3.0 STUDY AREA DESCRIPTION

This chapter presents the background information of this study, including without project conditions, existing conditions, and future without project conditions. It is from this information that the restoration alternatives are formulated. In later chapters, the alternatives will be compared to the future without project conditions, and compared to one another in order to select the best possible solution to the problem.

3.1 Setting

Bolinas Lagoon is part of the Gulf of the Farallones National Marine Sanctuary, and is surrounded by open lands owned by Audubon Canyon Ranch, Point Reyes National Seashore, Golden Gate National Recreation Area, and Mount Tamalpais State Park, as well as small residential and agricultural areas in the towns of Stinson Beach and Bolinas. The watershed surrounding Bolinas Lagoon is 16.7 square miles, with a dimension of three miles in width by nine miles in length (Figure 3.1) (BLMPU 1996). The Bolinas Ridge, which is on the eastern side of the lagoon, rises to an elevation of 2,000 feet. The largest single contributor of water and sediment to the Bolinas Lagoon watershed is Pine Gulch Creek, a perennial tributary located on the northwestern side of the lagoon, near the town of Bolinas. It comprises about half of the fresh water flowing into the lagoon. On the eastern side, there are several smaller intermittent creeks flowing in from the Bolinas Ridge, including Easkoot Creek. The sand spit of Stinson Beach forms the western boundary of the lagoon, terminating at the lagoon inlet. The residential area along the Stinson Beach sand spit, which was developed in the 1950's by placing dredge spoils from the sand spit into Bolinas Lagoon, thereby forming Seadrift Lagoon, forms the Seadrift Lagoon community. Access to Bolinas Lagoon is provided by Highway One, which runs parallel along the eastern border, the Bolinas/Olema Road, Wharf Road, Seadrift and Dipsea Roads (BLMPU 1996).

Located along the Pacific Flyway, receiving over-wintering birds during their migration periods, Bolinas Lagoon was designated as a Ramsar Site or Wetland of International Importance in 1998 by the U.S. Fish and Wildlife Service (Ramsar 2001). The wetlands identified on the Ramsar list "acquire a new status at the national level and are recognized by the international community as being of significant value not only for the country, or the countries, in which they are located, but for humanity as a whole" (Ramsar 2001). Stinson Beach and Bolinas Lagoon are tourist destinations for local, domestic and international travelers, especially during the summer months.

3.2 Historical Conditions

Bolinas Lagoon had already been in use by local and migratory species for more than two thousand years when Egypt's 4th dynasty ruler Khufu built the Great Pyramid in 2560 B.C. This estuary has been naturally maintained for some 7,000 years (BLMPU 1996). Under normal conditions, due to the build up of sediments, lagoons have a geologically short life span. Their normal life cycle is to change first, from an estuary into intertidal wetland habitat, then into upland habitat. However, due to a rare balance between sedimentation, sea level rise, and tectonic subsidence, Bolinas Lagoon has remained, until recently, much as it was 7,000 years ago.

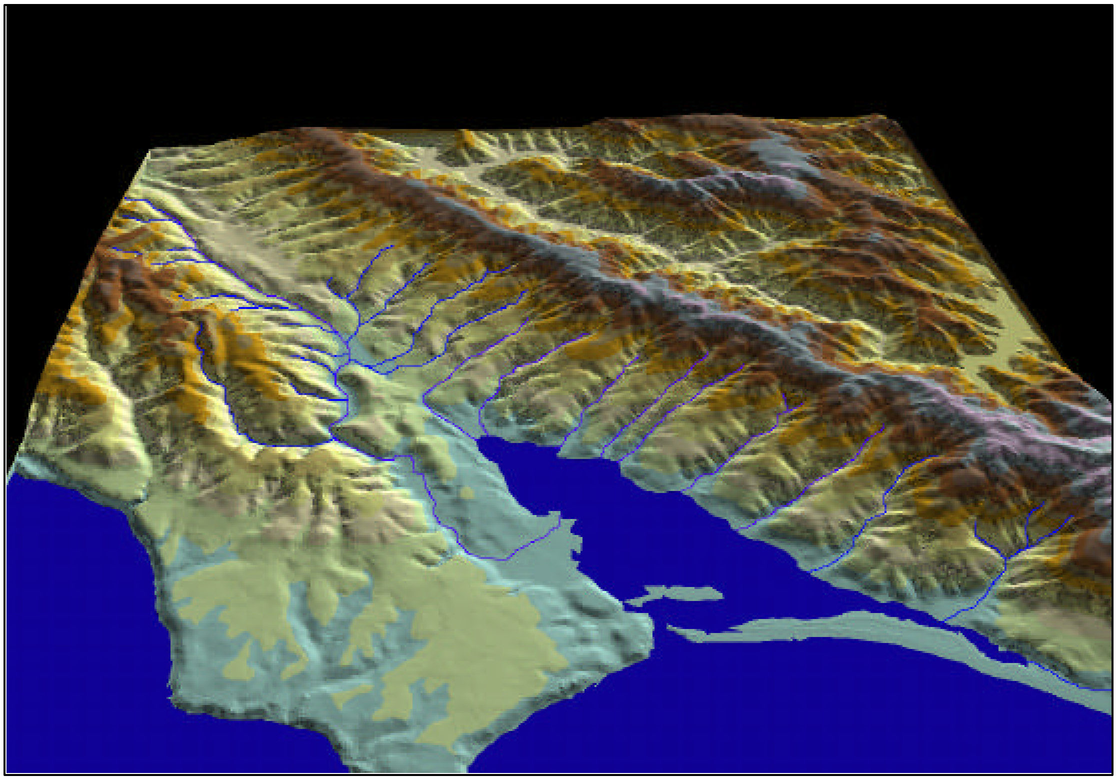

Figure 3.1 Digital Terrain Model of the Bolinas Lagoon Watershed

It appears the reason Bolinas Lagoon continues as a "self maintaining" system, and did not long ago transform into a meadow, is due to large seismic events along the San Andreas Fault (BLMPU 1996). The seismic activity dramatically increases tidal prism by physically dropping the lagoon bottom elevation and causing channel realignment, which essentially turns the clock back for the lagoon with each major earthquake. In a study performed by Knudsen et al. in 1999 for the USGS, considerable evidence lead to the conclusion that significant earthquakes occur along the San Andreas Fault in this region, at regular intervals of three hundred to four hundred years.

In 1998, the lagoon looked similar to the way it did in 1854 (Figure 3.2). The size of Kent Island, the size and layout of the channels, and the extensive mudflats are all very much the same. In addition, in his 1978 report, Bergquist argued that although the 1854 map does not show the subtidal area in the north end of the lagoon, there is evidence of such a subtidal area in core samples. This suggests the 1854 lagoon did look very much like the 1998 lagoon, as there was also subtidal area in the north end of the lagoon in 1998. Regular seismic events have continued this cycle of lowering the lagoon bottom after hundreds of years of sediment accrual, keeping the lagoon open longer than would normally be expected.

