MALIBU LAGOON RESTORATION

FEASIBILITY STUDY

FINAL ALTERNATIVES ANALYSIS

Prepared by:

Moffatt & Nichol

In Association With:

Heal the Bay

Prepared for:

California State Coastal Conservancy & California State Parks

March 2005

CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES (UNDER SEPARATE COVER)

EXECUTIVE SUMMARY

Malibu Lagoon is a sensitive habitat area that is characterized by poor water quality and impaired habitat conditions owing to prior modifications, urban encroachment, and watershed influences. The Malibu Lagoon Task Force has identified restoration of the site as a highest-priority short-term goal. This Restoration Feasibility Study presents existing conditions, describes conceptual restoration alternatives to address problems, and presents analyses of their performance. Results of this study enabled the Lagoon Technical Advisory Committee (LTAC), State Department of Parks and Recreation (State Parks), and the State Coastal Conservancy to identify a preferred restoration alternative. The analyses presented herein have been conducted in response to comments provided by the LTAC and Lagoon Restoration Working Group and have been completed in close coordination with the LTAC, State Parks, and the State Coastal Conservancy.

Solving the habitat and water quality problems at the lagoon is not entirely possible without major improvements to the quality and/or quantity of incoming surface water and groundwater. Many of the problems in the lagoon cannot be efficiently remedied using "end of pipe" solutions. Therefore, all restoration work in the lagoon must be coupled with extensive efforts to reduce source loads of pollutants and nutrients from the Malibu Creek watershed. Major source control efforts must be conducted to reduce the nutrient and bacterial loads delivered to the lagoon from local surface water runoff, storm drains and septic-impaired groundwater. The alternative restoration actions were designed to achieve the goals set forth by the Malibu Lagoon Task Force and set the stage for greater improvements as future actions throughout the watershed are employed. All restoration alternatives have been designed to accommodate future projects and water quality enhancements throughout the watershed.

The LTAC, State Parks, and the State Coastal Conservancy are recommending Alternative 1.5, the Modified Restore and Enhance Alternative, as the preferred alternative based on the results of the analyses. Alternative 1.5 is a naturalized lagoon planform with modified lagoon elevations to improve conditions for habitat establishment. Per the request of the LTAC, Alternative 1.5 was augmented with a feature called the North Channel connecting the western arms to flows just upstream of Pacific Coast Highway to create Alternative 1.75. Alternative 1.75 with the North Channel is not recommended as the preferred alternative at this time due to uncertainty associated with its effectiveness. Although the North Channel is theorized to provide greater restoration benefits, uncertainty exists about the magnitude of the beneficial effects. Therefore, it is recommended that Alternative 1.5 be implemented as part of a restoration program, and combined with a program of adaptive management and monitoring to track the changes at the lagoon.

Alternative 1.5 is expected to most readily achieve the goals of the restoration while introducing the least amount of impact to the existing lagoon ecosystem. All work should be performed in succinct stages to minimize impacts to the existing wetland habitat and to provide refuge for species displaced by construction activities. A strong adaptive management approach will be implemented to minimize work required to accomplish restoration success while providing a level of security against the possibility of failing to meet restoration objectives. A key component of the adaptive management framework will be a detailed monitoring and maintenance program. The monitoring program will be developed specific to the footprint of Alternative 1.5 and will be presented in a Restoration Plan. Alternative 1.5 will be further developed to enable it to move through the subsequent phases of restoration design optimization, environmental review, permitting, final engineering, and implementation.

1. INTRODUCTION

1.1. GENERAL

This restoration feasibility study is presented to all interested groups associated with the Malibu Lagoon Restoration Project. Information presented in text, matrices and figures of this report consists of alternatives and their analyses to help facilitate the selection of a preferred alternative. An important part of restoration planning is to manage the expectations of all interested parties. A combination of ecological, social, and regulatory variables was considered in the design and evaluation of all restoration alternatives.

The most influential outside factor limiting the potential for restoration success by this project is the impaired quality of the water delivered to the lagoon from the watershed. Surface water and groundwater contributed daily to the lagoon are severely impaired with bacteria and nutrients (Tetra Tech, 2002; CH2MHill, 2000; Ambrose and Orme, 2000; Sutula et.al, 2004; Stone Environmental, 2004; USEPA, 2003a&b). Solving the habitat and water quality problems at the lagoon is not entirely possible without major improvements to the quality and/or quantity of incoming surface water and groundwater. Many of the problems in the lagoon cannot be efficiently remedied using “end of pipe” solutions. Therefore, all restoration work in the lagoon must be coupled with extensive efforts to reduce source loads of pollutants and nutrients from the Malibu Creek watershed. Major source control efforts must be conducted to reduce the nutrient and bacterial loads delivered to the lagoon from local surface water runoff, storm drains and septic-impaired groundwater.

The project team has worked closely with the Lagoon Technical Advisory Committee, the Lagoon Restoration Working Group, and appropriate regulatory agencies to modify initial alternatives and specify a range of effective restoration actions from which to choose. The alternative restoration actions were designed to achieve the goals set forth by the Malibu Lagoon Task Force and set the stage for greater improvements as future actions throughout the watershed are employed. All restoration alternatives have been designed to accommodate future projects and water quality enhancements throughout the watershed.

1.2. SEASONAL COASTAL LAGOON DESCRIPTION

Malibu Lagoon is a historic seasonal coastal lagoon. It is only a small remnant of the larger historic lagoon area, but it provides a very important and valuable remaining seasonal coastal habitat. Seasonal coastal lagoons are low-lying basins just inland of the beach seasonally connected to the ocean. Coastal lagoons are connected to the ocean typically during the wet season when storm runoff breaches the barrier beach. This allows tidal inundation into the lagoon while the barrier is open, resulting in at least muted tidal fluctuation and some establishment of coastal salt marsh features. During the dry season, the lagoons generally become isolated from the ocean as the barrier beach rebuilds between the lagoon and sea without being breached by stormflows. This rebuilding is often relatively rapid with tidal fluctuation diminishing with time and being more and more restricted to the highest tides.

The dry season lagoon gradually fills by freshwater contributions from the watershed. Water in the lagoon becomes brackish as incoming freshwater mixes with existing salt water. According to observations by Swift related below (personal communication, 2004), this is exemplified by the small lagoons on Vandenberg Air Force Base (Shuman and San Antonio Lagoons) that often close with relatively low salinities. If subsequent high spring tides occasionally breach the barrier berm, some salt water may occupy some of the deepest areas of the lagoon. Seasonal lagoons remain as brackish, non-tidal lagoons, for most of the year such as at San Mateo Lagoon on Camp Pendleton. Much of the existing vegetation at these lagoons is cattails and other riparian vegetation more typical of freshwater marshes than salt marshes. Usually only larger lagoons remain tidal longer and remain more saline such as the mouths of the Santa Ynez and Santa Margarita Rivers where tidal influence lasts longer and lagoons close with saltier regimes. These systems suffer anoxic episodes more often because they receive excess nutrients and possess higher salinity levels and thus absorb more solar radiation, leading to eutrophication.

Seasonal coastal lagoons are unique in that they possess certain attributes of salt marshes due to their partial tidal inundation during the wet season, but mainly serve as brackish lagoons during the remainder of the year. The mix of habitats present at seasonal coastal lagoons is unusual compared to other estuarine habitat areas with freshwater species mixing with salt water species. Seasonal lagoons also experience some of the greatest extremes of any other estuarine habitat areas by being mostly freshwater in certain conditions and partially saline in other times. They are only saline for very short periods (days to a couple of weeks) and the rest of the time they are only slightly tidal or non-tidal (microtidal). They can also be entirely covered with water as a true lagoon during closure of the barrier beach and can be almost entirely drained when the breach is open and they are exposed to tidal conditions.

Seasonal lagoons typically form as small basins at the mouths of coastal streams, and periodically fill and drain as hydrology and beach dynamics dictate the condition of the opening. Sediment accretes in the lagoons over time until severe storm flows flush it from the lagoon to the ocean. As such, the bed of a seasonal lagoon can accrete to be higher than mean sea level, thereby limiting the extent of tidal flushing that occurs while the lagoon mouth is open.

Seasonal coastal lagoons can function as diverse habitats that include subtidal, salt marsh, brackish marsh, freshwater marsh, alkali meadow, and riparian and upland areas. The unique aspect of these lagoons is that these habitats can all exist within relatively small geographic areas within the lagoon, and persist over time thus providing a rare opportunity for high habitat diversity in concentrated areas. These lagoons can also be relatively fragile, and vulnerable to influence from the surrounding or upstream watershed developed areas. As such, water quality and habitat problems at these lagoons signify problems existing in other areas of the watershed that are concentrated at the downstream basin.

1.3. HISTORIC CONDITIONS AND POSSIBLE RESTORATION

Coastal lagoons are often defined as including the main body of water being parallel to the beach or barrier berm. This is the way they often develop, and the earliest records, and maps of Malibu show this characteristic of the lagoon being oriented mostly east-west behind a barrier berm. On the earliest aerial photograph available, the UCLA (2000) report notes that even by the time that photograph (1920's) was taken the elevated berm for the railroad that crossed near where Hwy 1 now crosses the lagoon had already greatly modified the western extent of the lagoon. This area of the lagoon was re-excavated during the first restoration project in 1983 but not to its historic extent due to limited available land. Thus, originally there was larger lateral refuge area and the mouth was basically directly or nearly south of the axis of the stream, with migration of the mouth to the east (as occurs today) due to natural longshore sand build up in an west to east direction. Previous lagoon restoration efforts accomplished conversion of upland to wetland, but did not create the appropriate physical conditions necessary for evolution of a self-sustaining ecosystem. Lagoon planform and geometry were not conducive to promoting circulation or nutrient cycling. Lagoon channels were narrow, looped, steep-sided, and contained dead-ends causing circulation to be impeded, sediment and organics to deposit, and eutrophication to occur.

Breaching is due both to winter storm runoff and from winter waves that erode the beach down to cobble, facilitating breaching. Spring and summer waves come more from the southwest and south and tend to build the beaches back up with the sand delivered from upcoast and upstream. In addition to the overwhelmingly complete observations of many of these lagoons over a long period of time, the literature provides support for this history (Bascom, 1980; Carter, et.al, 1994; Kjerfve, 1994; Woodroffe, 2002).

Restoration of Malibu Lagoon to its historic condition is limited in potential due to the extent of outside influences, however, the correct combination of positive actions can help to achieve more immediate, short-term restoration goals. The actions required are a combination of site-specific restoration activities to improve habitat, coupled with larger-scale watershed improvements to increase upstream water quality to preserve the restored condition. The combined effect of physically improving the lagoon and maintaining higher quality inflows from the watershed leads to greater likelihood of success.

Malibu Lagoon can be restored to an improved condition over the lower area south of PCH bridge due to the availability of public land area, the presence of suitable biogeochemical and hydrologic conditions for restoration, and the supportive spirit of stakeholders and funding agencies. The lower lagoon can be restored to a more natural seasonal coastal lagoon possessing the conditions described above.

Few other habitat areas are more dependent on improvements and actions throughout the watershed for success as Malibu Lagoon. Development in the lower watershed significantly influences lagoon water quality. The upper watershed possesses less development, but is the source of releases from the Tapia treatment plan and several lakes, also influencing all downstream areas. Improvements to the quality of upstream discharges, both local and distant, are mandatory for the success of lagoon restoration.

Lagoon restoration toward historic conditions is also affected by encroachment at the lagoon perimeter by developed land and private property. The restored area will only be a relatively small fragment of the historic area, but its value will be extremely high owing to the lack of similar habitat areas in the vicinity. It may also be expanded in the future upon the acquisition of adjacent properties.

The most effective approach to restoring the lagoon is to quantify its problems, and identify effective and feasible solutions. This Restoration Feasibility Study follows this approach. Problems are discussed in detail in the following sections, and generally consist of impaired water quality and compromised habitat owing to poor circulation, extensive sedimentation, insufficient nutrient cycling and existing eutrophication. Restoration solutions involve reconfiguring the physical lagoon to:

- Improve flushing and water turnover during open mouth conditions, and water storage and circulation during closed conditions for water quality;
- Increase the area of the submerged lagoon bed to increase denitrification and nutrient cycling processes, and reduce eutrophication;
- Reduce future sedimentation for habitat preservation and to reduce eutrophication; and
- Provide suitable soil and hydrologic conditions for colonization of appropriate habitat.

In many of the other lagoons, the predominant lagoon bed substrate is sand after winter flushing by stormflows. A thin layer of finer substrate can develop under closed conditions. A layer of fine-grained sediments typically only develops on the lagoon bed in backwater areas such as the western arms that are not adequately flushed. Flushing currently does not occur in the western arms at Malibu lagoon leading to more prevalent anoxia, as described in more detail herein. Flushing the western arms would be a benefit, although it will not be easily accomplished under current or alternative conditions.

2. RESTORATION GOALS

Restoration goals as identified by the Malibu Lagoon Task Force (MLTF) include:

- Salt Marsh Enhancement at Site A1(West Arms)
    - Increase tidal flushing
    - Improve water circulation
    - Increase holding capacity
    - Reduce predator encroachment
- East Lagoon Restoration at Site A4 (Adjacent to Adamson House)
    - Regrade to restore typical salt marsh hydrology
    - Create nesting island for least terns and Snowy Plovers
    - Create channel connections to the lagoon

These goals are to remain the focus of this restoration effort and this study is to yield a restoration plan that meets them.

3. EXISTING CONDITIONS

The primary processes that strongly influence the condition of Malibu Lagoon are circulation, sedimentation, nutrient cycling, eutrophication, and habitat evolution. These processes also correspond to existing problem areas to be addressed by this project.

