Bolinas Lagoon Ecosystem Restoration Feasibility Project

Final Public Reports

I Executive Summary

Executive Summary

Project Background

The 1996 Marin County Open Space District's *Bolinas Lagoon Management Update* suggested that Bolinas Lagoon had lost significant tidal prism since 1968 and recommended that additional studies be conducted to corroborate this finding and determine the future magnitude of tidal prism loss. A Reconnaissance Study conducted by the United States Army Corps of Engineers (COE) in 1997 concluded that corrective action – dredging and/or other means of removing accumulated sediment or minimizing its entry into the lagoon – was a matter of national interest because of the lagoon's environmental significance. The COE, with financial support from the federal government, the State of California, and the Marin County Open Space District (MCOSD), commenced a Feasibility Study in 1998 to develop a plan to restore the lagoon's habitats. The COE released the Draft Bolinas Lagoon Ecosystem Restoration Feasibility Study and Draft EIR/EIS in 2002. The study called for dredging approximately 1.4 million cubic yards of sediment from the lagoon. Public comments challenged the conclusions of the Draft EIR/S and cited the need for a clear, scientifically sound description of how the lagoon would evolve if no action was taken—without which the purpose and need for taking corrective action could not be supported.

In response, MCOSD hired a consulting team to conduct a rigorous scientific review of the study's assumptions and conclusions and to provide a 50-year projection of the lagoon's hydrological and ecological evolution. As part of this effort, MCOSD assembled two panels of independent scientists with expertise in a variety of relevant disciplines to assist the consultant team in identifying data gaps and collecting and analyzing new data. These panels, known as the Technical Review Group and the Project Reformulation Advisory Group, also provided peer review of the consultant's reports. The consulting team prepared a series of five reports documenting its findings. The conclusions contained in the most recent report, entitled "Projecting the Future Evolution of Bolinas Lagoon", are based on the consultants' previous reports related to lagoon management objectives, data review, sediment delivery, and other subjects. All reports are posted on MCOSD's website, www.marinopenspace.org.

About This Report

"Projecting the Future Evolution of Bolinas Lagoon" describes the past and present physical and ecological state of the lagoon. It also contains a 50-year projection of the lagoon's physical and ecological evolution. The 50-year projection assumes that neither a major earthquake nor intentional human actions will occur to alter the lagoon's evolution. The Report is a "no-action alternative" that would be compared to other action or intervention alternatives, should MCOSD decide to revise and complete the 2002 Feasibility Study and its EIR/EIS.

The Report does not make any recommendations with regard to actions to alter the lagoon's evolution. Even so, this does not indicate that intervention is or is not warranted. The purpose and need for intervention will be assessed in the next steps of the Feasibility Study process, which includes public meetings scheduled for the second half of 2006.

The Report recommends monitoring as an essential activity whether or not intervention occurs. This is because there are inherent uncertainties in deciphering and understanding past changes and predicting future changes in a complex and dynamic natural system such as Bolinas Lagoon. Monitoring will provide essential data to confirm and/or refine, reanalyze, and readjust the 50-year projection. If intervention measures—large or small—are implemented, monitoring the effects of these actions will allow us to test our understanding of how the lagoon functions and the need for and efficacy of additional intervention.

General Lagoon Context

Key Points:

- Bolinas Lagoon is a complex, dynamic ecosystem that is governed by interactions between climate, geologic processes, and land use.

Bolinas Lagoon is a complex ecosystem that is constantly changing. The lagoon exists because of geologic processes associated with the San Andreas and San Gregorio faults. Great earthquakes along these faults are especially important because they deepen the lagoon and counteract sediment accumulation.

Climate interacts with geology to control the amounts of sediment and water that enter and exit the lagoon. Climate controls sea level, the delivery and removal of sediment by the tides, storm size and frequency, winds, watershed erosion, and the delivery of sediment and water through local watersheds. The process of deepening by earthquakes is followed by periods of rapid sediment accumulation and reduction of tidal prism because of increased transport of ocean sediment through the inlet and its deposition in the deepened recesses of the lagoon.