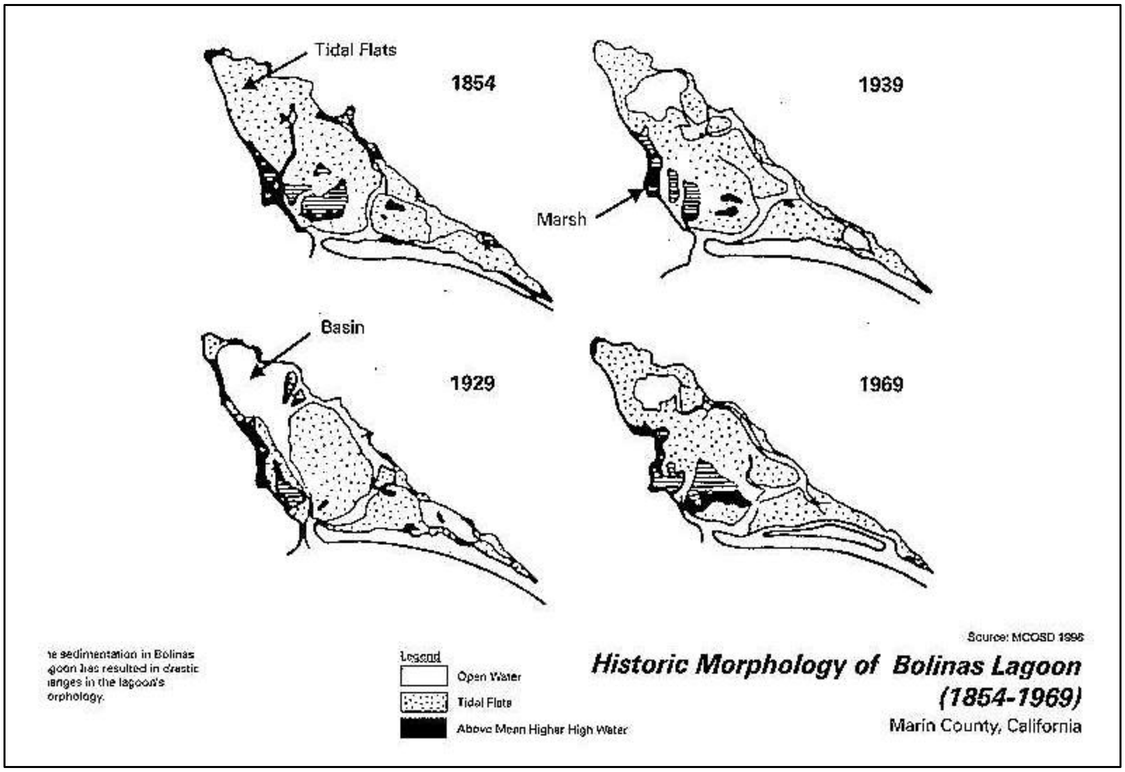

Figure 3.2 Lagoon Morphology 1854-1969

For most, if not all of its 7,000 years, the Lagoon has been part of the Pacific Flyway, one of the four North American bird migration routes. The Pacific Flyway is comprised of the western Arctic, including Alaska and the Aleutian Islands, and the Rocky Mountain and Pacific coast regions of Canada, the United States and Mexico, south to Central and South America, where it mixes with the other migration flyways.

In the last hundred years, most of California's estuarine habitat has disappeared due to human activities, like urbanization, development, agriculture, logging, etc. Bolinas Lagoon is one of the last relatively undeveloped estuarine habitats remaining on the coast of California, and hosts an array of biologically diverse species, including benthic invertebrates; marine algae; threatened, endangered and special status species such as Coho salmon, steelhead trout, and black rail; migrating birds on the Pacific Flyway; and other resident and migratory fish, birds, and seals. As other estuarine habitats continue to disappear, Bolinas Lagoon becomes increasingly important to both its local populations and the migratory populations and was designated a Ramsar Site, or Wetland of International Importance, in 1998.

The *Bolinas Lagoon Management Plan Update of 1996*, and more recently the *Bolinas Lagoon Watershed Study of 2001* (BLWS 2001), provide a summary of past studies such as Ritter (1970), Rowntree (1973), Bergquist (1978), and Bergquist and

Warhaftig (1993). These reports agree that poor management of the watershed after the year 1850 appears to be the major cause of the above normal sedimentation rate in the lagoon. Activities such as logging, grazing, road construction, stream channelization and natural fires all contributed to the increased level of sedimentation. This conclusion was verified by the coastal engineering work completed for this study (discussed in Section 3 of the Engineering Appendix).

Feasibility studies have shown that, due to the continued loss of lagoon volume over time, even at the near normal rate (as discussed in Section 3 of the Engineering Appendix), the lagoon's inlet could experience temporary closures in approximately thirty years, given the right combination of meteorological events (discussed in detail in Section 3.10 of the Engineering Appendix). Extrapolating this information to the 1854 lagoon would suggest that the lagoon would have been at risk of closure around the year 1900. In actuality, it was probably sooner, since it has been estimated that some of the highest years of sedimentation occurred soon after 1850.

In the years between 1850 and the early 1900's much of the old growth forest in the watershed was logged, particularly the redwood stands. In fact, from 1849 to 1860, Dog Town's mills reportedly generated nearly 15 million board feet of lumber. Logging roads were often created by filling in creeks with rubble and earth, causing much of the sediment to be transported into the lagoon during heavy rainfall events. Lands harvested of timber along the slopes of the Bolinas Ridge were converted to cattle grazing and agricultural uses when the logging activities ceased. Several mining operations were also active in the area, peaking in operation during WWII, and continuing until 1963. After these activities ceased, and the watershed was in the beginning stages of recovery, a devastating fire swept through the area, burning out most of what remained of the forest and its under story, and likely caused severe erosion on the denuded slopes. Fires have swept through Marin at regular intervals throughout recorded history, and are understood to have done so long before European settlement. Major fires in the Bolinas watershed are recorded in 1890, 1904, 1923, and 1945, most of which burned through the ranchlands on the northern and eastern sides of the watershed. All these factors contributed substantially to a greater amount of sediment being delivered to the lagoon. In 1906, however, a large earthquake occurred which reportedly dropped the bottom of the lagoon by over one foot (BLMPU 1996). At about the time the lagoon was approaching the potential of closure, the earthquake effectively opened the system back up.

The lagoon is now approaching potential closure in the year 2050, but a sizable earthquake is not expected until the years 2200 to 2300, based upon the 1999 Knudsen Report. This suggests the lagoon will reach a point 150 years after the last major earthquake, which, had human activities not disturbed the natural cycle, would not have been reached for another 300 to 400 years. The lagoon's sedimentation rate in the recent past has averaged two to three times its normal rate.

There are numerous discrepancies among reports concerning the sedimentation rate timeline of the lagoon. Bergquist's 1978 report attempted to correct the information and methodologies used by earlier investigators, and added information gleaned from his own research, to create a sedimentation rate timeline that seemed fairly comprehensive. However, in 1993, Bergquist and Warhaftig refuted some of the conclusions reached in Bergquist's earlier report. The *Bolinas Lagoon Management Plan Update of 1996* also attempted to summarize the reports and reach a sedimentation rate timeline (shown as Figure 3.3), but uncertainty remains as the timeline is largely based on the same information Bergquist used. The *Bolinas Lagoon Watershed Study of 2001* also summarized many of the previous studies, and although it does not highlight or explain the discrepancies, they are evident in the information therein.

Instead of trying to determine an exact sedimentation rate timeline from 1850 forward, the Corps used a different method to determine the severity of past sedimentation and its effects in the lagoon. This method incorporated historical maps, bathymetries, and a recent report on earthquake frequency, to calculate the average sedimentation rate for the last 150 years. The normal rate was estimated by using information from Bergquist's 1978 report. In that report, the sedimentation rate prior to human impacts was estimated at 3 millimeters per year. This measurement is two-dimensional, and shows how sediment builds up on the surface of the lagoon floor. The Corps used a three-dimensional measure to estimate the actual volume of sediment accumulating. The average sedimentation rate from 1850 to 2000 was found to be .900 million cubic feet (ft^3) to 1.25 million ft^3 per year (see Section 3 of the Engineering Appendix for more details).

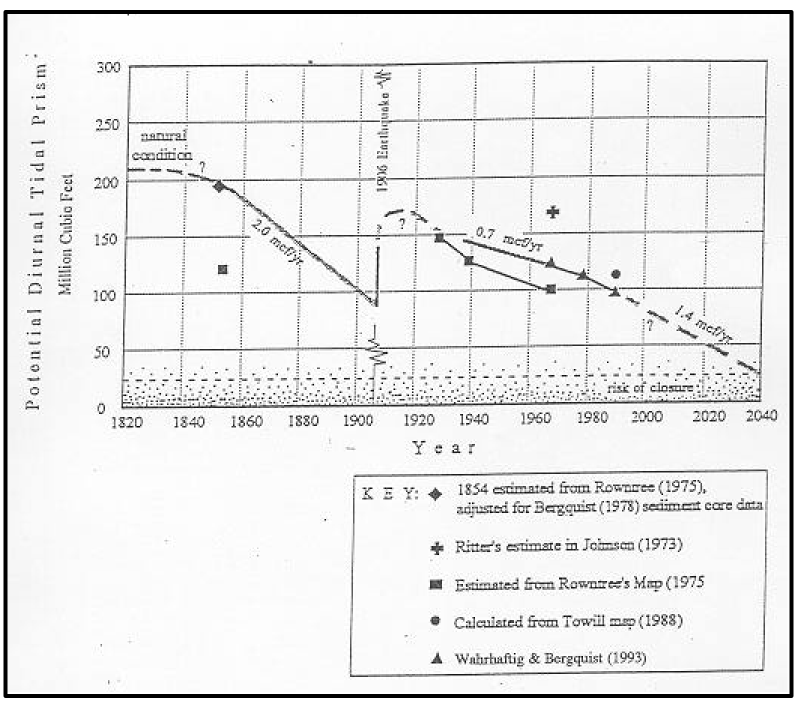

Figure 3.3 Sedimentation Rate Timeline (BLMPU 1996)

The earthquake-based estimation was compared to the estimated sedimentation rate time line shown in Figure 3.3. This was done by totaling the sediment that would have entered the lagoon for each time period, then averaging that over the 150 year time period (Table 3.1). A comparison between the two average rates shows that they are surprisingly close, which provides some level of confidence in the sedimentation rate estimates.