3.1. CIRCULATION

Existing circulation is a function of hydrology and forcing mechanisms that are described below. The dramatic physical seasonality of the Malibu Lagoon hydrology has a strong influence on existing problems of water and sediment quality.

Hydrology

The existing hydrology and implications of physical seasonality of the Malibu Lagoon are discussed below. The temperate climate of Central and Southern California produces fairly wet winters and relatively dry warm summers. Rarely does rainfall occur from the months of May through September in this geographic region.

Rainfall can be heavy in winter, however, causing stormflows to be episodic and of high. magnitude. Figure 1 shows peak storm flow discharges of particular storms.

Figure 1 – Malibu Stream Gage (2 Miles Downstream of Cold Creek)

Annual Peak Flow Frequency Analyses

Return period (yr)	1	2	5	10	25	50	100
Peak Flow Rate (cfs)	400	2,012	7,630	12,727	20,281	26,517	33,129

Recent Storm Events

Water year	Feb. 03	Mar. 01	Feb. 98	Feb. 95	Feb. 92	Mar. 83
Peak Flow Rate (cfs)	5,410	10,900	19,100	15,700	23,300	24,200

As stated earlier, the seasonal hydrodynamics of Southern California lagoon systems transition from a highly dynamic well-mixed delta-like environment in the wet months (November-March) to a brackish lagoonal system in the dry months. These seasonal variations in climate result in dramatic differences in water circulation, water residence times and water quality within the lagoon areas. Seasonal differences in environmental variables are shown in Table 1 below.

Table 1. Comparison of Seasonal Physical Differences of Malibu Lagoon

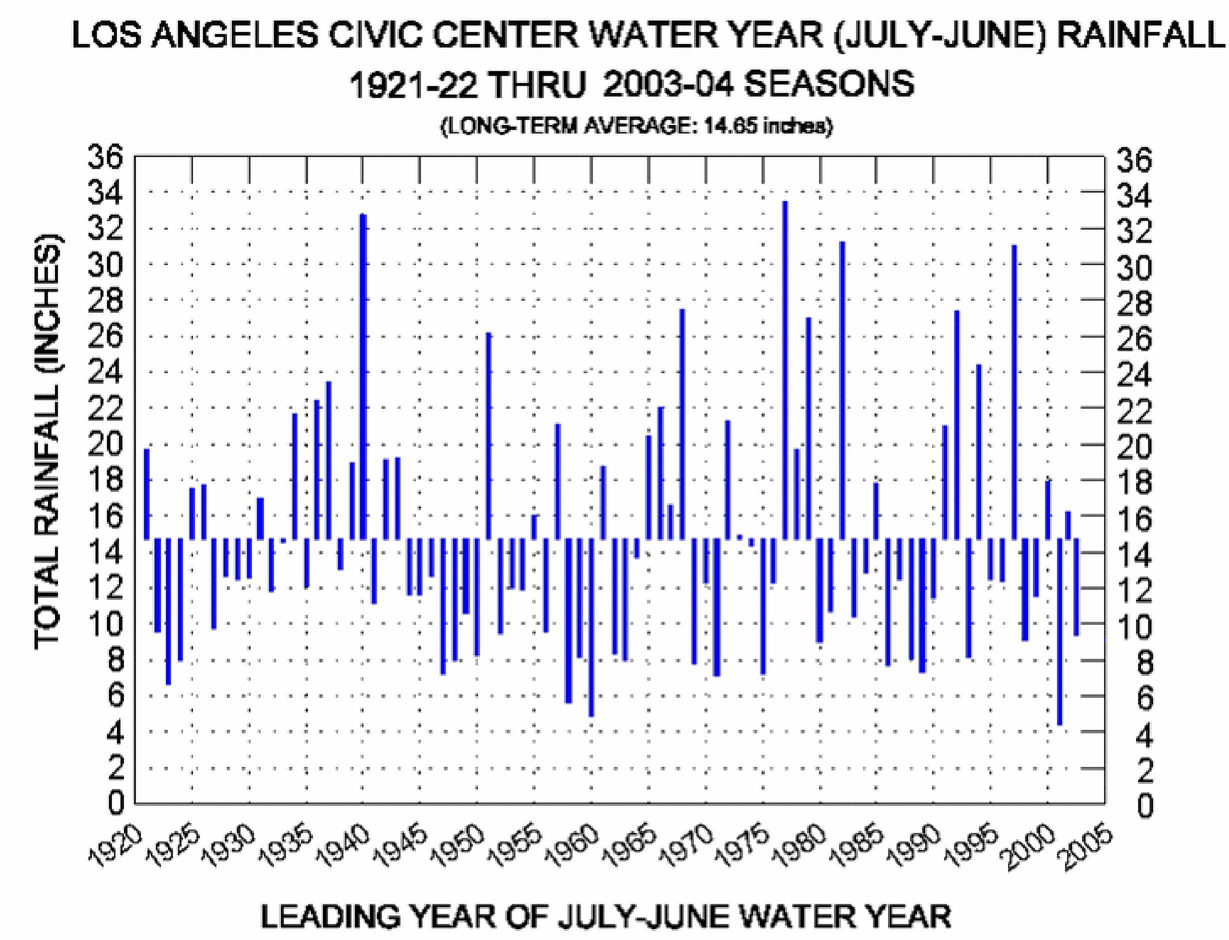
Physical Parameter	**Wet Season (November-April)** **Open Lagoon Conditions**	**Dry Season (May-October)** **Closed Lagoon Conditions**
Tidal exchange	High	Low (sandbar present)
Fresh water inflow	High (peak Q = up to 33,000 cubic feet per second, or cfs)	Low (average Q = 3 to 10 cfs)
Water residence times	Order of hours	Order of months
Water temperatures	Low (average daily 15º C)	High (average daily 24º C)
Solar irradiance (daily duration)	Low (12 hrs)	High (15 hrs)
Predominant sediment deposition	Coarser materials (transported by storm flows)	Fine materials (settling of organic material)

The sandbar at the mouth of Malibu Lagoon typically first forms in May or June and may proceed through a series of natural closures and breaches until a sustained closure is endured through the summer and early fall. The timing and duration of summer closures are dependent upon a number of factors including previous winter rainfall (streamflow magnitude and duration), Malibu Creek water table base flows, alongshore sand transport, and tidal and swell dynamics of the Pacific Ocean. Sutula et.al (2004) suggest that the differences in the winter rainfall totals between 2002 and 2003 (5.92 inches and 13.76 inches, respectively) resulted in the 2003 sandbar closing nearly 2 months later in the season. Data from LA Civic Center for 2004 shows rainfall of approximately 9.25 inches (with 4.75 inches in 2002 and 16.25 inches in 2003). Historic precipitation levels in the area are shown in Figure 2. Table 2 shows climatic factors over the last three years affecting the lagoon environment.

Table 2. Climatic Factors for Recent Years

Variable	Year		
	2002	**2003**	**2004**
Rainfall (inches) from Sutula et. al. (2004) **LA Civic Center**	5.92	13.76	Approx. 9.25
Time Period of Closure (months)	7 months (Sutula et. al, 2004; Tapia data)	5 months (Sutula et.al, 2004; incomplete Tapia data)	3.5 months as observed by M&N
Maximum Water Level (in feet above mean sea level or msl)	5.5	6.0	No data (appears lower than last year)
Average Lagoon Water Temperature (degrees Celsius)	23.5	27	25.2 in July; 20.8 in October; total average is 23

Figure 2



Tidal flushing is eliminated when the lagoon closes and water levels within the lagoon steadily rise until daily input volumes are very similar to daily losses (an equilibrium or steady-state).

Summer water inputs to the lagoon include;

- Groundwater seepage and
- Dry-weather runoff.

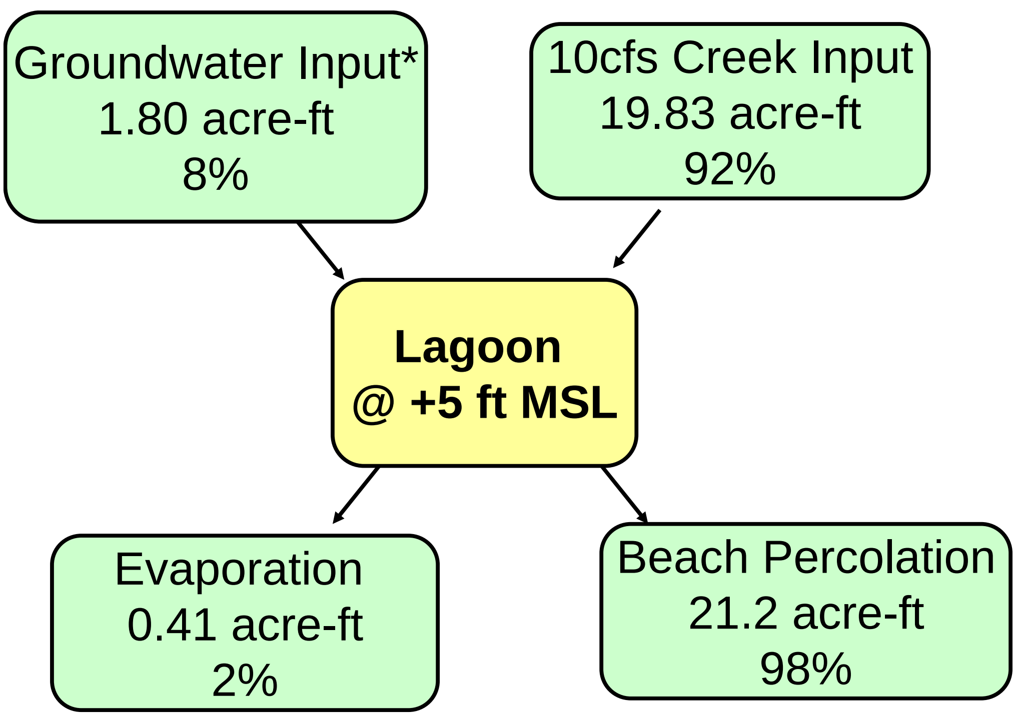
Summer water losses include:

- Seepage through the sand berm and
- Evaporation/Evapotranspiration.

The water budget is shown in Figure 3.

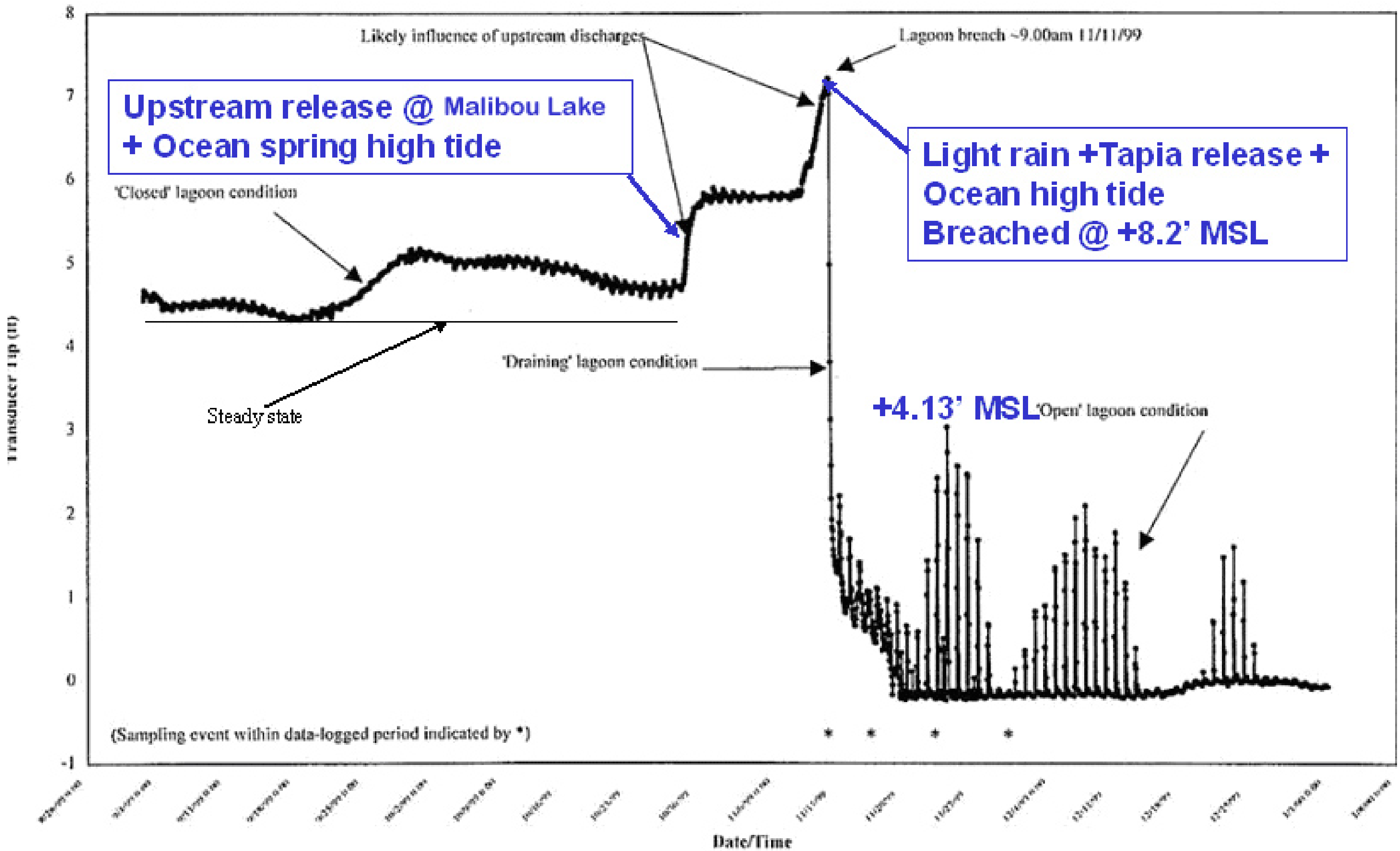
Once equilibrium is reached water levels remain relatively stable until the sandbar separating the lagoon from the ocean is breached (URS, 2000; Tapia data) (Figure 4, Appendix 1, Slides A1 and A2). Water levels tend to stabilize at +5 feet above msl initially in summer as occurred in summer of 2002 and 2003, then rise to +6 feet msl and higher over time with upstream releases as occurred in Fall of 1999 until the lagoon ultimately breaches. Water temperatures dramatically increase relative to open conditions and the water column may stratify based on density and/or thermal gradients. Water temperatures for 2004 after closure are shown in the Table 2 above.