The rapid filling phase gradually slows until a dynamic equilibrium state is reached where sedimentation is offset by sea level rise and the tidal prism is relatively stable. Waves caused by the wind contribute to stabilizing tidal prism 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. The system remains in a state of dynamic equilibrium until it is suddenly disrupted by another major earthquake.

The sudden lagoon deepening, followed by rapid and then slower sediment accumulation and progression towards a dynamic equilibrium, results in sudden and then incremental habitat shifts and a natural succession of plant and animal communities.

Past Evolution of Bolinas Lagoon

Key Points:

- Since the early 19th Century, land use changes have altered the historical shoreline and watershed of Bolinas Lagoon and increased sediment delivery to the lagoon, resulting in a loss of tidal prism and changes in habitat types.
- In 1854, the lagoon was very shallow, with well developed tidal channels in the north basin.
- Land use changes that occurred in the watershed during the latter half of the 19th century at least doubled the amount of sediment entering the lagoon.
- The 1906 earthquake deepened the lagoon. A period of rapid sediment accumulation followed.
- The Bolinas Bluffs collapsed during the 1906 earthquake, creating a substantial source of sediment that was carried throughout the lagoon.

- Most of the sediment entering the lagoon is from the ocean rather than the lagoon's watershed.

New data indicate that five major earthquakes have affected the lagoon over the past 1,600 years. The earthquakes occurred every 340 years on average. The time between earthquakes varied substantially, from over 600 years to as few as 140 years.

The first topographic map of the lagoon, prepared in 1854, provides the earliest picture of the physical state of the lagoon. The lagoon was very shallow with well developed tidal channels in the north basin. The lagoon mouth and the large flood tide island (Kent Island) were similar in location and extent as in 2004. The Pine Gulch Creek delta did not exist. The Bolinas Channel was large and connected to Pine Gulch Creek and the north basin.

The latter half of the 19th century was a period of significant land use change in the lagoon's watershed. Logging, road and house building, grazing, and farming increased sediment delivery from the watershed by two to three times compared to the period prior to European settlement.

The 1906 earthquake deepened the lagoon by an average of 1.5 to 1.9 ft. and increased tidal prism from an estimated 3.2 to 6.7 million cubic yards (MCY), an increase of 3.5 MCY. First hand accounts indicate that Kent Island disappeared, tidal marsh became submerged to the north of Kent Island, and that the eastern portion of the lagoon experienced greater down drop than the western portion.

A 1929 map shows the first picture of the lagoon following the 1906 earthquake. The map shows that the lagoon had extensive deep water habitat and a direct channel from the inlet to the north basin, with only a small patch of tidal marsh where Kent Island existed in 1854. In general, the 1906 earthquake resulted in a shift from a shallow mudflat-dominated to a deeper open-water lagoon.

New data indicate that, following the earthquake, there was a period of rapid sediment accumulation, consisting primarily of beach sands and silt. The Bolinas Bluffs, which collapsed during the 1906 earthquake, were the source of the silt. Rapid sediment accumulation is reflected in the loss of tidal prism during the period from 1906 to1929, which averaged 48,000 cubic yards (CY) per year. As the lagoon became shallower and the rate of sediment accumulation declined, tidal prism loss did also: 48,000 CY/yr

(1906-1929), to 33,000 CY/yr (1929-1968), to 27,000 CY/yr (1968-1998). This decline is due to the lagoon becoming progressively shallower as it recovers from the earthquake and progresses toward a dynamic equilibrium.