Table 3.1 Sediment Volume Summary

Years	**Rate** (million ft^3/year)	**Total** (million ft^3)
1850 to 1900	2 .0	100
1900 to 1970	0.7	49
1970 to 2000	1.4	42
Total Sediment Volume Entered Over 150 Year Period		191
Average Annual Sedimentation Rate Between 1850 and 2000		1.27

3.3 Existing Conditions

3.3.1 Hydraulic

1968 to 1998 Sedimentation Rate

Detailed bathymetric surveys that were taken in 1968, 1978, 1988, and 1998 were used to determine the average sedimentation rate for each of those decades. By dividing each ten-year measure of sediment volume change by ten, the data were converted into an annual sedimentation rate. Between 1968 and 1978, the average sedimentation rate was found to be 2.27 million cubic feet per year (ft^3/yr), or 84,000 cubic yards per year (yds^3/yr); between 1978 and 1988 it was 0.86 million ft^3/yr (31,850 yds^3/yr); and between 1988 and 1998 the sedimentation rate was 0.71 million ft^3/yr (26,300 yds^3/yr). An illustration of how and where sediment filled in the lagoon between 1968 and 1998 can be seen in Figures 3.4 and 3.5.

In order to determine whether human activities had an impact on the annual sedimentation rate, a "normal" infilling rate was determined by incorporating data from past studies. For example, as referenced in the *Bolinas Lagoon Management Plan Update of 1996*, Bergquist (1978) used soil borings to estimate that the lagoon, on average, had a sedimentation rate of approximately 3 millimeters (mm) per year prior to 1849, that is, before Europeans arrived in the area. This information was combined with the bathymetric data in a way that made it possible to estimate an average "normal" infilling rate (the methodology used for this calculation is discussed further in the Engineering Appendix). The normal volumetric infilling rate was found to be 0.45 million ft^3/yr (16,700 yds^3/yr). Comparing this normal infilling rate to the data above, it

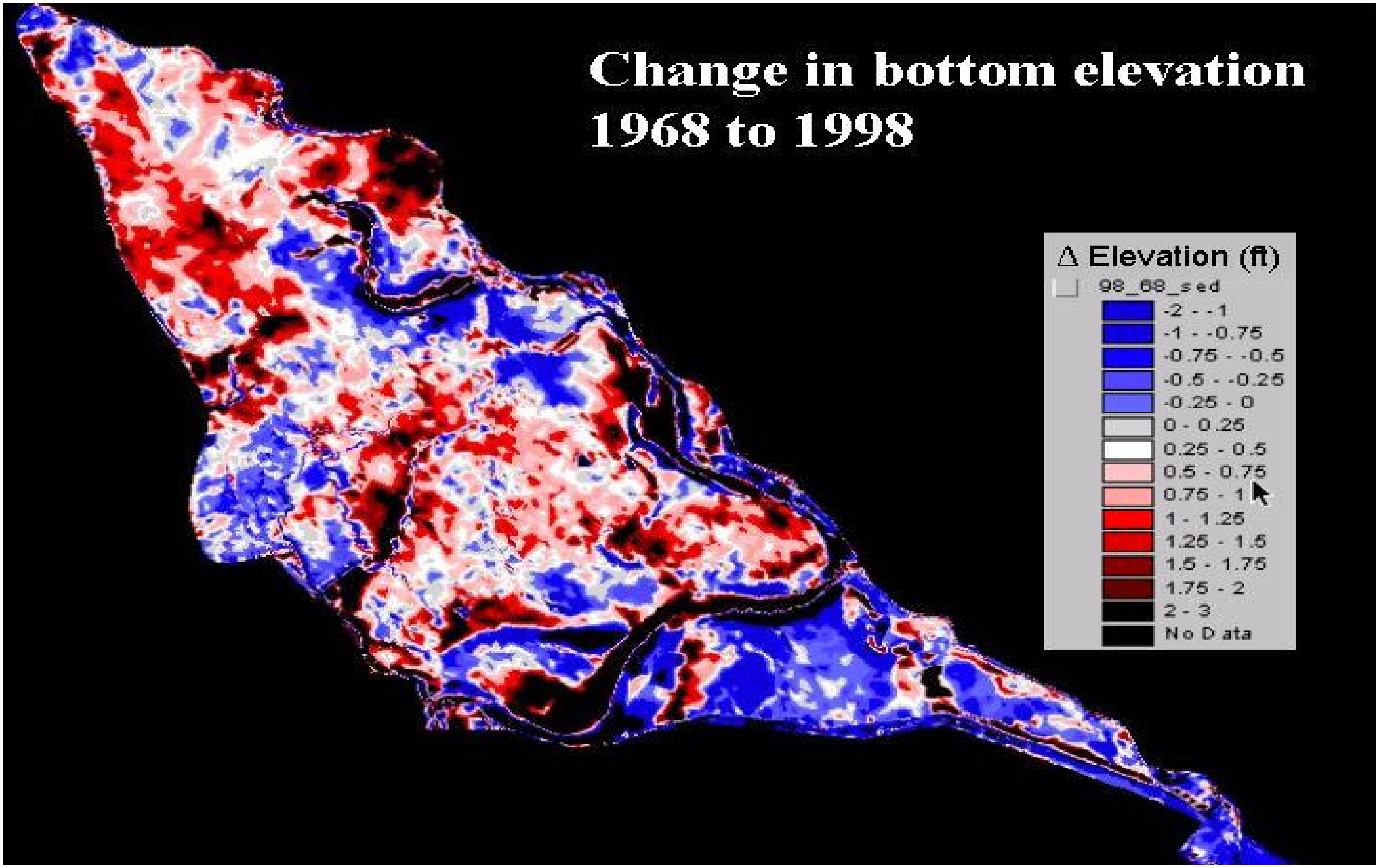

Figure 3.4 Change in Depth from 1968 to 1998 (feet)