Figure 3 – Closed Lagoon Daily Water Budget



* Stone Environmental Inc. 2004

Figure 4 – Malibu Lagoon Water Level at Malibu Bridge



3.1.1. *Forcing Mechanisms for Lagoon Water Movement*

Lagoon waters circulate during periods when the mouth is open and water quality (higher dissolved oxygen levels, lower temperatures) is typically at its best (Sutula et.al, 2004) and Figure 5. Lagoon water quality is still impaired by watershed inflows, but regular tidal flushing and circulation during open periods keep the quality higher than at any other times of the year (Figure 6). Periods of open lagoon conditions are coincident with impaired ocean water quality (bacteria) at Surfrider Beach (Personal communication with Mark Gold, Heal the Bay, 2004).

However, lagoon waters do not effectively circulate when the mouth is closed, occurring roughly from May through October every year (with variations depending on climate) (Sutula et.al, 2004) (Figure 7). Low dry season flows entering from upstream are unable to promote any perceptible lagoon circulation because the lagoon is configured with the main body as a broad basin that receives and dissipates any imparted current. Also, vegetative growth within the lagoon reduces potential circulation, and shades lower levels of the water column enhancing stratification.

Observations by team members during closed conditions (using floating fruit to observe surface water movement) show no effective surface water movement other than minor surface movement across the lagoon from west to east in the afternoon from the prevailing breeze. Little or no other perceptible water movement occurs during closure periods. The slight afternoon surface water movement only affects the east shore of the lagoon and is insufficient to promote mixing throughout the lagoon or the western lagoon arms (Figure 8). Visual observations indicate that surface water movement is limited to the southeast portion of the lagoon, with little or no return flow toward the west. This may be a function of the lagoon planform or depth preventing a sustained return current from moving westward. Also, the western arms are sheltered from the wind by relatively high-relief islands, and are too narrow and shallow to promote a wind fetch as well as horizontal water exchange and thus do not effectively circulate. Existing wind conditions are described below.

A wind gage was installed at the lagoon from July 1 to October 1 of 2004. The wind direction and velocity recorded by the instrument is shown in Figure 9. The prevailing wind direction is almost due west at 270 degrees. Wind velocities 15 feet above the ground average 10 miles per hour in the afternoon on a typical summer day, and 5 miles per hour on the ground. The existing fetch could be increased by aligning the west arm(s) in an east-west direction and lengthening the reach of relatively deeper, unimpeded lagoon surface water area.

The existing fetch results in wind waves observed up to 6 inches high along the east shore in the late afternoon on a typical summer day (Moffatt & Nichol, 2004). Existing wind-driven currents are able to blow floating objects (fruit, kayakers) from the mouth of B channel to the east shore within just a few minutes as observed on June 9, 2004, considered to be a typical afternoon condition at the lagoon (Moffatt & Nichol, 2004, Figure 8).

Figure 5 - Circulation - 6/9/04 for Ebb Tides

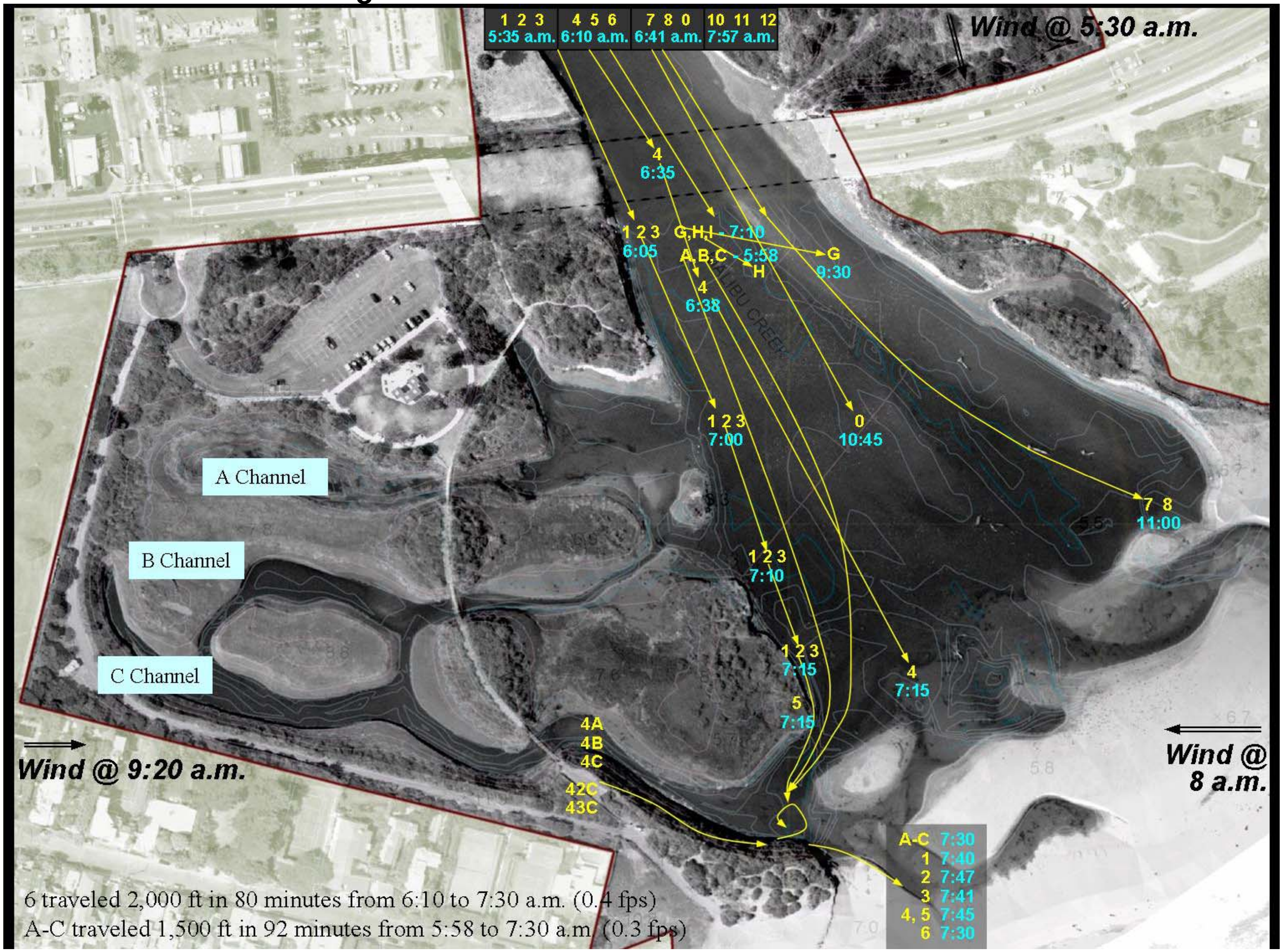
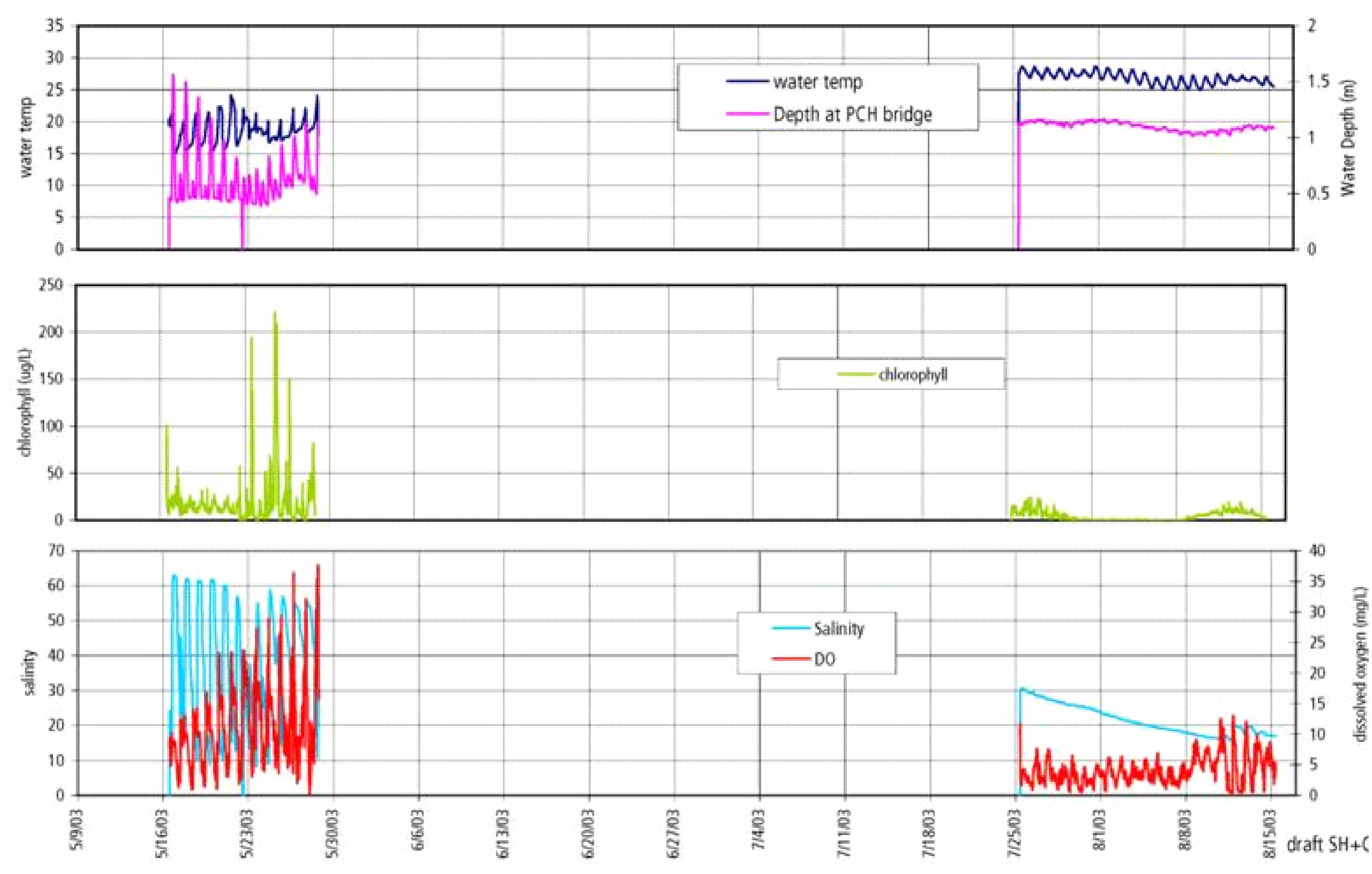


Figure 6 – 2003 Tapia Gage Data PCH Bridge
Malibu Lagoon



This lack of lagoon circulation throughout the warmest, high sun season can result in water stagnation leading to heating and stratification (layering), retention of nutrients, and hypoxia (low oxygen levels) or anoxia (no oxygen) in the water column (Sutula et.al, 2004; field data collection by M&N and Heal the Bay as part of this study, 2004).

The western arms are narrow, relatively shallow and looped in planform as shown in Figure 7. As such, the hydraulic channel pattern is ineffective at sustaining circulation throughout the entire reach of the channels. In contrast, hydraulic systems composed of one main channel are more able to circulate water throughout the entire channel length in the direction of the hydraulic gradient (from the reaches with relatively higher water levels toward the reaches with lower water levels). In contrast, a channel network such as Malibu Lagoon that is characterized by two or more main channels leading to the same location of a lagoon (looped planform) results in a dead zone of flow velocities where flows in the channels converge. This dead flow zone is where sedimentation occurs and circulation is poorest. At sites with sedimentation issues such as Malibu Lagoon, allowing for circulation to be maintained throughout the entire channel length is most effective at improving circulation and keeping the system clear of excessive fine sediments. Field observations made in June of 2004 by the project team confirm the existence of dead flow zones throughout the western arms. Hydraulic modeling done to test the performance of alternatives also confirms that multiple sites within the western arms possess no circulation even under conditions of an open mouth as presented in Section 5.

The existing bed elevations of the western arms (A1) are above mean sea level (msl) and thus too high to promote tidal circulation when tidal elevations are below msl (approximately 50% of the time). Therefore water motion and turnover is reduced under existing conditions below the potential to flush the western lagoon with tidal flow. Evidence of poor circulation and flushing exists in the fact that very fine soil particles and much higher organic content exists in the beds of the western arms as recorded by Sutula, et.al. (2004).

