallow sediments on mudflats.

D. Inlet Closure

The Report uses the O'Brien stability index to determine the probability of inlet closure. Closure potential is largely determined by the relative balance of wave-driven transport of beach sands and scour by ebb tidal currents. Larger and more frequent waves will deliver more sand to the lagoon inlet; smaller tidal prism and tidal range, and a wider inlet, lowers the ebb tidal power at the inlet and the ability to scour sand from the inlet.

The Report examines the occurrence of inlet closure at various tidal prism values and inlet widths. These values are from 1) current (2004) conditions, 2) year 2050 estimates, and 3) the quasi-equilibrium estimate (year 2125). Wave power values were derived from 17-years of buoy data. Stability index values of 12 or above indicate closure.

Table 5-2. Results of Inlet Stability Analysis

Scenario	Tidal Prism (MCY)	Inlet Width (ft at MSL)	Number of Closures (S > 12)	Maximum Value of Stability Index
1	3.5	300	0	6.9
2	2.5	300	0	9.2
3	2.0	200	0	9.4
4	2.0	300	2	13.8

Conclusion:

- The lagoon inlet will not close over the next 50-years given an estimated tidal prism of 2.5 MCY in year 2050.
- At the next estimated quasi-equilibrium (year 2125), tidal prism is estimated to be 2.0 MCY. With an inlet width of 200 feet (reduced by 100 ft over the current average width due to the lower tidal prism volume), the analyses suggests that the inlet would not close. With an inlet width of 300 ft., closure would occur on average every 10 years.

E. Habitat & Wildlife Changes

There have been dramatic shifts in habitats and, presumably, wildlife and plant communities in the lagoon since 1854. The sharpest distinction is between 1905 (largely shallow intertidal mudflat habitat) and in 1907 (a much deeper lagoon)—a shift from an estuarine to a marine habitat. This has been reversing over the last 100 years and will continue to do so—albeit at a slower rate.

The Report provides information in changes in habitats from 1854 through 2050 (and to 2125 at the predicted quasi- equilibrium). Tables 5-1 and Table 3-2 (from the Report) summarize these changes. Clearly, the change from the quasi-equilibrium in 1854 to after the earthquake (actually our first data set is 63 years after the 1906 earthquake) shows significant habitat shifts (e.g., an increase from 130 to 487 acres of subtidal channel and shallows).

Table 3-2. [Habitat Distribution in 1854 and 1929]

Habitat	1854	1929
Flood-tide island	13	0
Freshwater marsh	21	0
Salt Marsh	170	77
Intertidal flats	910	682
Subtidal Channels & Shallows	130	487
TOTAL	1244	1246

Table 5-1. Projected Change in Lagoon Morphology

Morphologic Unit	Year 0 Area (acres)	Year 50 Area (acres)	Change in Area (acres)	Percent Change (%)
Flood Tide Island	28	28	0	0
Flood Tide Shoal	40	40	0	0
Subtidal Channel	171	169	- 2	- 1
Subtidal Shallow	27	0	- 27	- 100
Frequently Submerged Mudflat	399	293	- 106	- 26
Frequently Exposed Mudflat	264	327	+ 63	+ 24
Salt Marsh	200	244	+ 44	+ 22
Brackish Marsh	3	5	+ 1	+ 46
Fluvial Delta	30	54	+ 24	+ 82
Transitional	5	6	+ 1	+ 17
Total*	1,165	1,165		

* Values have been rounded to the nearest acre, resulting in slight differences between the total report and the sum of individual rows. Total value is smaller than ca. 1,200-acre value since developed areas of Seadrift Lagoon are excluded.

The largest habitat changes between 1854 and the 2050 projection shows 1) more tidal marsh and frequently exposed mudflat, 2) loss of subtidal shallow and less frequently submerged mudflat habitat, and 3) more fluvial delta and transitional habitat (due to expansion of Pine Gulch Creek delta).

The Report provides lists and descriptions of plant and animal species and communities that may be found in each of the habitat types shown in Table 5-1. Where data or anecdotal reports are available, the Report identified species that have declined in recent years (e.g., eel grass, several large invertebrates [ghost shrimp, gaper and Washington clams], shiner surfperch etc.). The Report also predicts overall trends in groups of animals based on predicted habitat shifts: e.g., one-third of the 99 invertebrates listed as occurring in the lagoon (Table 4-1) are associated with subtidal and frequently submerged mudflat and are expected to experience further declines as their habitat area decreases. Similarly, the Report states that decreases in deeper water habitat will reduce foraging habitat for two feeding guilds of birds (diving fish-eating and diving benthos-feeding birds) and most fish listed in Table 4-2 (38 species known to occur in the lagoon). The Report also suggests how shorebirds and marsh birds may respond to the predicted shift in habitat types. Some shorebird species are expected to benefit and others to suffer population declines. Most marsh birds should benefit.

Conclusion:

The Report could plainly state that the punctuated dynamic equilibrium—sudden deepening followed by rapid and then a declining rate of sediment accumulation—leads to large shifts in habitat types, ecological function, and plant and animal communities. The shifts may be rapid or incremental and are a natural consequence of the tectonics and sediment accumulation in the lagoon. However, anthropogenic impacts may (compared to a pristine condition) decrease the period the lagoon is in the more marine condition and alter the trajectory of the lagoon, the overall mix of habitat types, and the tidal prism—thus affecting plant and animal communities in the lagoon.