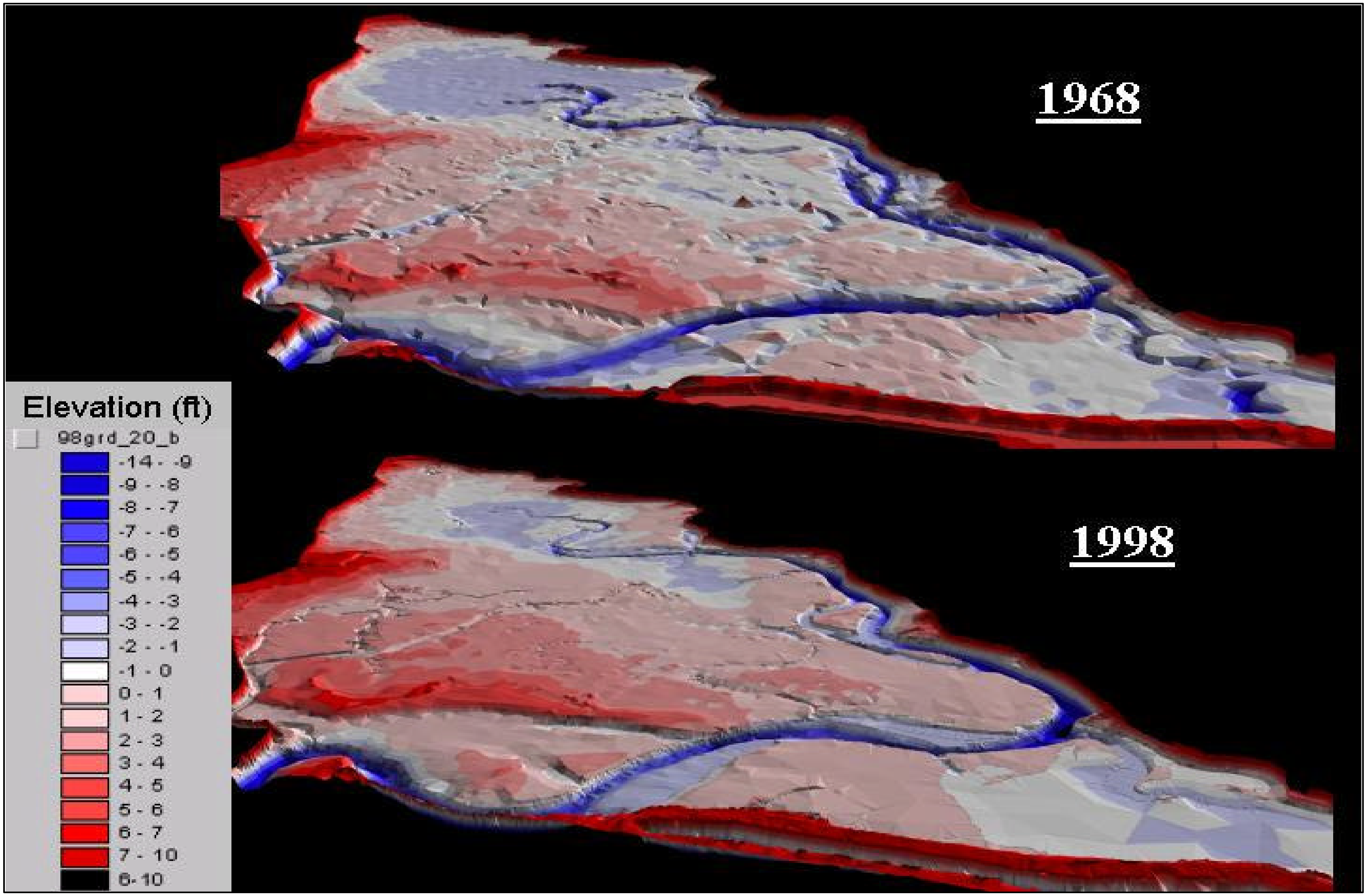

Figure 3.5 Bolinas Lagoon Bathymetries - 3D Digital Terrain Models

is obvious the sedimentation rate between 1968 and 1978 was significantly higher than what is considered normal (in fact, it is about five times higher), and that the infilling rate has decreased over time to the extent that, between 1988 and 1998, it was approaching normal.

This "normal" rate (0.45mft^3/yr) has been tagged with the letter (n) to signify the normal infilling rate. Although this method is prone to error, it represents a best guess with the available data, which is substantial compared to other studies that lack historical data. The results of this analysis are illustrated in Figure 3.6. Future estimates for sediment infill were made by visually extrapolating the graph. That is, a best-fit line was drawn using the normal sedimentation rate as the asymptote (a straight line associated with a curve where the distance between the two approaches zero).

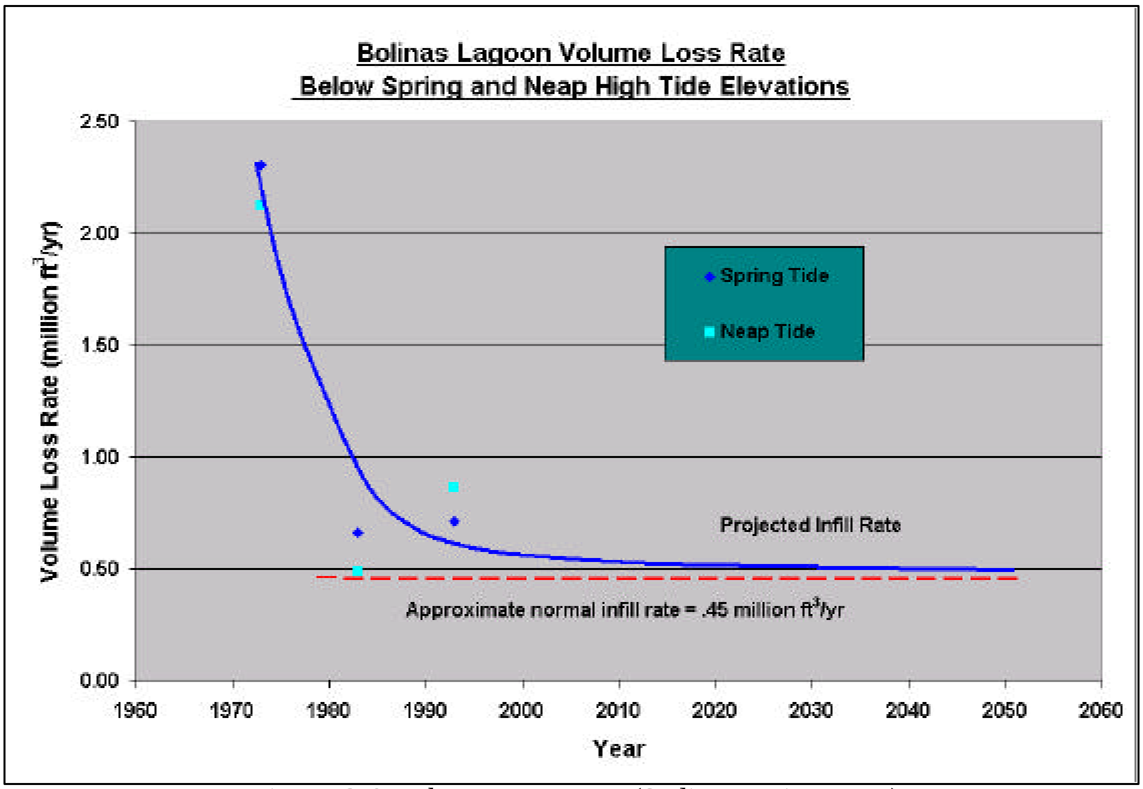

Figure 3.6 Volume Loss Rate (Sedimentation Rate)

<u>*Sedimentation Source - Corps Analysis*</u>

Based on work completed in this Feasibility Study, past sedimentation studies, lagoon history, and the physical processes of the system, it was found that the most likely cause of the abnormally high sedimentation rate was human activities in the watershed after European settlement of the area. This is in agreement with previous reports (see Section 3 of the Engineering Appendix). Some have argued that above normal sedimentation in the lagoon was caused by the development of the sand spit, the construction of the Bolinas Groin, and other "ocean side" alterations to the system. Presumably, those activities have had effects on the lagoon; however, considering the evidence, they do not appear to be significant when compared to the watershed. In addition, this theory would not explain why the sedimentation rate has significantly decreased since 1968.

Figure 3.6 shows that the sedimentation rate between 1968 and 1978 averaged 2.27 million ft^3/year, but decreased steeply to 0.71 million ft^3/yr between 1988 and 1998. If the alterations on the ocean side of the system were the most significant contributors, it seems unlikely that the sedimentation rates would have fallen, since the conditions have not improved on the ocean side. In fact, they are most likely worse than they were in the early 1970's. On the other hand, better watershed management practices have been enacted, the last logging occurred in 1969, logging roads have washed out or have started to become vegetated, development has been curtailed, mining activities have stopped, ranching and agricultural practices have either been decreased or have improved, and much of the watershed is in public ownership as parklands and for conservation purposes, all of which have led to less erosion in the watershed and the possibility of recovery. Over time, the watershed has healed itself. This information suggests that the volume of sediment coming from the watershed has decreased since the 1960’s (BLWS 2001).

In addition to the sedimentation rate analysis, further evidence was provided by a sediment grab sample study that was conducted in 1998 (PWA 1999). Using thirty-five grab samples to map the lagoon’s sediment, it was hoped that sediment markers, such as mineralogy, angularity, and grain size could be used for identifying the most likely source of sediments throughout the lagoon. Unfortunately, the results were not as discernable as had been hoped, but a grain size map was developed (Figure 3.7), which allowed important information to be interpolated for the northern and southeastern portions of the lagoon. The material in the northern part of the lagoon was classified as very fine sand, bordered by a large area of silt to the south. This was twofold evidence that material in the north part of the lagoon came from the watershed. First, larger particles settle out more quickly than smaller particles, indicating that the sediment originated in the watershed. Second, one would expect that, if the sediment were coming from the ocean (mostly sand and gravel, with limited silt), the silt area would be north of the sand area, since the sand would drop out first.

3.3.2 Environmental

Bolinas Lagoon has a variety of habitats that can be grouped into the following three categories: subtidal channels, intertidal flats, and emergent marsh. As discussed earlier, sediment accumulation in the lagoon has resulted in a loss of tidal prism and a decrease in the deeper estuarine habitats of the lagoon. Between 1968 and 1998, subtidal habitat decreased by 60%, intertidal flats increased by 37%, and emergent marsh increased by 100% (BLMPU 1996). Overall, all of these habitats have begun to decrease as estuarine habitats convert to upland habitat; between 1968 and 1998, total estuarine habitat decreased by 7% (BLMPU 1996). This trend will continue if no remedial measures are taken.