Figure 7

Photo. © K. Adelman 2002 California Coastal Records Project

Figure 8 - Circulation - 6/9/04, p.m. - Flood Tide

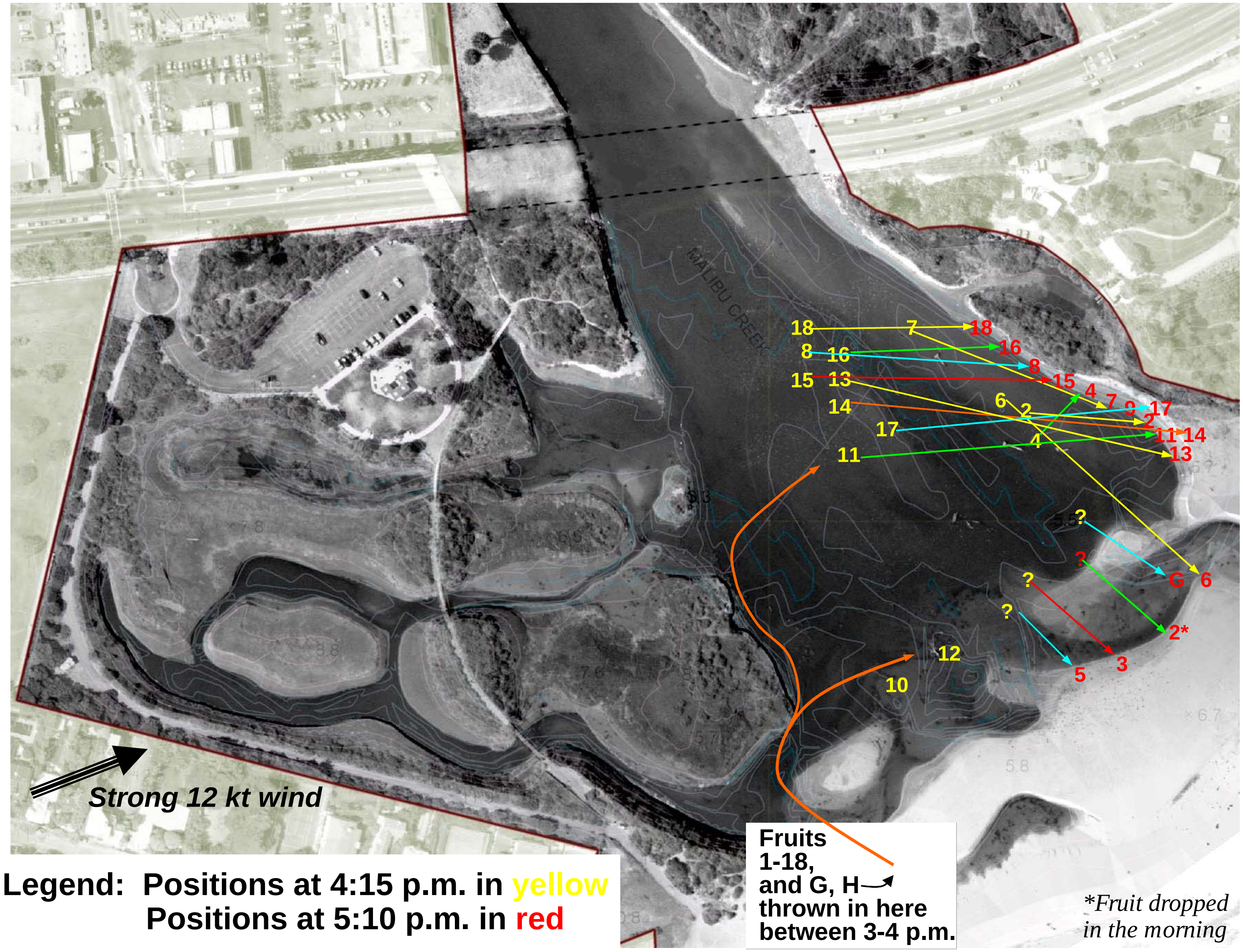
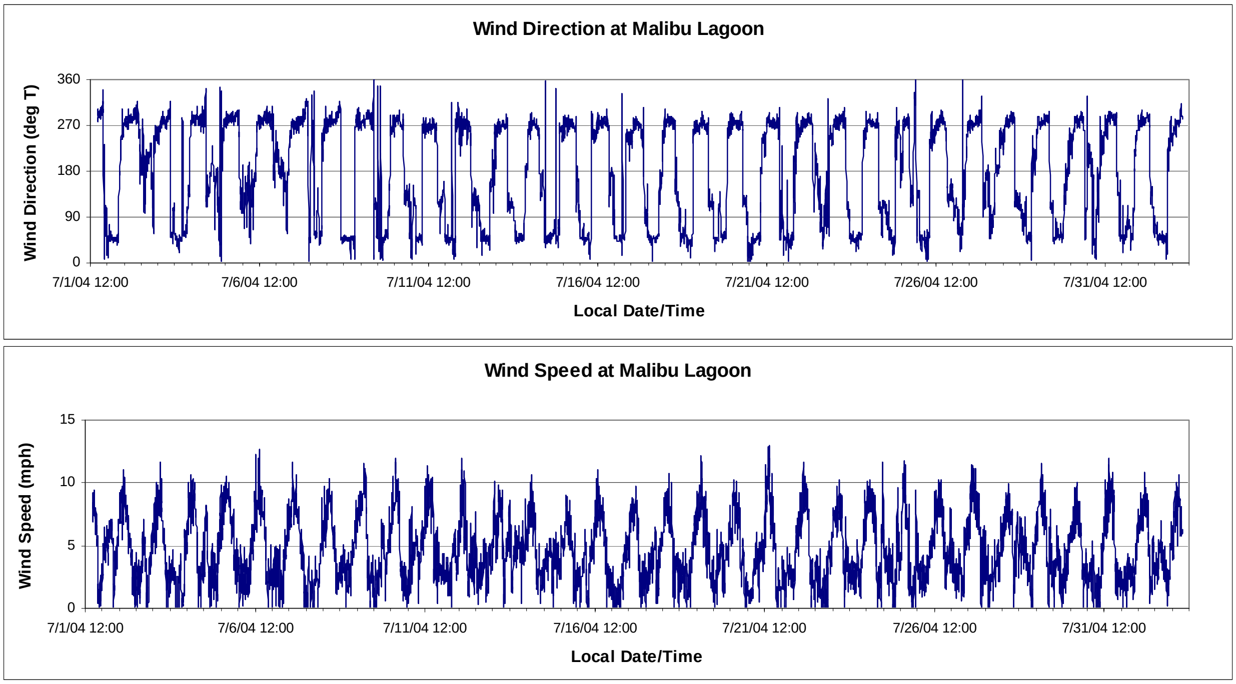


Figure 9 - Summer Wind at Malibu Lagoon



3.2. SEDIMENTATION

The current configuration of Malibu Lagoon includes two physically and hydrologically different wetland areas (the main channel and the west arms). The main lagoon channel (right-hand side of Figure 7) is oriented perpendicular to the coast and typical of a coastal watershed river mouth. As described above, the main channel is subjected to elevated stream flow velocities during winter runoff, resulting in transient bed sediments that aggrade and degrade the lagoon bed as storm flows increase and recede.

The west arms consist of three distinct channels that are oriented perpendicular to the main flow path of Malibu Creek and are connected to the main channel through elevated sills at their junctions with the main lagoon. Surface water from the main channel must enter and exit the west arms via existing sills at between 1.0 to 4.0 feet above msl as shown by the 2004 bathymetry map (Figure 10). Currently the western channels are located at an average elevation of between 2.0 feet to 3.0 feet above msl, 1 to 2 feet higher than the bed of the main channel.

The western arms of Malibu Lagoon appear to be slowly accreting over time, as indicated by comparison of UCLA survey data from June 1, 1998, with M&N survey data from early March of 2004. The storage volume within the lagoon as estimated by UCLA compared to that calculated by M&N shows a decrease in storage volume throughout the entire lagoon of 11 acre-feet over 6 years. Although annual variations in sedimentation and scour are evident of short-term changes due to climate, the longer-term trend is toward infilling. An example of short-term variation is the temporary increase in storage volume after the El Nino winter of 1997/1998. The lagoon may have been scoured by severe storm flows the winter prior to the 1998 survey resulting in increased storage capacity in the lagoon. After that period, drier climatic conditions occurred up to the present causing the lagoon to gradually infill with sediment, decreasing the storage capacity.

Assuming that the loss of storage volume represents sedimentation, the annual sedimentation rate throughout the lagoon is 0.76 inches per year, with the majority of that likely occurring within the western arms (Figures 11 and 12). These rates are similar to the average rates of approximately between 2 and 4 centimeters at the western arms (0.79 to 1.57 inches) estimated by Sutula et.al (2004).

Figure 10 - Existing Lagoon Bathymetry

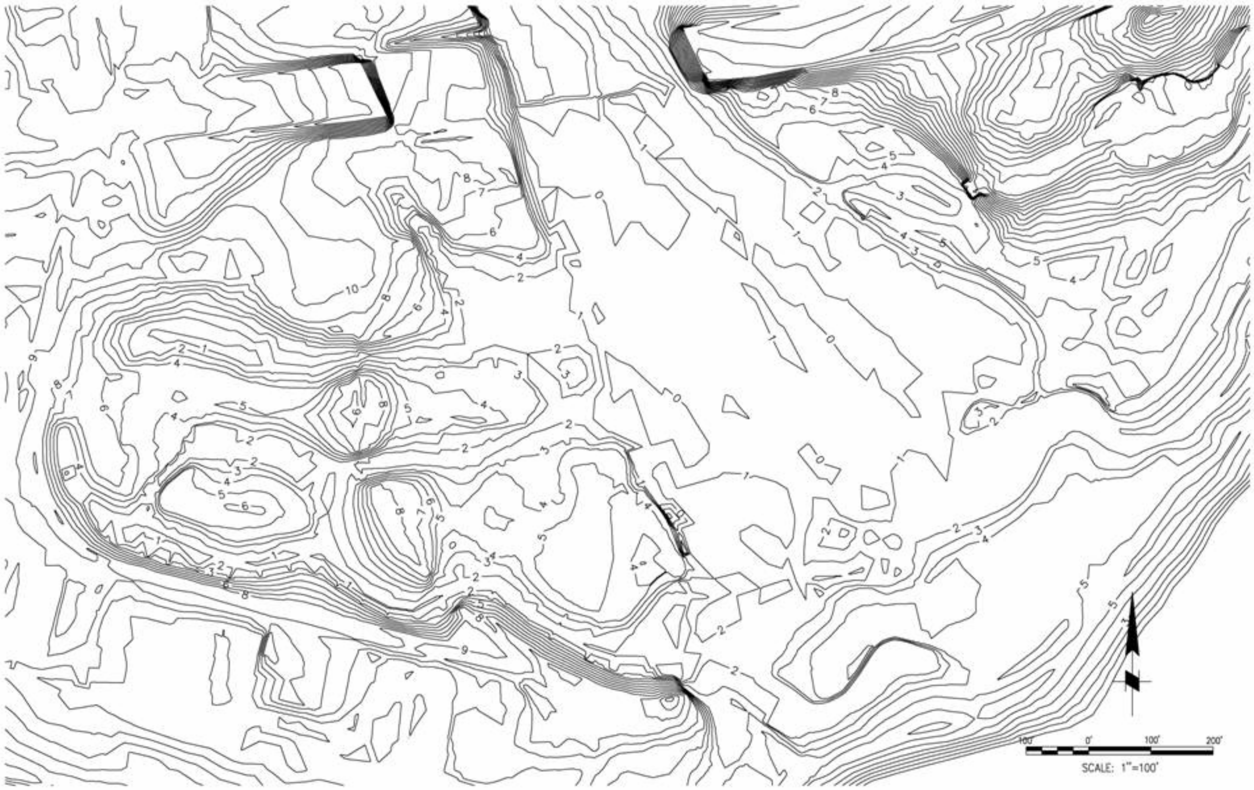


Figure 11 – Lagoon Storage Below +5.0 ft MSL

Survey Date	Sept. 1997*	Jun. 1998*	Oct. 1998*	Feb. 2004**
Storage (acre-ft)	81.40	98.01	94.87	87.40

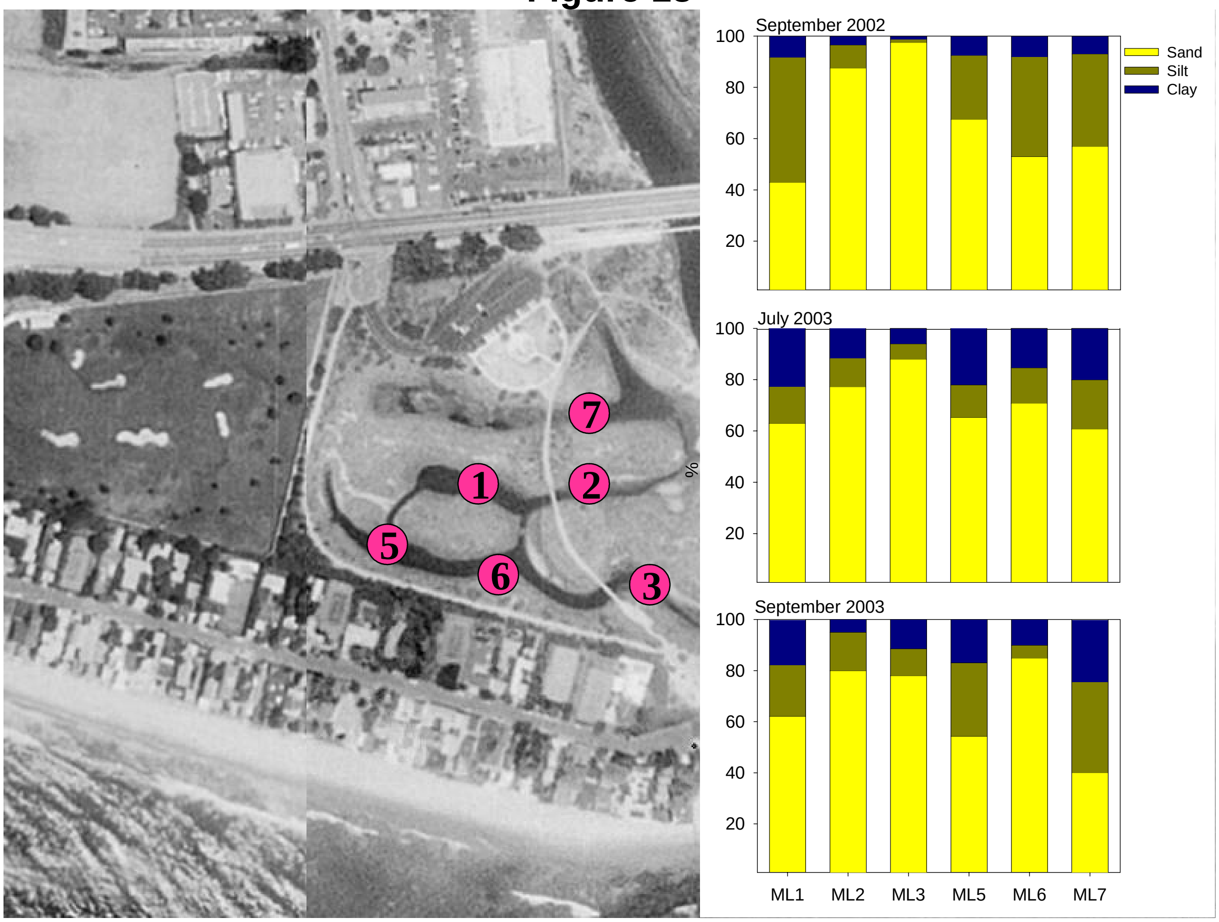
Surface area at +5' MSL is 28.06 acres in Feb. 2004
*UCLA, 2000 **M&N, 2004