Sediment delivery from the watershed occurs mostly during severe winter storms. Watershed and ocean sediments account for 20-25% and 75-80% of all sediment in the lagoon, respectively. Delivery of sediment from the watershed continues to be higher than in the period prior to European settlement that began in the mid 19th century. Pine Gulch Creek delivers the majority of watershed sediment to the lagoon. Pine Gulch Creek delta does not appear on the 1854 map of the lagoon. The growth of Pine Gulch Creek delta has occurred because the creek has been channelized and can no longer deposit sediment on its historic flood plain. Instead, the creek deposits its sediment load upon entering the lagoon. Kent Island and Pine Gulch Creek delta shelter a significant portion of the western shoreline from locally generated wind waves that resuspend sediments and keep mudflats below elevations suitable for establishment of tidal marsh. In sheltered areas, reduced wind-wave agitation has resulted in conversion of mudflat to tidal marsh (a shift in habitat type) and a reduction of tidal prism. The expanding Pine Gulch Creek delta and adjoining tidal marsh have resulted in continuing blockage and diminution of the Bolinas Channel. The pattern of Tectonic subsidence and uplift on the eastern and western portions of the lagoon may have also altered the underlying geomorphology of the channel compared to that in 1854.

There have been dramatic shifts in habitats and, presumably, wildlife use of the lagoon since 1854. The sharpest distinction is just before the 1906 earthquake, when the lagoon was largely shallow intertidal mudflat habitat, and just after, when the lagoon became much deeper—a shift from an estuarine to a more marine habitat. This has been slowly reversing over the last 100 years and will continue to do so.

In addition to the land use changes that began in the mid 19th century, the lagoon's perimeter and inlet have been affected by the construction of roads, retaining walls, a groin, and the placement of fill. Creek channelizations and diversions have also increased sediment delivery to the lagoon, beyond that attributable to land use changes.

Existing Lagoon Conditions

Key Points:

- The lagoon today is a single snap shot within a continuum of changing ecological and physical conditions as the lagoon continues to respond to the 1906 earthquake and human induced influences.
- Because the lagoon is becoming shallower as sediment accumulates, the populations of fish, wildlife and plant species associated with deeper water habitats are declining

The lagoon of today is similar in many ways to the lagoon shown in the 1854 map: the lagoon is shallow, intertidal mudflat habitat predominates, the tidal prism is approximately 3.5 MCY, and there is a large flood tide island. Differences are also evident and include the Pine Gulch Creek delta, the expanding tidal marsh on the west side and in the south arm, and the diminution of the Bolinas Channel.

Bolinas Lagoon provides an important estuarine environment for a rich variety of plants and wildlife. Major habitat types include subtidal channels and shallows, frequently submerged and frequently exposed mudflat, salt marsh and brackish marsh, riparian and flood tide island. Together these provide habitat for a wide array of fish, diving and dabbling ducks, shorebirds, harbor seals, and bottom-dwelling invertebrates. The lagoon provides habitat for numerous special status plant and animals and is one of only three RAMSAR sites (List of Wetlands of International Importance) on the west coast. The lagoon is particularly valuable for migratory waterfowl and shorebirds, as a nursery area for fish and invertebrates, and as a pupping and haul-out site for harbor seals.

Future Evolution of Bolinas Lagoon

Key Points:

- There is a very high probability that the inlet to Bolinas Lagoon will remain open in 2050.
- The area of subtidal habitat will decline by 26%, with a corresponding increase in frequently exposed mudflat and tidal marsh.
- The Pine Gulch Creek delta will nearly double in size.

In the absence of a major earthquake along the San Andreas Fault, the loss of tidal prism will continue beyond the next 50 years as Bolinas Lagoon evolves towards a new equilibrium form. Tidal prism loss over the next 50 years is expected to average 19,000 CY/yr, and 7,000 CY/yr between 2050 and 2125. In the year 2050, tidal prism will be an estimated 2.5 MCY, as compared to 3.5 MCY presently. At 2.5 MCY, the inlet is expected to remain open, but as tidal prism decreases further, the possibility of closure during extreme conditions increases. Closure of the inlet would, depending on the length of closure, lead to significant ecological changes due to the lack of tidal water exchange. The predicted date for the lagoon to reach its dynamic equilibrium form, at which time sediment accumulation would be balanced by sea level rise and erosional processes within the lagoon, is in 2125. By this date the lagoon's tidal prism could be close to 2 MCY and would remain so until the next large earthquake.