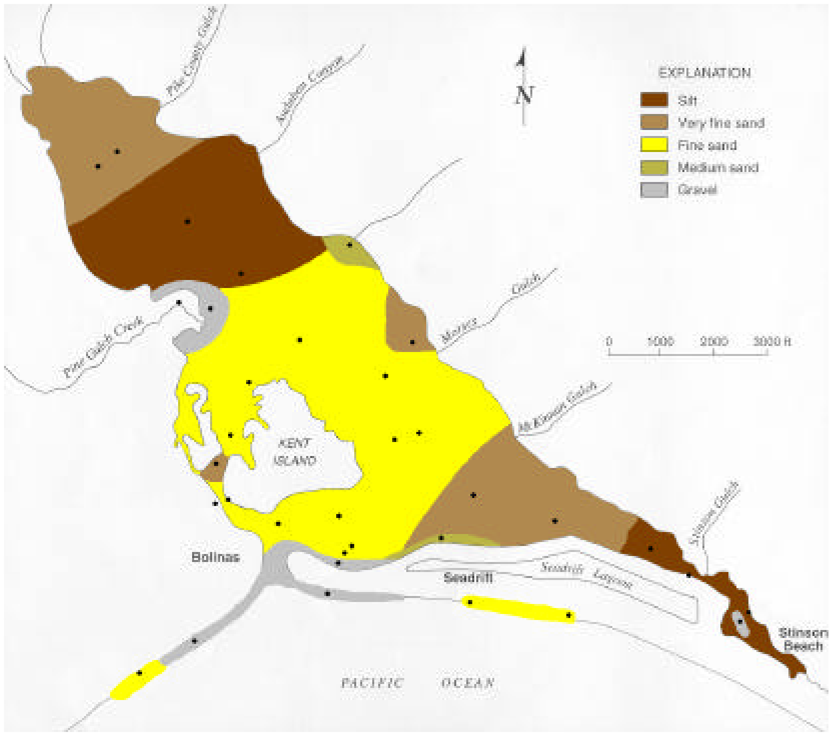

Figure 3.7 Grain Size Distribution within Bolinas Lagoon

In general, the primary production and predation functions in the lagoon occur in the intertidal mudflats and shallow subtidal areas (BLMPU 1996). Filter and deposit feeders found in the mudflats, such as clams, segmented worms, and snails, consume the primary producers like benthic algae and diatoms, and take advantage of the detritus inputs from marsh and terrestrial sources. Soft-bodied invertebrates, small crustaceans and gastropods are prey for probing and surface feeding birds like sanderlings, greater yellowlegs, godwits, curlews, plovers, stilts, and American avocets. The dominant fish in the lagoon eat primarily in these subtidal shallows and intertidal flats as well. Food webs associated with these habitat areas appear to be some of the most significant in the lagoon (BLMPU 1996).

Subtidal Channels –

The subtidal or open water area of Bolinas Lagoon is a rich habitat of primary producers, including phytoplankton, benthic diatoms, eelgrass and algae; grazers of phytoplankton, including such zooplankton organisms as copepods, cladocerans, ostracods, arrow worms and planktonic stages of benthic invertebrates such as bryozoans, echinoderms, polychaetes, bivalves and gastropods; primary consumers of phytoplankton and zooplankton like fish, filter feeders such as clams and worms and birds; benthic invertebrates that burrow into the mud and sand surface; algae; ghost shrimp common in the sandy substrata; deposit feeders like polychaetes and mollusks; and fish, which are the main secondary consumers (BLMPU 1996). This habitat area is strongly influenced by the tidal cycle, as incoming tides bring in suspended and actively swimming organisms that feed, and are fed on, in the lagoon (BLMPU 1996). Important secondary consumers that require relatively deep water habitat, which is often found in the subtidal channels, are in the diving duck guild. Diving ducks once found in Bolinas Lagoon include cormorants, scaups, scoters, goldeneyes, mergansers, ruddy ducks, and ospreys. Because the depth and volume of subtidal habitat has been decreasing over time, so has the available habitat for diving ducks. Quantitative anlyses showing changes to this group of species is detailed later in this section, and in Chapters 4 and 5.

Intertidal Flats –

Intertidal flat habitat is most commonly defined as the area between mean lower low water (MLLW) and mean high water (MHW) (BLMPU 1996). In general, this area is not colonized by vascular plants; algae generate the primary production. The macroalgae species *Enteromorpha* and *Ulva* are the most common in Bolinas Lagoon. Macroalgae and benthic diatoms are important primary producers in coastal lagoons in general, as they are consumed by a large number of animals. Benthic meiofauna are significant primary consumers in this habitat area. Crabs, particularly the mud crab, serve as important grazers on the mudflat. In higher elevation areas the California hornsnail is more dominant. Gobies, sculpin, sharks and rays can be found foraging in subtidal and flooded tidal flat areas. Some of the smaller fish species are consumed by shorebirds like egrets, herons and kingfishers. Some fish species, like topsmelt and jacksmelt, enter and exit the lagoon with the tides, or may be consumed by osprey while visiting the lagoon (BLMPU 1996).

The most distinctive feature of the intertidal mudflat is the presence of shorebirds (BLMPU 1996). These species include dunlin, least tern, western sandpiper, marbled godwit, willet and American avocet. Special adaptations that enable birds to feed in this area include a variety of bill lengths (short, long, curved, etc.), and different feeding methods, such as surface feeding and probing, as well as feeding in different types of substrates and habitat areas, including sandy and muddy substrates and exposed or inundated flats, intertidal marsh areas or upland habitat areas. Prey items include snails, clams, amphipods, marine worms, molluscs, grasshoppers, small burrowing crustaceans, polychaete worms, and the like (BLMPU 1996).

Emergent Salt Marsh –

In Bolinas Lagoon, emergent salt marsh can be found on Pine Gulch Creek Delta, Kent Island, and along the fringes of the lagoon perimeter. Salt marsh is defined as the area between MHW and extreme high water (EHW) (BLMPU 1996). In tidal marshes, benthic algae are important primary producers, pacific cordgrass (*Spartina foliosa*) and pickleweed (*Salicornia virginica*) are common plants, and bird's beak (*Cordylanthus maritimus*) can potentially occur in this zone. In areas sparsely populated by vascular plants, algal biomass, in the form of algal mats, is usually high. Other plants in this habitat area include jaumea (*Jaumea carnosa*), arrow grass (*Triglochin concinnum*) and sea lavender (*Limonium californicum).* Salt marsh dodder is a parasite that occurs in many salt marsh areas, and is found in association with pickleweed and other species at various elevations. Alkali heath (*Frankenia grandifolia*) is commonly found in the midrange elevations, while in higher elevation areas, salt grass (*Distichlis spicata*) and saltbush (*Atriplex watsonii*), along with rush (*Juncus spp.*) are common (BLMPU 1996).

Consumers in this area are dominated by benthic invertebrate omnivores that live under the surface and consume the microbial decomposers on the surfaces of the detritus. Salt marsh plants do not actually provide much nutrition to consumers in this area compared to the mudflat and subtidal areas, but the macroinvertebrates do work to break them down. The horn snail is an important grazer of algae found on salt marsh plants.

Epibenthic invertebrates (those that live on top of the surface) are secondary consumers, and become prey for a number of fish (BLMPU 1996). Many fish arrive on incoming tides to feed, and leave with the outgoing tides. Benthic fish such as staghorn sculpin and longjaw mudsucker, however, remain in the tidal channels and burrow into depressions when the tide goes out (BLMPU 1996).

Other important species that rely on emergent marsh habitat areas include herons and egrets, and a variety of land birds, rails and raptors, including the black rail and other special status species (BLMPU 1996). These birds feed on amphibians, crustaceans, fish, young birds, small mammals and invertebrates. Mammals found in this area include the California vole (*Microtus californicus*), which feeds on grasses, sedges and other green vegetation (BLMPU 1996).

Habitat Quantification

For this Feasibility Study, three habitat types were quantified using bathymetric data. For each habitat type except upland, surface area and volume were used to measure habitat quantities. Only surface area was used for upland habitat since volume of upland represents nothing pertinent to the study. It is the air space above the lagoon and therefore is not an accurate measure of actual habitat.