F. Anthropogenic Factors

Several anthropogenic forces have affected the lagoon system over the past 150+ years. The most apparent include:

- Construction of Seadrift:
  - destruction of native dune plant community.
  - development of a non-native shrub and tree community.
  - elimination of overtopping of the sand spit during severe winter storms
  - filling of the lagoon leading to the loss of 0.3 MCY of tidal prism and approximately 90 acres of intertidal habitat
  - hardening of the ocean side of the spit with rip rap.
  - hardening of the lagoon side of the outer spit by a retaining wall.
  - creation of a non-tidal saline lagoon.
- Fill for Highway 1
- Fill for road and housing along Wharf Road in Bolinas
- Fill in south arm of lagoon
- Hardening (rip rap and retaining wall) of inlet at end of Wharf Road in Bolinas
- Construction of the Bolinas groin
- Construction of the retaining walls along the Bolinas bluffs
- Loss of Easkoot Creek storm overflow ("Poison Lake" at the Stinson Beach parking lot)
- Construction of the causeway in the South arm of the lagoon
- Rapid marsh expansion following the Lone Tree Mitigition Project in the south arm
- Invasion by non-native plant/wildlife species (e.g., non native dune grass which may stabilize dunes on Kent Island and lead to its expansion)
- Conversion of native bunch grass to annual grassland in the watershed

The Report identifies anthropogenic impacts that directly and indirectly influence sediment accumulation, tidal prism loss, and habitat changes. These are factors that have increased alluvial sediment delivery in the lagoon, contributed to sediment accumulation and resulted in tidal prism loss. Construction of Seadrift, housing development, logging, road building, farming, grazing, and creek channelization contribute to enhanced alluvial sediment delivery to the lagoon compared to pristine conditions. Approximately 12% of the sediment accumulation in the lagoon over the last 100 years can be attributed to enhanced alluvial sediment delivery due to anthropogenic impacts. Current alluvial sediment delivery is twice that of pristine conditions. This is most clearly seen in the continuing progradation of Pine Gulch Creek delta—a landform that was not present in 1854. Historically, the creek would change orientation during large storms and most bedload was deposited in what is currently Weber Ranch. The growth of Pine Gulch Creek delta (and to a lesser extent other creeks) will result in an estimated loss of 0.25 MCY of tidal prism over the next 50 years.

Secondary impacts from enhanced alluvial sediment delivery results from the progradation of Pine Gulch Creek delta and the resulting decrease in wind fetch and wind wave action both to the North and South of the delta. As noted previously, the 1906 earthquake resulted in differential down drop along the fault line—the western portion dropped less and may have actually elevated in some areas. This would, in part, explain why the western part of the lagoon is shallower and may also contribute to the diminution of the Bolinas Channel. Wind waves are sheltered by Kent Island (a natural geomorphic unit present on the 1854 map) and in 1854 there was tidal marsh in the sheltered area to the north of the island. The 1929 map shows Kent Island had largely disappeared and along with it much of the tidal marsh in its lee. More recent maps show the reestablishment of Kent Island, the new Pine Gulch Creek Delta, and more tidal marsh habitat than in 1854. Over the next 50 years there will be a continued shift in habitat type and an overall loss of 0.55 MCY of tidal prism resulting from conversion of low mudflat to higher mudflat and higher mudflat to tidal marsh. The Report attributes this to loss of wind wave action from Pine Gulch Creek delta. The Report indicates that this will continue and at the quasi-equilibrium (year 2125), loss of wind wave action will result in tidal marsh expansion along the west side of the lagoon (Figure 5-13), an additional increase of 80 acres and a loss of 0.2 MCY of tidal prism.

A major change observed in the lagoon is the diminution of the Bolinas Channel. The 1854 map shows a large channel that connected Pine Gulch Creek to the lagoon mouth. In 1929, the channel is larger and opens directly and widely into the north basin. Subsequent maps show the channel getting smaller as Kent Island expands its size. Several factors may contribute to this trend: 1) less down drop on the west side of the lagoon (although the 1929 map does indicate that down drop contributed to a direct and wide channel to the north), 2) progradation of Pine Gulch Creek delta that cut off the channel from the north basin, an 3) growth of tidal marsh between Kent Island and Pine Gulch Creek, further cutting off the head of the channel. The Report states that anthropogenic impacts may be, in part, responsible for the latter two factors.

Summary of Anthropogenic Activities and Effect on Tidal Prism to 2050
(from Table 5-3)

Construction of Seadrift	0.30 MCY
Creek Channeliztion	
Sediment delivery	0.25 MCY (direct due to sediment accumulation)
Wind fetch	0.25 MCY (resulting in salt marsh expansion)
Change in Wind Fetch	0.30 MCY (conversion of low to high mudflat)
Other Fill	0.10 MCY
TOTAL	1.2 MCY

Conclusion:

When taken together, all human related actions will lead to a new habitat mix and a different tidal prism (loss of 1.2 MCY between 1854 and the 2050 projection). At that point there will be more marsh and high intertidal flat and less low intertidal flat than in 1854 - during the most recent quasi equilibrium period. The tidal prism at the future quasi equilibrium point (125 years from now) is projected to be 2.0 MCY versus 3.7 MCY in 1854 and 3.5 MCY today. The Report identifies expected shifts in populations of plants and animals associated with these habitat shifts. Even with the anthropogenic-related changes, in 2050 the lagoon inlet is not projected to close.