Figure 12 – Sedimentation Rate

- Storage volume change from 6/1998 to 3/2004 = 10.6 acre-feet
- The average sediment accumulation in the lagoon = 2,853 cy/yr
- The average annual sedimentation rate = 0. 76 inches per year
- The sedimentation rate over 2002-2003 wet season = 1.18 inches (Sutula, et al)

Due to the circulation disconnect and the higher elevations, the substrate of the western arms was found to range from 45-85% sand (depending upon sampling period), compared to the 95% sand found in the main channel of the lagoon (Sutula et.al, 2004) (Figure 13).

Figure 13

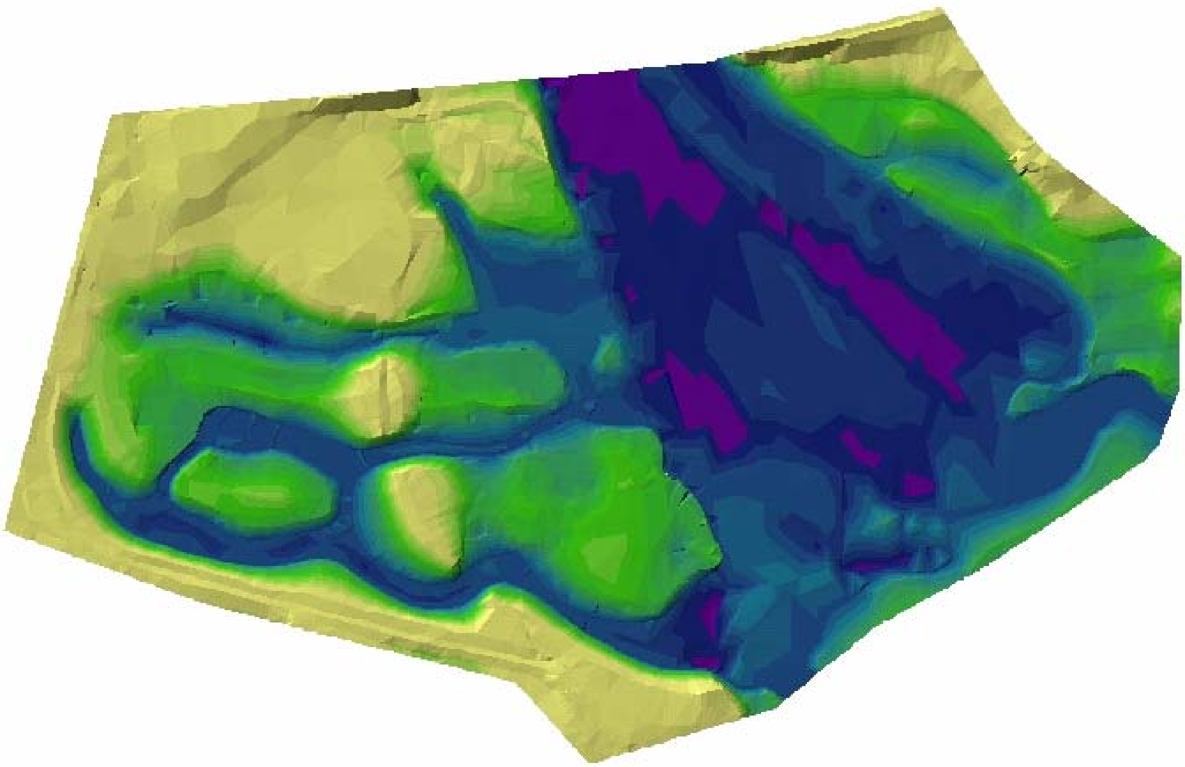


Also, comparison of lagoon cross-sections from the UCLA study and M&N suggest that the lagoon bed has accreted since the late 1990's. M&N cross-sections were overlain on the UCLA sections L1 through L5 (progressively moving south of PCH bridge toward the beach). The 2004 lagoon bed at cross-sections L3, L4 and L5 (from near the beach to near mid-lagoon) are higher than at the 1997/98 cross-sections. Cross-sections L1 and L2 (closest to PCH bridge) are roughly equivalent in bed elevation from 1997/98 to 2004. See Appendix 1, Slides A3 and A4 for the data. The accuracy of these observations is limited due to the difficulty of locating the UCLA cross-sections in space, but the data show trends consistent with calculations presented above.

Nearly the entire lagoon bed is perched above mean sea level (msl) causing it to be insufficiently flushed by tides during open conditions. The western arms are the highest elevations of the lagoon. The channel beds of the ends of all three channels are nearly at mean high water relative to msl (Figure 10). According to calculations performed using existing bathymetry, if the lagoon drained properly only 0.4 acres of Malibu Lagoon south of PCH would be inundated by water when the water surface is at msl (Figure 14) and most of the lagoon would be covered by water when the water level reaches +3 feet msl (Figure 15). The blue color tones in these figures indicate the approximate water depths, with darker blue indicating deeper water and lighter blue indicating shallower water. The figures were prepared based on the concept of "filling" the existing lagoon bed topography with water up to 0 feet msl and +3 feet msl, respectively.

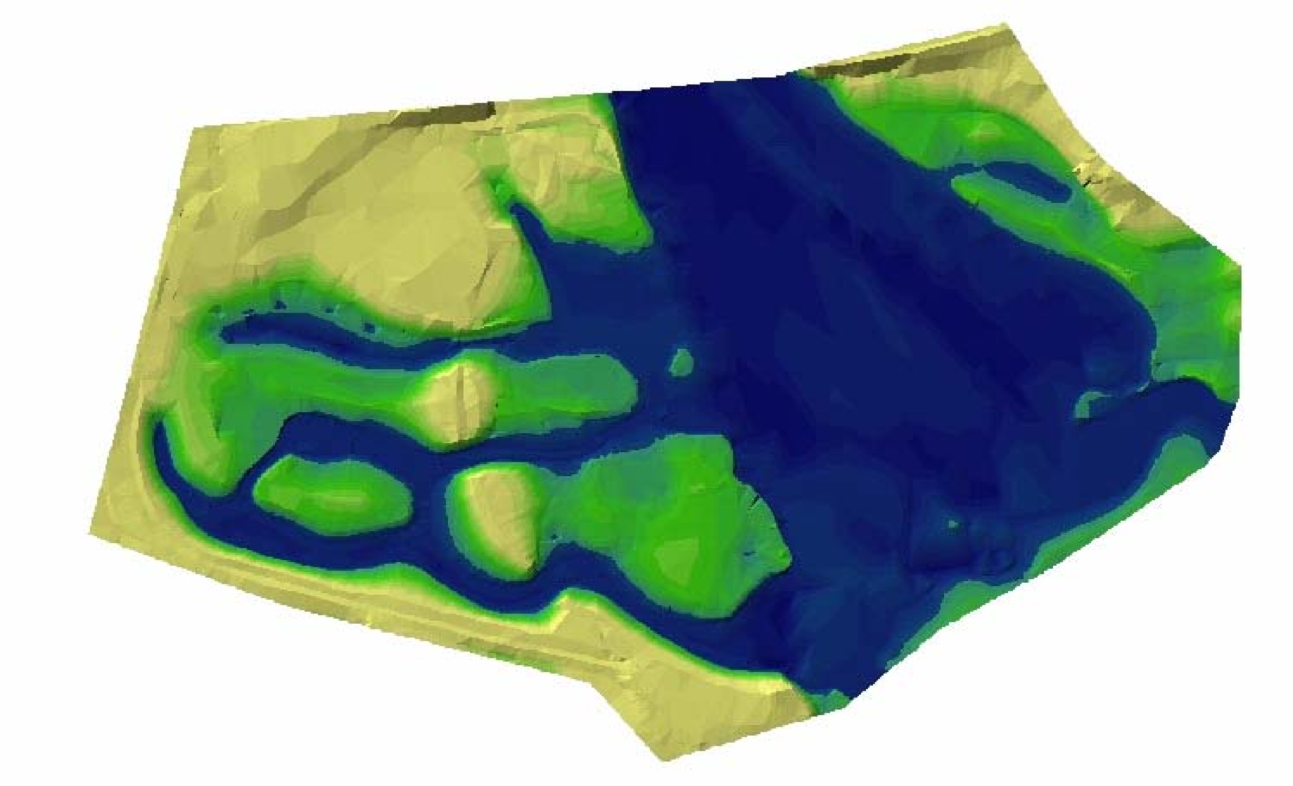
The current "perched" condition of Malibu Lagoon is likely a result of previous construction and site evolution. Bed sediments within the western arms are generally very fine in grain size indicating insufficient flow velocities to cause scour. The source of sediment to the lagoon is predominately storm flows (UCLA, 2000; Sutula et.al, 2004) and the majority of sediment transport occurs during storm flows due to their high flow velocities and transport capacities (UCLA, 2000). Storm flows typically move downstream and inundate lower-lying areas, including the western arms.

Figure 14 - Tidal Elevation at 0 ft MSL



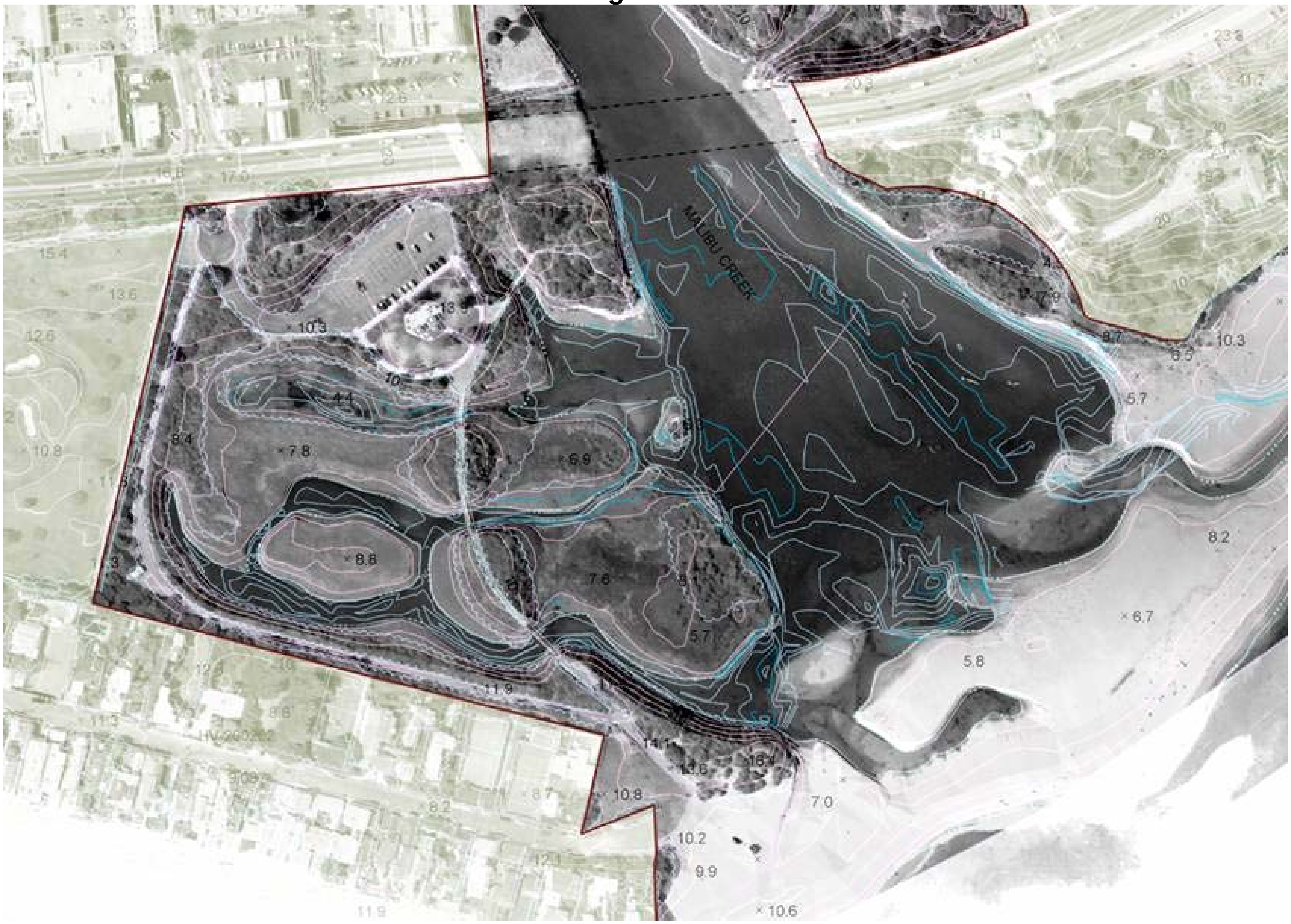
Blue color tones indicate approximate water depths, with darker blue indicating deeper water and lighter blue indicating shallower water.