Habitats were defined as follows:

Upland – The area that remains above the water line at high tide during a typical spring tide [ocean high tide of 3.15 feet National Geodetic Vertical Datum (NGVD)/5.99 feet Mean Lower Low Water (MLLW)]. Upland habitat is the area that is always dry.

Intertidal – The area that experiences wetting and drying during a one-month period, with typical spring and neap tides. This habitat area includes tidal mudflats and emergent salt marsh habitats.

Subtidal – The area that remains submerged during a typical spring or neap tide (ocean low tide elevation of -3.45 feet NGVD/-0.61 feet MLLW or -2.05 feet NGVD/0.79 feet MLLW, respectively). The tide that produced the lower elevation within the lagoon was used for this study. Subtidal habitat is always covered with water.

Although these definitions are simplified in terms of habitat variation (e.g., it is recognized that different depths of subtidal habitat have different qualities, and that there are several intertidal zones, like low salt marsh and high salt marsh, just to name a few), they serve the purpose of this Feasibility Report in that they indicate, in a general way, the habitat areas that will be affected by the project. During the Pre-construction, Engineering and Design (PED) phase, habitat zones will be further delineated and defined. More detailed information on these habitats will be useful for the development and execution of the monitoring and adaptive management program.

This Feasibility Study identifies lagoon volume as being an important factor not only to lagoon hydraulics, but also to lagoon habitat composition. To explain, there is a direct correlation between lagoon volume and water level. As the lagoon volume increases, the efficiency of the lagoon's hydraulics improves, resulting in a larger tidal range. An increase in lagoon volume results in a greater increase in intertidal habitat because of the parallel increase in tidal range. Conversely, the overall gain in subtidal habit is reduced slightly because an increase in tidal range takes back some of the subtidal habitat (in favor of intertidal habitat). A gain in intertidal habitat results in a loss of upland habitat because an increase in tidal range makes the water elevation higher, and thus, more upland habitat is converted to intertidal habitat. In essence, some intertidal habitat will be converted to lower intertidal and subtidal habitat, and some upland and subtidal habitat will be converted to intertidal habitat, for an overall greater proportional increase in intertidal habitat. For this reason, intertidal volume has been selected as the major indicator of project-caused changes to lagoon hydraulics and habitat composition. This will be discussed further in the Plan Evaluation chapter, Chapter 5.

Lagoon Habitats 1968 and 1998

As discussed in Section 3.7 of the Engineering Appendix, water level data and detailed bathymetric surveys for the lagoon were used to determine habitat quantities. To do this, ArcView software was used to find the corresponding surface area and volumes at, below, and between the defining water surface elevations. This provided both the surface area of habitat in acres and volume of habitat in cubic yards. Based on this data, it was clear that intertidal habitat had decreased significantly over that period of time and subtidal had decreased but to a lesser degree. The values for 1968 and 1998 can be seen in Table 3.2.

Lagoon Habitats 1978 and 1988

Because water level data was not recorded in 1978 and 1988, water levels had to be interpolated, as discussed in Section 3.7 of the Engineering Appendix. Detailed bathymetric maps were available for 1978 and 1988, so ArcView software was used to determine habitat quantities for these years. The values for 1978 and 1988 are also shown in Table 3.2.

Table 3.2 Historical Habitat Levels*

Historical							
	Lagoon Volume (3.15' NGVD)	Upland	Upland	Intertidal	Intertidal	Subtidal	Subtidal
Year	yds^3	acres	yds^3	acres	yds^3	acres	yds^3
1968	6,489,855	155.82	7,634,688	876.12	5,580,284	213.38	641,298
1978	5,635,908	197.29	7,943,862	867.50	4,363,639	157.06	533,966
1988	5,390,737	243.43	7,894,691	844.65	3,868,717	127.25	690,093
1998	5,126,588	238.10	8,243,436	848.53	3,584,714	146.39	523,318

*Measured from bathymetries and water level data

Habitat Quantification - Diving Duck Habitat

In order to provide a more tangible connection between lagoon bathymetric change and effects on habitats (and species dependent on those habitats), habitat surface areas and volumes of the habitat type specifically used by diving ducks were calculated. The Lesser Scaup was used in this illustration to represent the diving duck guild. This species prefers water depths between -2.70 feet NGVD and -8.70 feet NGVD. Using these defining elevations, habitat surface area between these depths was calculated for years 1968 and 1998, and was interpolated for years 1978 and 1988. As seen in Figure 3.8, the lagoon lost 44 acres, or 46%, of its diving duck habitat between 1968 and 1998. The small rise in the 1988 value is caused by an anomaly or bathymetric shift in the lower elevations of the lagoon (discussed in Section 4.4 of the Engineering Appendix). As discussed previously, deeper estuarine habitats have been lost to upper intertidal and upland habitats at a significant rate.

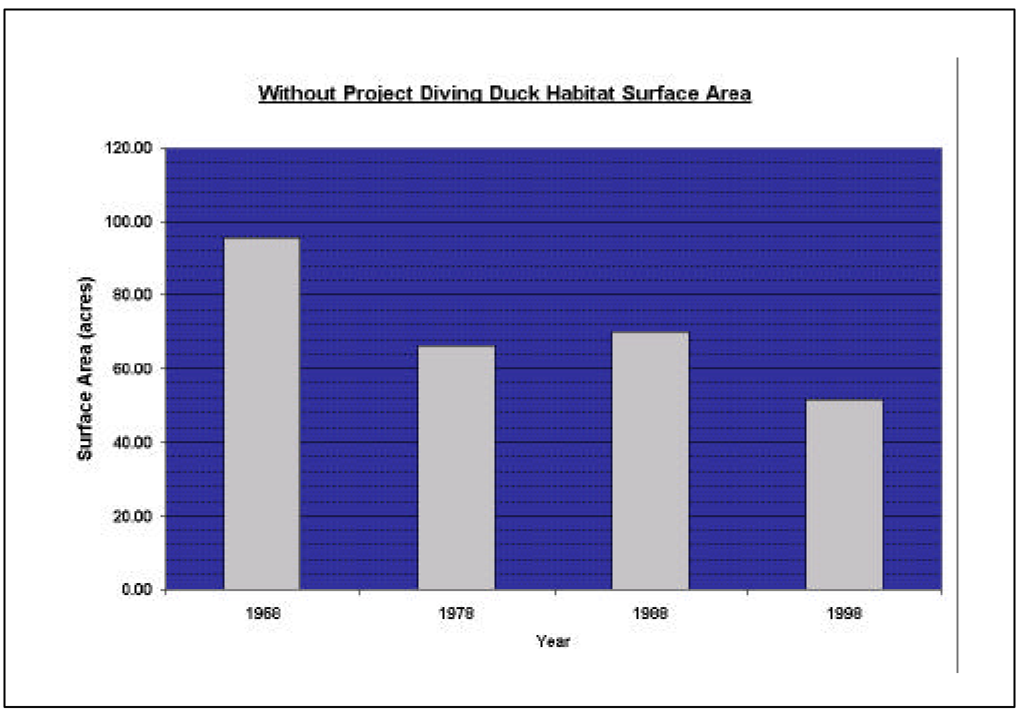

Figure 3.8 Historic diving duck habitat surface area

3.4 Future Without Project Conditions

3.4.1 Hydraulic

Lagoon Habitats 2008 and Beyond

With fairly reliable habitat values and lagoon volumes calculated for 1968 and 1998, a ratio of lagoon habitat change to volume change was calculated. For the lagoon's future volumes (listed in Section 3.6 of the Engineering Appendix), the habitats were determined by multiplying the expected change in volume by the change in habitat to change in volume ratio (Appendix 15 of the Engineering Appendix). This was a linear extrapolation. The idea of formulating a polynomial relationship – or using an average ratio of habitat change versus lagoon volume change – based on all the years of data (1968, 1978, 1988, and 1998) was considered, but ruled out since 1978 and 1988 did not have water level data. The interpolated water level data was used to calculate habitats for those years, so the habitat levels calculated for those years were already dependent on data interpolated from lagoon volume. The projected without project lagoon habitats for the next 50 years are shown in Table 3.3 and Figures 3.9 and 3.10.