Predicted habitat changes include expansion of salt marsh and a continued rise in the mudflat elevation. General habitat changes include the loss of subtidal shallows, a 26% reduction of the 399 acres of frequently submerged mudflat with a corresponding increase in frequently exposed mudflat and tidal marsh, and an 82% increase in the size of Pine Gulch Creek delta. Species that depend on these habitats are expected to either increase or decrease depending on the trends in habitat loss or gain. For example, one-third of the 99 invertebrates listed as occurring in the lagoon are associated with subtidal and frequently submerged mudflat and are expected to decline in population as their habitat area decreases. Similarly, the decreases in deeper water habitat will reduce foraging habitat for two guilds of birds (diving fish and benthos eating birds) and most of the 38 species of fish known to occur in the lagoon. Some shorebirds are expected to lose habitat while others will gain; marsh bird populations are expected to benefit as are migratory and resident land birds by the increase in riparian forest on Pine Gulch Creek delta. The predicted changes in plant and wildlife species are based on habitat changes. However, population changes cannot be attributed entirely to the lagoon's physical evolution. Other factors operating within a larger regional or even global scale may profoundly affect these populations as well.

Human-Caused Factors

Key Points:

- Multiple human activities have resulted in direct changes to the lagoon's habitat distribution and tidal prism and have also affected the physical processes that drive the evolution of the lagoon.
- Human activities cannot account for all the changes that are observed or predicted in the lagoon based on comparisons with 1854.
- It is difficult to quantify the proportion of changes in the lagoon's evolution caused by human activities compared to natural processes.

In addition to the watershed changes (logging, cord wood cutting, road building, grazing, and agriculture) and creek channelization mentioned previously, numerous other anthropogenic forces have affected the lagoon system over the past 150 years. These include, but are not limited to, construction of Seadrift (e.g., fill of 90 acres of intertidal habitat and loss of 0.3 MCY of tidal prism; hardening of the ocean side and lagoon side of the spit with rip rap and retaining walls); fill for Highway 1; fill for the road and housing along Wharf Road in Bolinas; fill in south arm of lagoon; hardening (rip rap and retaining wall) of the inlet at the end of Wharf Road in Bolinas; construction of the causeway in the South arm of the lagoon; and invasion by non-native plant/wildlife species.

It is difficult to precisely quantify the amount of anthropogenic change against the backdrop of large natural changes in the lagoon. Even with no anthropogenic effects, changes resulting from each earthquake will result in the lagoon moving toward a unique dynamic equilibrium form. Our best estimates are that anthropogenic changes will result in a tidal prism loss of 1.2 MCY (based on comparison of the predicted Year 50 condition and tidal prism derived from the 1854 T-sheet). In addition to the reduction in intertidal lagoon volume, human-induces changes have altered the relative distribution of mudflat, salt marsh and riparian habitats.

Monitoring and Adaptive Management

Key Points:

- Monitoring the lagoon's condition is necessary to test and refine the assumptions and conceptual models upon which the 50-year projection is based.

Although studies carried out as part of this project have increased our ability to explain how Bolinas Lagoon has evolved in the past and how it may change in the future, our understanding of ecosystem functions remains incomplete. Consequently, key indicators of the lagoon's physical and ecological condition should be monitored to test specific assumptions regarding future lagoon evolution and examine the validity of the 50-year projections. Monitoring should include both physical parameters (e.g. tidal range, equilibrium mudflat elevation, net sediment accumulation and tidal prism change) and biological parameters (e.g., habitat extent and composition and trends in populations of selected invertebrate, fish, bird and mammals). All biological indicators should be considered together locally and within a regional context to determine if population changes are associated with local conditions, or are the result of conditions unrelated to the lagoon.

Monitoring provides the information upon which adaptive management of the lagoon could occur. An adaptive management plan for the lagoon would establish clear management goals and a decision-making framework in which management decisions and actions would be based on conceptual models of the lagoon's function and monitoring of key physical and ecological variables. Adaptive management increases the likelihood of achieving agreed-upon objectives, while reducing the potential for adversely affecting important resources of the lagoon.