Figure 15 - Tidal Elevation at 3 ft MSL



The mouths of the western arms are situated and oriented into the flow path of the main lagoon to be able to receive sediment-laden storm flows (Figure 16). As storm waters fill the western arms and slow in movement, sediment settles out of the flow and deposits on the lagoon bed.

Figure 16



The pattern of sedimentation throughout the lagoon bed is observed to produce the coarsest materials in the main body and upstream toward Pacific Coast Highway, with progressively finer sediments existing in the western arms and the finest sediments at the ends of the arms (as observed by Moffatt & Nichol in 2004; Sutula et.al, 2004).

Cycles of sedimentation/erosion likely occur at Malibu Lagoon. The main lagoon may be perched at the present due to a lack of severe storm activity since 1997/98. It is exposed to the maximum storm flow velocities and floods of wet winters that may scour and deepen the main lagoon (Figure 17). Thus the main lagoon bed elevation may oscillate over the long-term about some average condition and it may presently reflect recent dry conditions. The western arms may not experience the same cycles of sedimentation/erosion due to their relative sheltering from direct exposure to high velocity storm flows. Sheltering from scouring, while at the same time being open to sediment delivery, may result in a progressive process of accretion over time.

Sedimentation at the western arms leads to adverse conditions of nutrient build-up in the soils (Sutula et.al, 2004). This, together with a lack of circulation leads to eutrophication. Both processes are described in subsequent sections.

Figure 17 – Winter of 1998

Photo courtesy UCLA (Ambrose and Orme, 2000).

3.2.1. *Ramifications of Sedimentation Patterns on Water Quality*

Due to the increased surface area of finer grained particles, the sediment nitrogen (N) concentrations in the west arm can be an order of magnitude higher and the sediment phosphorus (P) concentrations can be two times higher in the western arms than in the main channel of Malibu Lagoon (Sutula et.al, 2004). The winter deposition of nutrient rich sediments has been identified as a potentially significant source of N (17%) and P (5%) to primary production in the summer lagoon (Sutula, et.al, 2004). However, the majority of the nutrient supply is coming from other local land use sources. Nutrient levels in Malibu Lagoon are higher than some of the most eutrophic systems worldwide (Sutula et.al, 2004) (Figure 18)

Figure 18

Malibu Lagoon #	**South SF Bay (waste water)+**	**Elkhorn Slough * (agriculture)**
Spring nutrient concentrations	Spring nutrient concentrations	Spring nutrient concentrations
DIN concentrations 100 uM	DIN concentrations 45 uM	DIN concentrations 50 uM
SRP concentrations 15 uM	SRP concentrations 7 uM	SRP concentrations 5 uM
# Sutula et al 2004	+ Cloern J, 1996	* Caffrey et al 2003

"*Sediment N and P in surficial sediments of the Western region of Malibu Lagoon (0.341 ± 0.228 % N and 0.081 ± 0.032 % P) were equal to or greater than values from several of the most eutrophic systems studied worldwide.*" Sutula et al 2004

All N-limited Systems

The Sutula et.al (2004) findings illustrate an increased nutrient availability to the summer lagoon with decreasing grain sizes (Appendix 1, Slide A5). The current suspended sediment depositional regime in the lagoon results in finer sediments being preferentially deposited in the western arms during winter flows. Restoration alternatives that increase the surface area of the Malibu Lagoon and that provide sufficient sediment transport and scour capabilities to mobilize sand size particles will improve the potential success of restoration to reduce summer eutrophic conditions.

3.3. NUTRIENTS AND BACTERIAL SUPPLY

Malibu Lagoon is listed on the federal 303(d) list of impaired water bodies due to the excessive abundance of primary producers and associated dissolved oxygen problems. Total Maximum Daily Loads (TMDLs) have been established to address these impairments (USEPA, 2003a). A main cause of this problem is excessive nutrient concentrations throughout the lagoon (Sutula et.al, 2004). The lagoon is severely enriched in N and P as a result of watershed land use practices. The primary sources of nutrients to the lagoon are watershed discharge and waste water releases from Tapia Treatment Plant (Ambrose and Orme, 2000). Watershed discharge includes groundwater contribution and stormwater runoff. The recent prohibition (1998) of Tapia summer releases to Malibu Lagoon has alleviated a significant nutrient source from April

15 to November 15. However, levels of nutrients (mainly phosphorus) during the summer are still too high to limit biological production.

Based on Sutula et.al (2004) and Ambrose and Orme (2000) estimates, the primary sources of N to the summer lagoon are:

- 52% septic systems leaching directly to lagoon;
- 25% surrounding watershed septic and surface runoff; and
- 17% sediment release.

The primary sources of P to the lagoon are:

- 95% watershed sources of septic and runoff; and
- 5% sediment release.

The most recent biologically available N and P values indicate winter dissolved inorganic nitrogen (DIN) values between 1 and 3 mg/L (70 to 210 uM) and soluble reactive phosphorus (SRP) between 300 and 600 ug/L (10-20 uM) (Sutula et.al, 2004). A comparison of biologically available N and P values to other highly eutrophic estuarine systems in California illustrate the extreme nutrient loading conditions present at Malibu Lagoon. For comparison, 90% of the freshwater inflow to the South San Francisco Bay is effluent from local waste water treatment facilities (Beck et. al, 2002), yet Malibu Lagoon has DIN and SRP concentrations more then double that of South San Francisco Bay.

Numerous studies have identified N as the limiting nutrient (Ambrose and Orme, 2000; Tetra Tech, 2002; CH2MHill, 2000) thus from a management perspective source reduction efforts will be best served by focusing on N load reductions to the Malibu Watershed. However, at the current state of chemical loading to Malibu Lagoon, N concentrations well exceed levels that would limit biological production (CH2MHill, 2000; Tetra Tech, 2002).

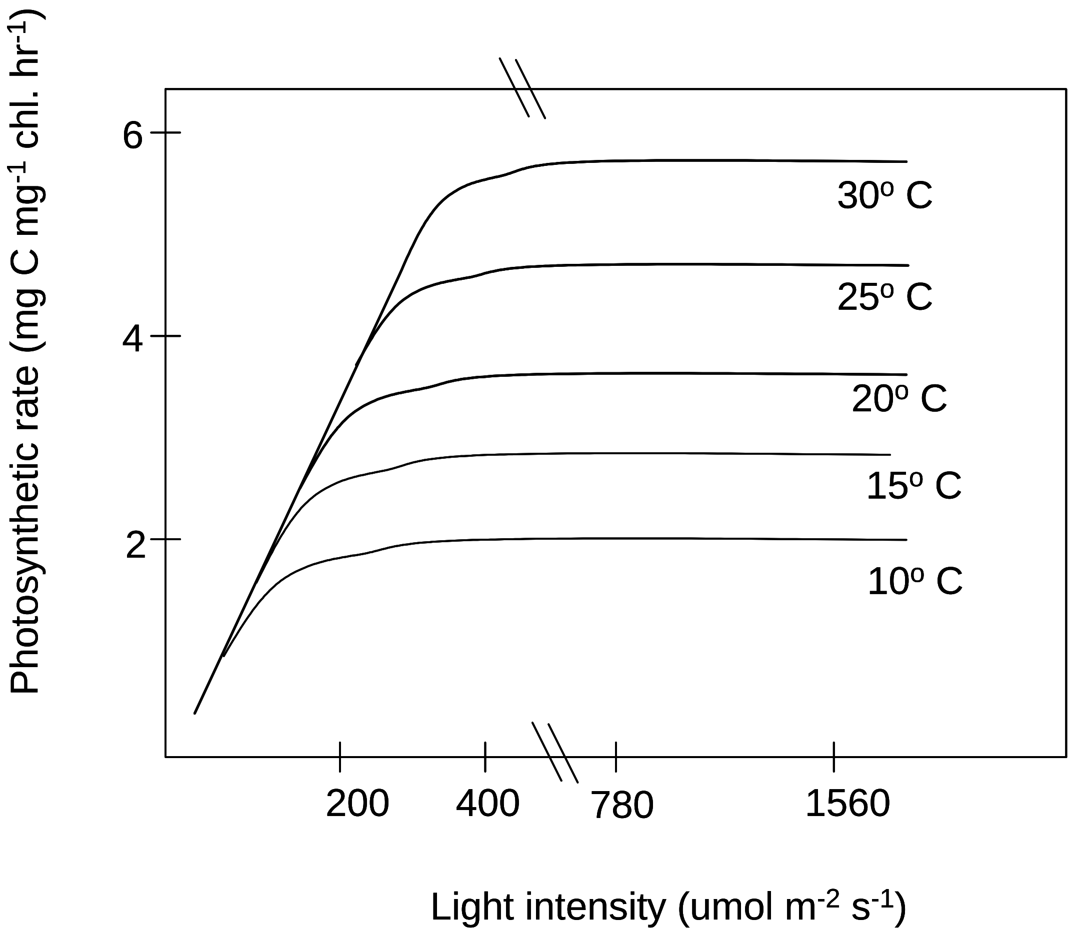
Although not an objective of this study, the other main water quality area of concern is bacterial levels within the lagoon. Source bacterial modeling estimates that 158,000 billion counts of fecal coliform are delivered annually to the lagoon. The primary sources to the lagoon are the local commercial and residential septic systems and resident bird populations (USEPA, 2003b). Based on the target reductions in fecal coliform loading from each of the sources within the watershed, the lagoon annual loading must be reduced to 21,800 billion counts to meet the Total Maximum Daily Load requirements, an 86% reduction in the fecal coliform annual loads. No information or estimates are provided for needed total coliform or Enterococci reductions.

3.4. CHEMICAL SEASONALITY OF EUTROPHICATION

The physical seasonality of the coastal California lagoon has a profound impact on the resultant water quality (Table 1 page 8). Both the seasonal changes in circulation and the resultant grain size distributions throughout the spring lagoon will influence the degree of eutrophication experienced in the summer Malibu Lagoon. Nitrogen and phosphorous are the key nutrients necessary for primary productivity (algal and emergent vegetation growth). Many studies have illustrated that Malibu Lagoon is significantly nutrient enriched due to surrounding land use impacts (Tetra Tech, 2002; CH2MHill, 2000; Stone Environmental, 2004; UCLA, 2000; Sutula, et.al, 2004). The N and P loading to the lagoon and concentrations within the lagoon in the winter are two times greater than the levels observed in the summer (UCLA, 2000; Sutula et.al, 2004; Tetra Tech, 2002). Yet the main water quality problems, nuisance algal blooms, low dissolved oxygen levels, ‘rotten egg odors’ and periodic fish kills, occur in the summer.

Photosynthetic rates increase exponentially with increasing water temperatures and light availability (Wetzel, 1978) (Figure 19). Therefore, the seasonality of physical conditions dramatically impacts water quality within the lagoon. Malibu Lagoon experiences far fewer problems with eutrophication during the winter months and the EPA did not find evidence to place the Malibu Lagoon on the EPA 303(d) list for algal impairment in the winter months.

Figure 19



From Wetzel, 1996

A YSI water quality gage was deployed and is maintained by the Tapia plant and located in the water column at PCH from 2002 and 2003. The limited available data from it suggest an increase in the average daily surface water temperatures in the Malibu Lagoon of 5 ºC in a matter of days following a closure in early to mid-May of 2002 (Figure 6, p. 13).

Monbet (1992) found that water mixing and circulation in tidally-influenced estuarine environments can reduce the chlorophyll by five-fold given the same dissolved biologically available nitrogen concentrations (Appendix 1, Slide A6). Tidal circulation in Malibu Lagoon keeps water temperatures relatively cool, reduces light penetration due to turbidity and dilutes the excessive nutrient concentrations delivered to the lagoon on a daily to bi-daily basis. Thus water quality impairments become the greatest of concern to Lagoon water quality when the it is closed in summer months.

3.5. NUTRIENT CYCLING

Sutula et.al (2004) data illustrate that a significant fraction of the inorganic N and P that is delivered to the summer lagoon is converted to organic material by primary producers. The uptake of nutrients by biological metabolism is the reason for the reduction in the nitrate and SRP levels in the summer lagoon surface waters. Figure 20 shows conditions over the last three years that bear on water quality at the lagoon.

Figure 20 – Climatic Factors for Recent Years

Physical Variable	**Year**		
	2002	**2003**	**2004**
Rainfall (inches)	5.92	13.76	Approx. 9.25
Time Period of Closure	March-October 7 mo	June-Nov 5 mo	closed May (breached) closed July 1-?
Maximum Water Level (msl)	5.5	6.0	No data
Average Lagoon Water Temperature (degrees C)	23.5	27	23
Peak winter Q (month)	514 cfs (Nov)	5410 cfs (Feb)	?
# of sunny days (intensity of summer solar irradiance) **?**			
Biogeochemical variable (closed)	**2002**	**2003**	**2004**
Bottom water DO	suboxic	+ 6 mg/L	suboxic
Lowest sfc salinity	3 ppt	6 ppt	3 ppt
SAV distribution	dense west arm none main channel	mod west arm none main channel	90% cover west arm 50% cover main chan

Data provide by Sutula et al 2004, LADPW pers com, Moffatt & Nichol obs.