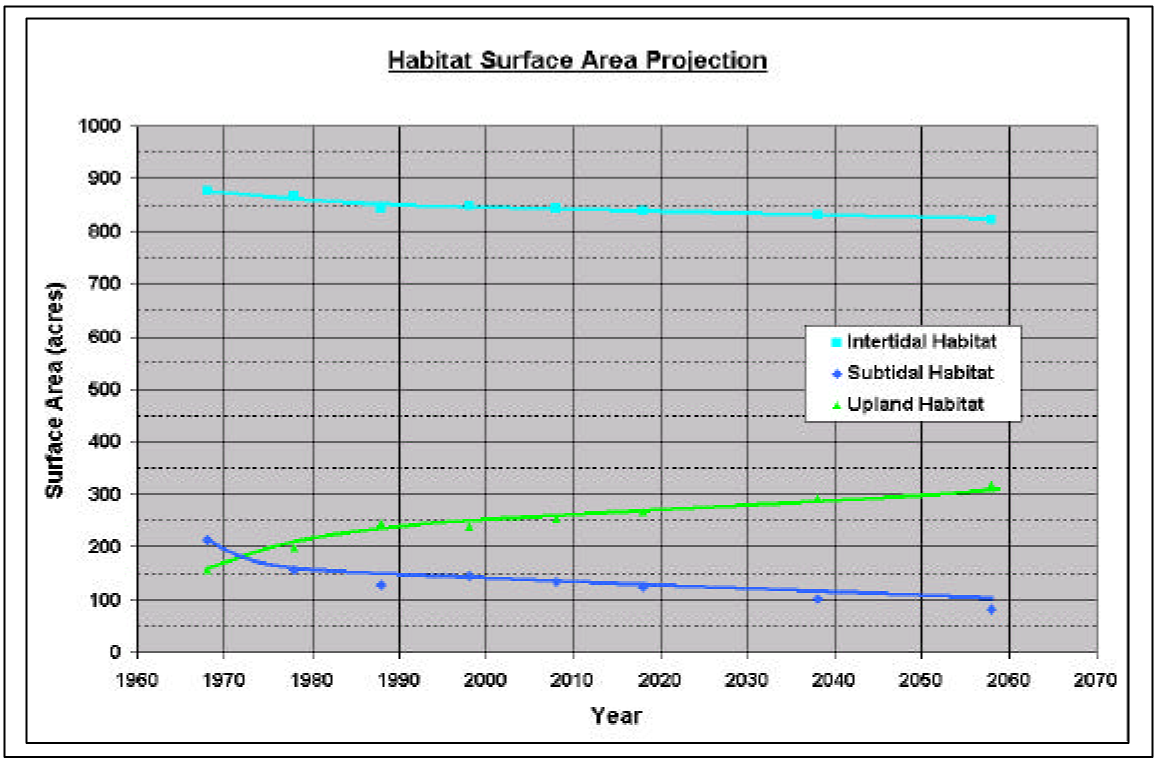

Figure 3.9 Habitat Surface Area Projections for Bolinas Lagoon

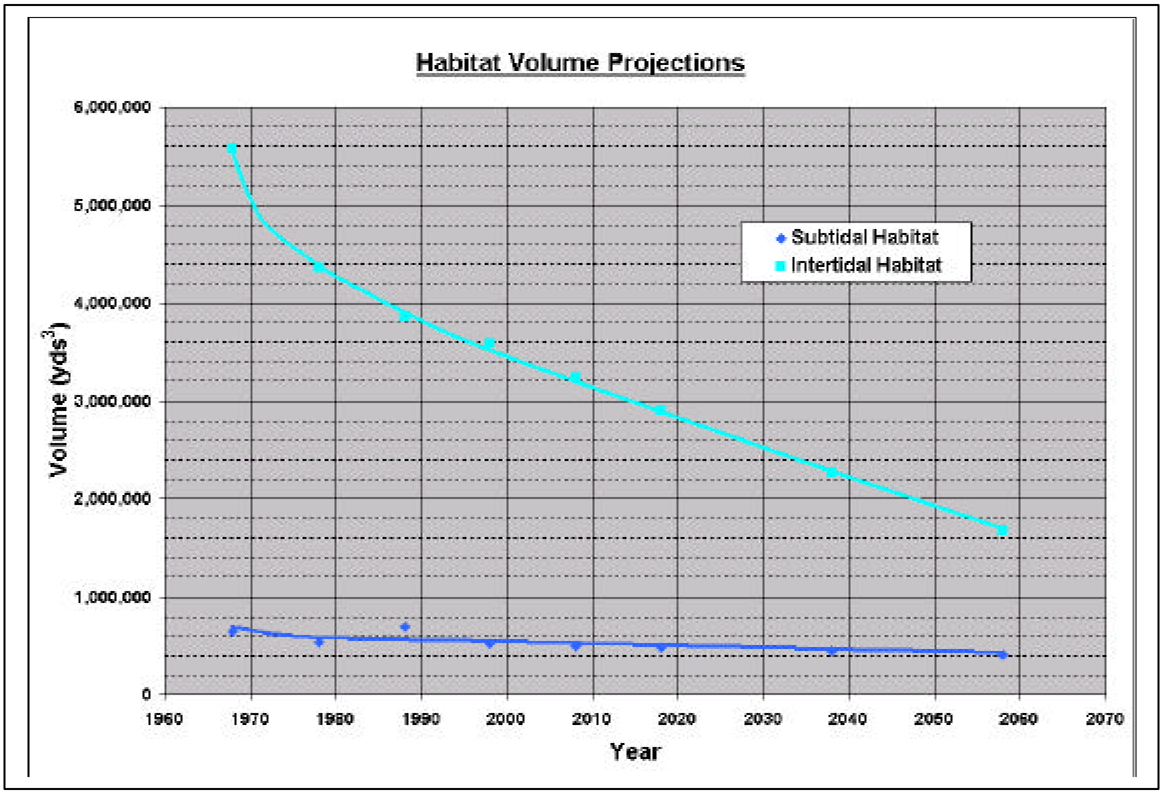

Figure 3.10 Habitat Volume Projections for Bolinas Lagoon

Table 3.3 Without Project Habitat Projections

Without Project							
	Lagoon Volume	Upland	Upland	Intertidal	Intertidal	Subtidal	Subtidal
Year	yds^3	acres	yds^3	acres	yds^3	acres	yds^3
2008	4,883,508	252.77	8,351,980	843.61	3,228,889	134.45	502,281
2018	4,652,007	266.74	8,455,354	838.92	2,890,014	123.07	482,246
2038	4,223,741	292.59	8,646,590	830.25	2,263,112	102.03	445,183
2058	3,841,791	315.64	8,817,144	822.52	1,704,008	83.26	412,128

It was predicted that by the year 2058, as much as 4.35 million cubic feet (158,000 cubic yards) of subtidal volume would be lost compared to 1998, representing a 29.3% loss. The same situation is true for intertidal habitat. It has been projected that 54.33 million cubic feet (2.01 million cubic yards) of tidal habitat volume will be lost by 2058 as compared to 1998, representing a 55.7% loss.

A gradual accretion of sediment in the lagoon will lead to a gradual change of the subtidal habitat to emergent intertidal saltmarsh, which will then change to a mature saltmarsh, giving way, in turn, to seasonal wetlands habitat, which will ultimately convert to upland habitat. Bolinas Lagoon will become, in effect, a meadow. While this is the natural progression of coastal lagoons, Bolinas Lagoon has remained as a lagoon for

7,000 years. The change in Bolinas Lagoon in the recent past is the result of human activities, which have accelerated the process unnaturally**.**

3.4.2 Environmental

Habitat Changes

Accumulation of sediments in the lagoon over time, and the gradual loss of tidal prism, would result in the narrowing of tidal channels; conversion of subtidal habitat, first to intertidal mudflats, then to emergent tidal marsh; an increase in the size of Pine Gulch Creek Delta and Kent Island as vegetation increases in range and area; intermittent closures of the lagoon mouth and, eventually, permanent closure of the lagoon to tidal waters; and decreasing tidal influence on the habitats within the lagoon (BLMPU 1996). Continued sediment accretion in the lagoon would result in an overall loss of estuarine habitats, and a conversion of these habitats to upland habitat. It is estimated that between 1998 and 2008, subtidal habitat area will decrease by 40%; intertidal flat area will decrease by 30%; emergent salt marsh will increase by more than 50%, and upland habitat will increase by 11%. If these trends continue, and are not mitigated by restoration measures, there will be significant changes in the diversity and abundance of species in the lagoon and in ecological functions the lagoon provides (BLMPU 1996).

Fish and Wildlife Changes

Macroinvertebrates –

Although little quantitative information is available on the macroinvertebrates living in Bolinas Lagoon, anecdotal evidences suggests that a decrease in estuarine habitats would result in a "diminution" of habitat available for benthic species, including large filter feeders, and a concomitant decrease in their population numbers (BLMPU 1996; O'Conner, personal communication, 2001). Studies in other similar estuarine environments have found that a higher diversity of invertebrate species can be found at the lower intertidal elevations (BLMPU 1996). This information suggests that a decrease in lower intertidal habitat would result in a decrease in species diversity as these areas are converted to emergent marsh habitat. In fact, a strong correlation between regular tidal flushing and the diversity and abundance of aquatic food chain members has been demonstrated (BLMPU 1996). Well-flushed systems show a higher species diversity and a higher abundance of marine populations while intermittent lagoons have depauperate (low diversity) flora and fauna. Inlet closure would obviously have a negative impact on marine species in Bolinas Lagoon.

Fish –

Population trends cannot be quantified by the data available, but anecdotal evidence suggests that a number of fish populations have declined in recent years (BLMPU 1996). In fact, local fishermen who work in the area no longer see some species that were once abundant in the lagoon. These species include flatfish such as

Diamond Turbot, English Sole, Sand Sole, Starry Flounder and California Halibut; many species of Sculpins, including Staghorn Sculpin and Plainfin Midshipman; Coho Salmon and Steelhead Trout; Leopard Shark; and Surfperches, such as Shiner, Dwarf, Black, Pile, Walleye, Rubberlip, Barred and White Surfperch species (Churchman p.c. 2001). Closure of the inlet would prevent pelagic fish from entering and living in the lagoon, and anadramous fish would only be able to enter the estuary if freshwater flows, high tides and storm surges opened up the lagoon and reinstated the connection between Bolinas Lagoon and Bolinas Bay (BLMPU 1996).

Birds –

More than 85 species of water birds can be found at Bolinas Lagoon, an estuary used primarily as a wintering destination by water birds, secondarily as a migrant stop, and relatively little by year-round or summer residents and local breeders. Since 1965, the Point Reyes Bird Observatory (PRBO) has conducted bird surveys in Bolinas Lagoon and other estuaries in the Point Reyes area. From 1968 – 1988, changes in water bird abundance mirrored known habitat changes. For example, the 60+% decrease in subtidal habitat during that time period resulted in fewer observed diving birds in the lagoon. Seven species, including the eared and horned grebes, canvasback, surf and white-winged scoters, American coot, and ruddy duck decreased in abundance, while only one species (the common goldeneye) showed a weak upward trend. Numbers of five species did not increase or decrease during this period. These species include the western grebe, double-crested cormorant, greater scaup, bufflehead, and red-breasted merganser.

U.S. Fish and Wildlife Service (USFWS) waterfowl census data, which looks at trends in the state of California, suggests that the abundance patterns of four species in Bolinas Lagoon were counter to strong upward trends for California as a whole: the scoters, Greater Scaup, and Bufflehead have decreased significantly. In addition, Ruddy Ducks showed no downward trend in the statewide data. Rather than echoing larger regional trends, the observed changes in waterfowl abundance in Bolinas Lagoon can reasonably be attributed to habitat changes in the Lagoon. A similar trend is evident with intertidal species as well. The 37% increase in intertidal habitat from 1968 to 1988 has been accompanied by increased abundance of 10 species that rely on intertidal habitat, including the Northern shoveler, gadwall, semi-palmated plover, willet, whimbrel, long-billed curlew, marbled godwit, western sandpiper, greater yellowlegs, and American avocet.

These bird surveys simply indicate trends that would be expected, based on habitat changes observed in the lagoon over the same time period, which are: “1) most intertidal-dependent shorebirds and waterfowl trended upward along with the increase in intertidal habitat, 2) subtidal-dependent waterfowl generally showed decreasing trends mirroring the decrease in subtidal habitat, 3) only one of the subtidal-dependent waterfowl species showed a trend opposite to that predicted by habitat change, and 4) many of the species’ abundance trends at Bolinas Lagoon [were] counter to regional or statewide trends, and 5) species dependent on emergent marsh wetland vegetation increased with increases in [this] habitat” (BLMPU 1996). Such predictions indicate that

Bolinas Lagoon would suffer an overall loss in avian abundance and diversity, and would therefore lose its value as an overwintering location and migratory stopover point for shorebirds and waterfowl on the Pacific Flyway. A much smaller number of species dependent on emergent salt marsh and upland habitats would benefit from the changes, and these benefits would continue to decrease over time as the salt marsh habitat converted into upland habitat, and the connection to Bolinas Bay was lost forever.

Bolinas Lagoon is an important estuary that can be characterized by the following attributes: 1) a high species diversity of aquatic birds; 2) an egret and heron rookery; 3) a wintering site for waterfowl, shorebirds, and raptors; 4) a black-crowned night heron roost; 5) traditional roost for fish-eating flocks of pelicans, cormorants, and terns; 6) a riparian migrant stopover (Pine Gulch Creek Delta); 7) valuable habitat for twenty species of special concern which are afforded special status on either state or federal lists of threatened, endangered or candidate species for the California Department of Fish and Game (CDFG) "Species of Special Concern" (USFWS 1991, CDFG 1992); 8) breeding habitat for several threatened species (snowy plover and black rail); and 9) foraging habitat for several raptors of special concern (osprey, peregrine falcon, and merlin).

Harbor Seals –

Approximately 200 harbor seals haul out regularly in the lagoon, giving birth to about 50 pups during the pupping season. The population of harbor seals in the Gulf of the Farallones is estimated to comprise 20% of the California population. Harbor seals have been closely monitored in the San Francisco Bay area and at Bolinas Lagoon since 1970. Both the total population and the number of pups at Bolinas Lagoon have increased in recent years. Bolinas Lagoon and adjacent waters are important to the Gulf's harbor seal population.

Harbor seals are opportunistic feeders and forage on shallow water estuarine and marine species of fish, cephalopods and crustaceans. Many of their preferred prey species (e.g., jacksmelt, topsmelt, starry flounder, and shiner perch) can be found in Bolinas Lagoon. If the lagoon shoals in, these feeding opportunities would be lost.

Although harbor seals do some foraging in the lagoon, the more important function that Bolinas Lagoon serves is as a place of refuge. Bolinas Lagoon is more isolated and sheltered than other sites along the north coast, or even in the San Francisco Bay. Bolinas Lagoon differs from these sites in that peak numbers occur during the molt (May-July), after the pupping season. Haul-out sites secure from disturbance are critical for harbor seal populations. Haul-out sites provide seals with resting, breeding, and nursery areas. These sites are used daily throughout the year, and successively, from year to year. The haul-out sites used in Bolinas Lagoon are areas with exposed sand bars, including parts of Kent Island and areas along the Main Channel. Continued sediment accretion in the lagoon would prevent harbor seals from using Bolinas Lagoon as a pupping area, and area of respite.

<u>*Species Diversity*</u>

Bolinas Lagoon hosts an array of biologically diverse species, including benthic invertebrates; marine algae; threatened, endangered and special status species such as Coho salmon, steelhead trout, black rail; migrating birds on the Pacific Flyway; and other resident and migratory fish, birds, and seals. Endangered brown pelicans are present from April to January during the anchovy migration period. Threatened snowy plovers are seen on the sand spit at the mouth of the lagoon. Merlin (a species of special concern), and large numbers of egrets, great blue heron, dabbling and diving ducks, and shorebirds are present, particularly during the fall and winter migration periods. Ghost shrimp, gaper clam, littleneck clams and Washington clams are present in the tidal and subtidal habitat. Pacific herring appear in the lagoon in winter.

Because of its proximity to large, mostly undeveloped and protected areas, Bolinas Lagoon is part of a large, complex and diverse ecosystem with significant ecological value. The lagoon contains a variety of habitats, including subtidal channels, intertidal mud flats, islands, and emergent salt marsh. Each habitat has its own combination of species, including primary productivity plants, benthic organisms, fish, birds, and seals. If the lagoon fills in, some of these habitats will be diminished, or lost completely. Rare Coho salmon and steelhead trout (both federally listed as Threatened along the Central California coast) have migrated through the lagoon to spawning areas in adjacent creeks. The overall effect of estuarine habitat loss in Bolinas Lagoon would be a significant loss in biodiversity, and the loss of a natural resource that plays an important role in the life cycles of many species. This loss would be significant and far-reaching.