The elevated primary production and subsequent respiration of the high organic loads (i.e., algae) is the cause of depressed dissolved oxygen concentrations, predominantly in the bottom waters of the lagoon (Figures 21 and 22). Heterotrophic bacteria consume the organic algae and plant biomass and convert them back to inorganic compounds utilizing oxygen in the process. The amount and rate of bacterial respiration is strongly influenced by the supply of organic matter to the system and the water temperature (Wetzel, 1975). Micro- and macrofauna algae also consume oxygen during respiration in wetland systems.

Figure 21

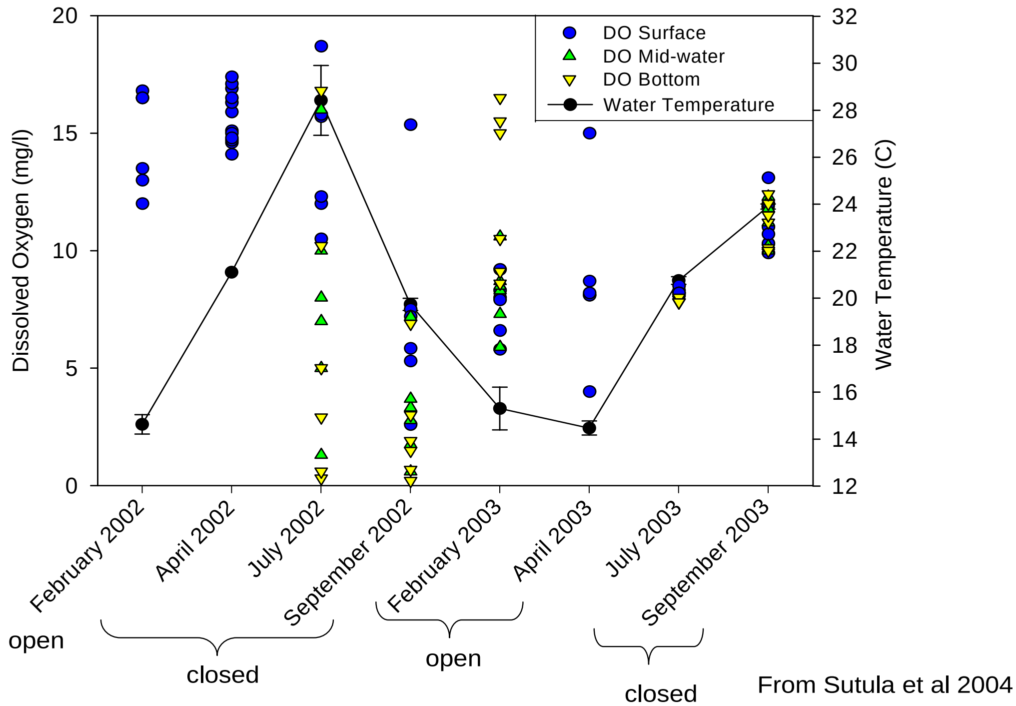
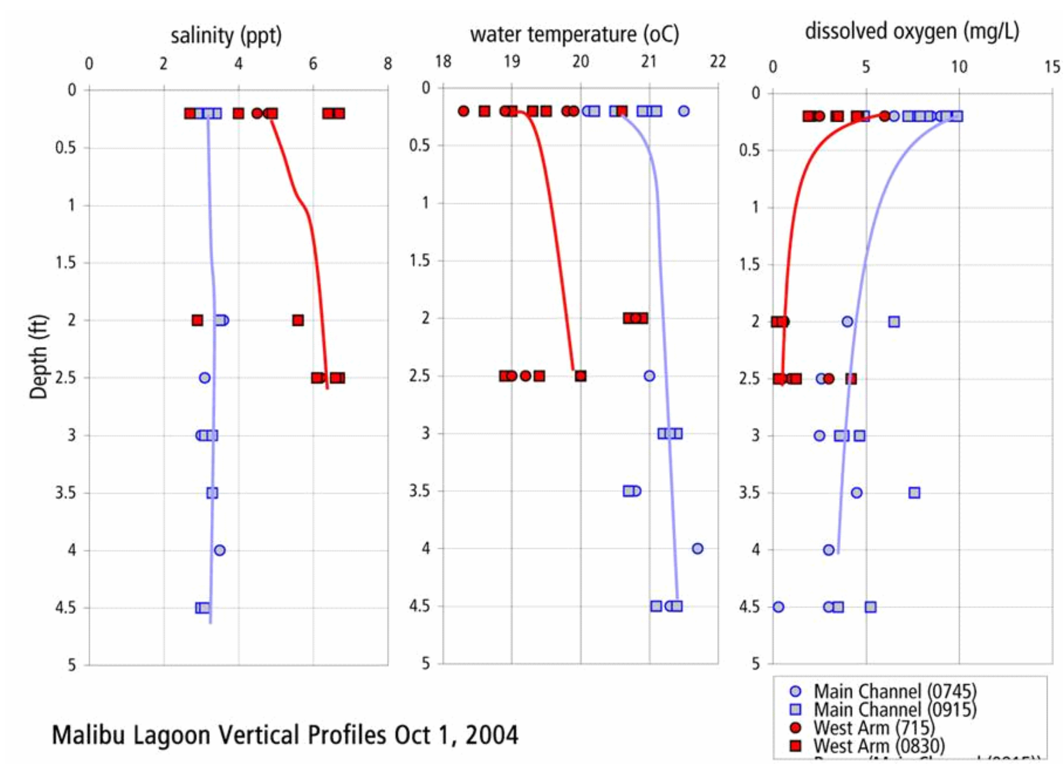


Figure 22



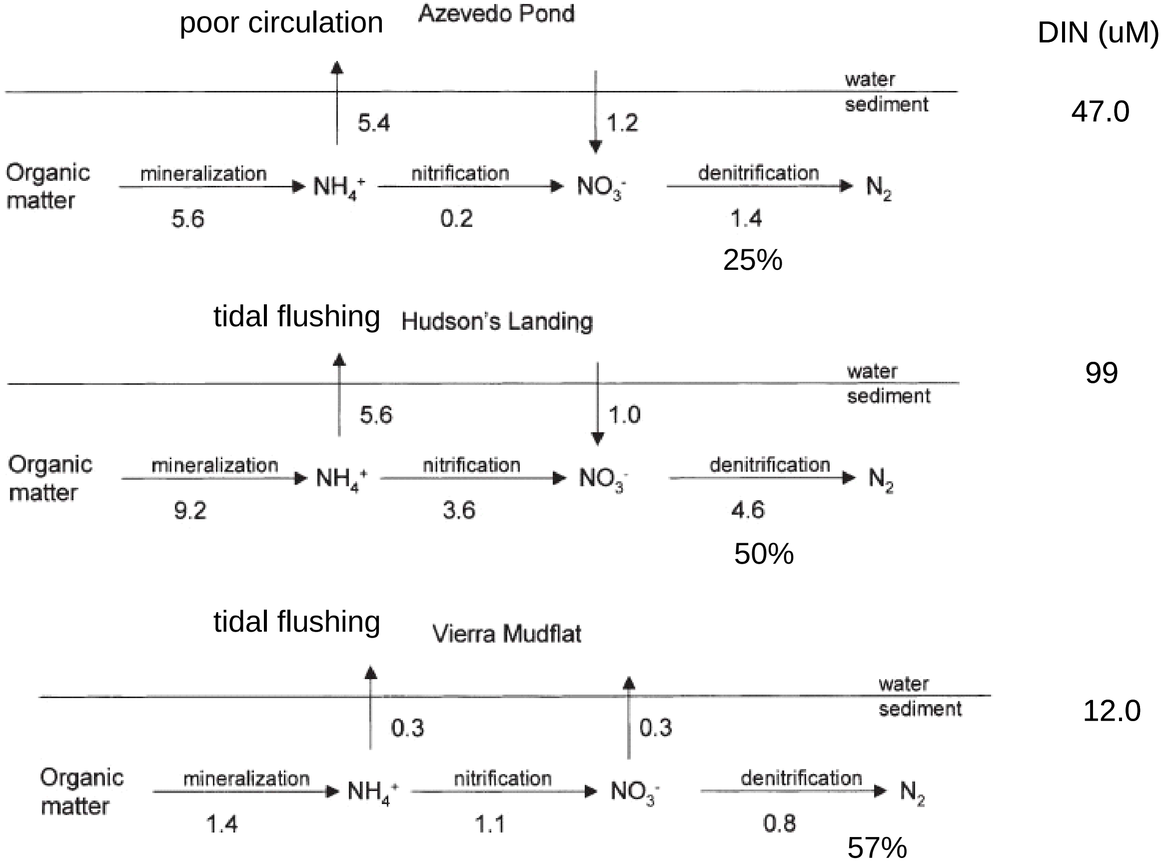
Once oxygen is depleted, heterotrophic bacteria begin utilizing other electron acceptors in a thermodynamically favorable sequence (MnO_2, NO_3^-, $Fe(OH)_3$, SO_4^{2-}, CO_2) (Stumm and Morgan, 1996) to recycle organic matter into inorganic forms. When respiration exceeds the supply of oxygen in the water column, nitrate is a thermodynamically favorable electron acceptor that oxidizes the organic material while reducing the biologically available N concentrations in the system (denitrification). The pore waters in highly eutrophic systems (with extreme plant production) become so reduced that the supply of other electron sources can be exceeded and sulfate reduction will result in the production of hydrogen sulfide. This compound produces the 'rotten egg smell' that can be highly toxic to fish and invertebrates.

3.5.1. *Denitrification*

The work by Sutula et. al. (2004) at Malibu Lagoon supports the existing knowledge that the primary form of recycled nitrogen (N) released from the sediments in coastal environments is NH_4^+ (ammonia). This NH_4^+ is generated by the decomposition of organic matter and/or the deposition of N-rich fine sediments in the bottom waters of Malibu Lagoon. In the presence of oxygen, the ammonia released from the sediments can be reoxidized to NO_3^- and then available for use as an electron acceptor in denitrification and the production of nitrogen gas (Kemp et. al.., 2000). Thus, if oxygen is regularly exposed to the sediments then nitrification of the ammonia released from the sediments will occur, followed by denitrification and the completion of the nitrogen cycle.

Research in highly eutrophic and temperate environments has found that ammonia released from the sediments in the early spring and fall was of the same order as the rates of denitrification (Kemp et. al., 1990). Yet in the summer months in Chesapeake Bay Kemp et. al. (1990) found that nitrification and denitrification were eliminated by the physical characteristics of the aquatic system. Vertical stratification in the summer of a highly nutrient enriched system resulted in low dissolved oxygen concentrations and high sulfide concentrations in the bottom and sediment pore waters, thus inhibiting nitrification of the ammonia released by the sediments. The ammonia released from the sediments is in essence recycled and biologically available for uptake by primary producers. Caffrey et. al., 2003 found similar results in a Central California estuary, where poorly circulated sites have 25% less denitrification than well flushed sites, suggesting circulation and residence times can significantly affect nitrogen removal by denitrification in eutrophic systems (Figure 23).

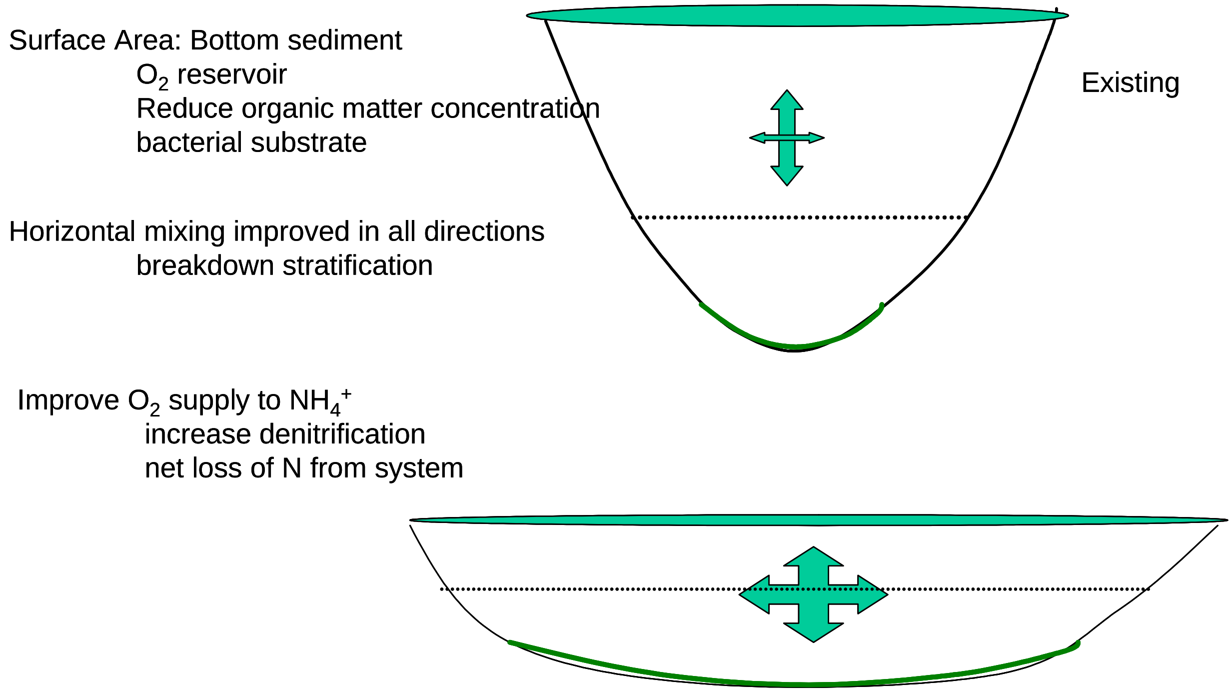
Figure 23



Caffrey et. al., 2003.

While there is no nitrification-denitrification research available for Malibu Lagoon, it is reasonable to assume that nitrification and denitrification are tightly coupled in Malibu Lagoon during open conditions in well flushed areas. However, the closed summer Malibu Lagoon may not have a significant nitrogen removal by denitrification. Vertical profiles in October of 2004 illustrate very low oxygen concentrations in the western arm bottom waters, concurrent with very slight density and temperature stratification (Figure 22). The existing configuration of the western arms possesses a much greater water surface area than the bed sediment surface area due to the steep-sided and deep channels (Figure 24). A decrease in the ratio of the water surface area (production) to bed sediment surface area (respiration) within the lagoon would increase the substrate area available for colonization of heterotrophic and denitrifying bacteria communities. These bacteria may not be as prolific on the sides of the channels compared to the channel bottoms where the organic matter accumulate.

Figure 24 - Channel Geometry



By the same actions, increasing horizontal water exchange in all directions may be sufficient to prevent the slight stratification and water stagnation observed in the western arms (Figures 24). Eliminating the stagnant areas in the summer lagoon may allow greater exchange of dissolved oxygen between the surface and bottom waters, increasing nitrification rates and reducing the amount of sulfate reduction (hydrogen sulfide production) in the system. Again however, nutrient source control will be the most effective strategy to alleviate the summer low oxygen conditions, and allow the positive feedback loop of denitrification to occur in the summer Malibu Lagoon.

3.6. HABITAT

3.6.1. *Vegetation Communities*

The habitat conditions within the lagoon are primarily dictated by elevation and hydrology. A recent field survey was conducted by Merkel & Associates (2004) to map the existing vegetation communities/habitats within the lagoon (Figure 25 and Table 3, see Appendix 2). Increasing human population and urban development have subjected Malibu Lagoon and the surrounding wetlands to considerable disturbance. While this has generally resulted in ecological degradation of the wetland, previous restoration efforts have successfully restored some of the habitat. In addition to expanding the functional area of the lagoon, past restoration efforts have included several revegetation efforts. While the success of many restoration efforts at Malibu Lagoon is evidenced by their continued persistence, the resulting mosaic of vegetation communities is often difficult to describe using common habitat classification systems (such as Holland or Sawyer and Keeler-Wolf).

Seventeen vegetation communities and habitats were mapped at Malibu Lagoon including southern willow scrub, Atriplex scrub, Baccharis scrub, mule fat scrub, Venturan coastal sage scrub, mixed scrub, southern coastal salt marsh, coastal and valley freshwater marsh, brackish marsh, southern sycamore alder riparian woodland (planted as landscaping), disturbed coastal dunes, non-native grassland, disturbed habitat, mud flat, sand beach/sand bar, open water and urban/developed land (Figure 25 and Table 3, see Appendix 2).

Opportunistic species responding to seasonal or annual differences in the lagoon water surface elevations, soil salinity, and soil oxidation-reduction potential (ORP) dominate a vegetated mosaic that is not truly reflective of any natural community. The long-term seasonal flooding and lack of tidal influence limits the capacity for the development of zonal marsh habitats. This same observation was made in 1987 and 1988 by Manion and Dillingham (1989). Further, high nutrient availability and dynamic inundation conditions within the system favors the rapid growth and dominance by opportunistic plants, including several exotic species. Interestingly, in the 1987-88 studies, the extensive occurrence of exotic plant species within the lagoon was also noted.

Many areas contain an atypical mix of both wetland and non-wetland indicator plants. This is likely explained both by the evidence of irrigation piping that may have been used during the establishment of the restoration sites, the seasonal inundation and dewatering of the lagoon area above ordinary high tide levels, the high elevation of many areas of the current lagoon, and the existing position of the parking lot. The western lagoon currently contains Uplands, Roads/Parking/Disturbed/Trails, Turf and Ornamental, and Riparian habitats comprising close to 40% of the total area.

Figure 25


Existing Situation
Vegetation Mapping
Adamson House
Legend
Vegetation Type
Atriplex scrub
Baccharis scrub
Brackish marsh
Coastal and valley freshwater marsh
Disturbed coastal dunes
Trails and Disturbed habitat
Mixed scrub
Mudflat
Mulefat scrub
Non-native grassland
Open water
Sand beach/sand bar
Southern coastal salt marsh
Southern willow scrub
Southern sycamore-alder riparian woodland
Urban Developed
Venturan coastal sage scrub
Ornamental Landscape OR Unvegetated
Existing Pedestrian Bridge
N
200 100 0 200
Feet

Table 3. Existing Vegetation and Habitats At Malibu Lagoon

Vegetation Type	Acres
Atriplex scrub	1.04
Mixed scrub	0.28
Coastal Dune/Bluff Scrub	**1.32**
Baccharis scrub	0.52
Venturan coastal sage scrub	0.01
Non-native grassland	0.02
Uplands / Non-Native Grassland	**0.54**
Roads & Parking	1.73
Unvegetated (under PCH)	0.28
Disturbed habitat	0.02
Roads & Parking / Disturbed	**2.02**
Southern sycamore-alder riparian woodland	0.16
Southern willow scrub	0.47
Mulefat scrub	1.34
Riparian	**1.97**
Brackish marsh	**0.17**
Coastal and valley freshwater marsh	**0.81**
Mudflat	**4.77**
Subtidal Softbottom	**0.51**
Intertidal Gravel/Sand Bar	**12.55**
Subtidal Gravel/Sand Bar	**0.13**
Sand beach	**1.95**
Southern coastal salt marsh	**4.95**
Turf & Ornamental (near Adamson House)	**0.89**
Total	**32.59**

3.6.2. *Aquatic Habitats and Tidewater Gobies/Steelhead Trout*

Physical processes within the current lagoon (i.e., random breaching, sedimentation and poor circulation) limit habitat suitability for many aquatic species while increasing the potential for eutrophic conditions. Eutrophic conditions often result in severe oxygen depletion, particularly during closed conditions in summer months, which can result in fish and invertebrate kills within the lagoon.

Natural breaching of the lagoon helps to control non-native freshwater exotic species and provides essential marine linkages critical to maintaining an anadromous fish presence (tidewater gobies and southern steelhead trout) within the Malibu Creek. However, significant breaches can substantially drain the lagoon resulting in the loss of gobies from all but a few remaining refuge pools and isolated channels because much of the lagoon is perched uncharacteristically high above sea level. While tidewater gobies are adapted to breaching events, non-seasonal breaches of the lagoon during the summer months may be particularly catastrophic if the only remaining refugia (i.e., deeper pools and isolated channels) contain anoxic conditions that would be unsuitable for goby survival.

3.6.3. *Wetlands and Jurisdictional Non-wetland Waters*

Waters under the regulatory authority of the U.S. Army Corps of Engineers, California Coastal Commission, California Department of Fish & Game, and Regional Water Quality Control Board have been mapped within Malibu Lagoon during the present investigations. While much of the lagoon is highly degraded, a significant portion of the study area supports jurisdictional wetlands and other waters (Appendix 2). As such, any actions taken to restore the lagoon must take into consideration the potential for significant alteration of existing wetlands and the necessity for substantial wetland permitting activities required under existing state and federal regulations.

3.6.4. *Avian Habitats*

Bird use within the lagoon has been well documented for numerous years (Garrett, unpub. field notes 1980-1996; Manion and Dillingham eds., 1989). In reviewing these data, the seasonal composition of the avian community appears consistent with what is expected on a regional and habitat basis. The lagoon supports a relatively rich avian fauna for the small size of the system, and there do not appear to be any consistent long-term trends in avian species representation or abundances.

Because historic data are not reported relative to habitat use or species distribution around the lagoon, it is not possible to draw quantifiable conclusions regarding bird use of particular habitat features. However, anecdotal notations, reports, consultant team observation, and prior analyses (Manion and Dillingham eds., 1989) have been used to identify habitat features that provide substantial benefits to the existing avian community that could be improved upon within the lagoon system. However, it is important to note that from the analyses conducted it appears that opportunities to improve the lagoon for avian resources would not be directed towards reversing adverse trends, but rather at enhancing conditions from a relatively static high quality baseline. Currently, major drawbacks to the existing lagoon include a lack of isolated islands and management activities directed to specifically minimize human and domestic animal disturbances to promote bird use of the barrier beach.

4. RESTORATION APPROACH FOR EACH DISCIPLINE AND DESCRIPTION OF ALTERNATIVES

4.1. RESTORATION APPROACH FOR EACH DISCIPLINE

This section specifies the problems to be addressed under each discipline and the improvements required for their solution or improvement envisioned with each alternative.

4.1.1. *Circulation*

The circulation problems to be addressed include:

- Lack of surface water movement during closed conditions due to no effective forcing mechanism (hydraulic head, wind fetch, imparted stream current); and
- Ineffective circulation of tides during open conditions due to a high lagoon bed and an unnatural planform of lagoon channels (multiple looped channels rather than an ordered, naturalized stream network).

Targeted improvements to address these problems include:

- Utilize an existing forcing mechanism (wind and/or hydraulic gradients) to generate increased surface water movement during closed conditions; and
- Increase the tidal range, penetration, and flushing during open conditions by lowering the channel beds and reconfiguring the hydraulic system to consist of an ordered, dendritic channel pattern.

4.1.2. *Sedimentation*

Sedimentation problems to be addressed include:

- Excessive accumulation of fine-grained sediments throughout the western lagoon arms over time due to the combined effect of poor flushing from ineffective hydraulic and an active creek sediment source; and
- Gradual sedimentation throughout the entire western lagoon from the same processes.

Targeted improvements to address these problems include:

- Reduce the deposition of fine-grained sediments in the western arms by reducing their direct exposure to creek flows, increasing flushing and expulsion of sediment under open hydraulic conditions; and
- Manage the overall sedimentation rate by the same process.

4.1.3. *Nutrient Cycling*

Nutrient cycling problems to be addressed include:

- Excessive build-up of nitrogen and phosphorus in the fine-grained sediments in the western lagoon; and
- Limited denitrification under existing lagoon conditions.

Targeted improvements to address these problems include:

- Reduce the build-up of nutrients by reducing deposition of fine-grained particles and summer organic matter in the western arms; and
- Increase denitrification by modifying the lagoon's three dimensional geometry to include a lower ratio of lagoon surface water area to lagoon bed sediment area thus exposing sediments more frequently to water with higher oxygen levels.
- Reduce nutrient sources by implementing control measures throughout the watershed.

4.1.4. *Eutrophication*

Problems associated with eutrophication to be addressed include:

- Excessive eutrophication during dry weather, and depressed oxygen (low to no oxygen) conditions in lagoon waters from lack of circulation, stratification of the water column, and continual build-up of nutrients.

Targeted improvements to address these problems include:

- Decreased nutrient sequestering in sediments with increased scour of fines and summer organic matter, and increased circulation and mixing of lagoon waters to create conditions with higher oxygen levels in the water and sediment.

4.1.5. *Habitat*

Problems with habitat to be addressed include:

- Humans and urban development have subjected the lagoon to considerable disturbance.
- Opportunistic species dominate a vegetated mosaic that is not truly reflective of any natural community.
- The western arms currently contain Uplands, Roads/Parking/Disturbed/Trails, Turf and Ornamental, and Riparian habitats comprising close to 40% of the total area.
- Physical processes within the lagoon limit habitat suitability for many aquatic species while increasing the potential for eutrophic conditions.
- Significant breaches can substantially drain the lagoon resulting in the loss of gobies.
- Drawbacks to avian use include a lack of isolated islands and management activities directed to specifically minimize human and domestic animal disturbances to promote bird use.

Targeted improvements to address these problems include:

- Alter the lagoon topography to enhance drainage and slopes under open conditions and to optimize substrate elevations under closed conditions.
- Develop the low alkali marsh/meadow and restore seasonally inundated habitat that has been historically displaced by upland fills.
- Promote the transit through and use of all available areas of the lagoon by desirable aquatic and terrestrial species under both open and closed lagoon conditions.
- Ensure that no significant impact would occur to main lagoon goby habitat due to project implementation.

- Provide habitat that is attractive for bird use and currently limited within the lagoon proper.

4.2. Description of Alternatives

Three alternatives were designed to address these problems and include improvements described above, and a fourth alternative has been requested for consideration by the Lagoon Technical Advisory Committee (LTAC). All alternatives are depicted below to indicate conditions with the berm open at low tide (-1 foot msl) and closed during high water conditions (+5 foot msl).

4.2.1. *Alternative 1 – Enhancement Alternative*

The Enhancement Alternative (Figures 26 and 27) is intended to improve conditions in the western lagoon arms with the least cost and least degree of disturbance to existing habitat. The elevations of the channels in the western portion of the lagoon are too high to allow for inundation at ocean tidal elevations below mean sea level when the barrier beach berm is open. The western channels are too narrow, constricted, and isolated from one another to allow for adequate circulation of lagoon water. In addition, it is believed that the existing topography has resulted in an overabundance of upland habitat.

The Enhancement Alternative would lower the elevations of existing channels to allow for increased tidal inundation during open conditions. Topography of the channels and islands in the western lagoon would be lowered to accommodate vegetation types typically associated with coastal estuaries. Channel widths and depths would be increased and channels A and C would be connected to remove existing dead ends.

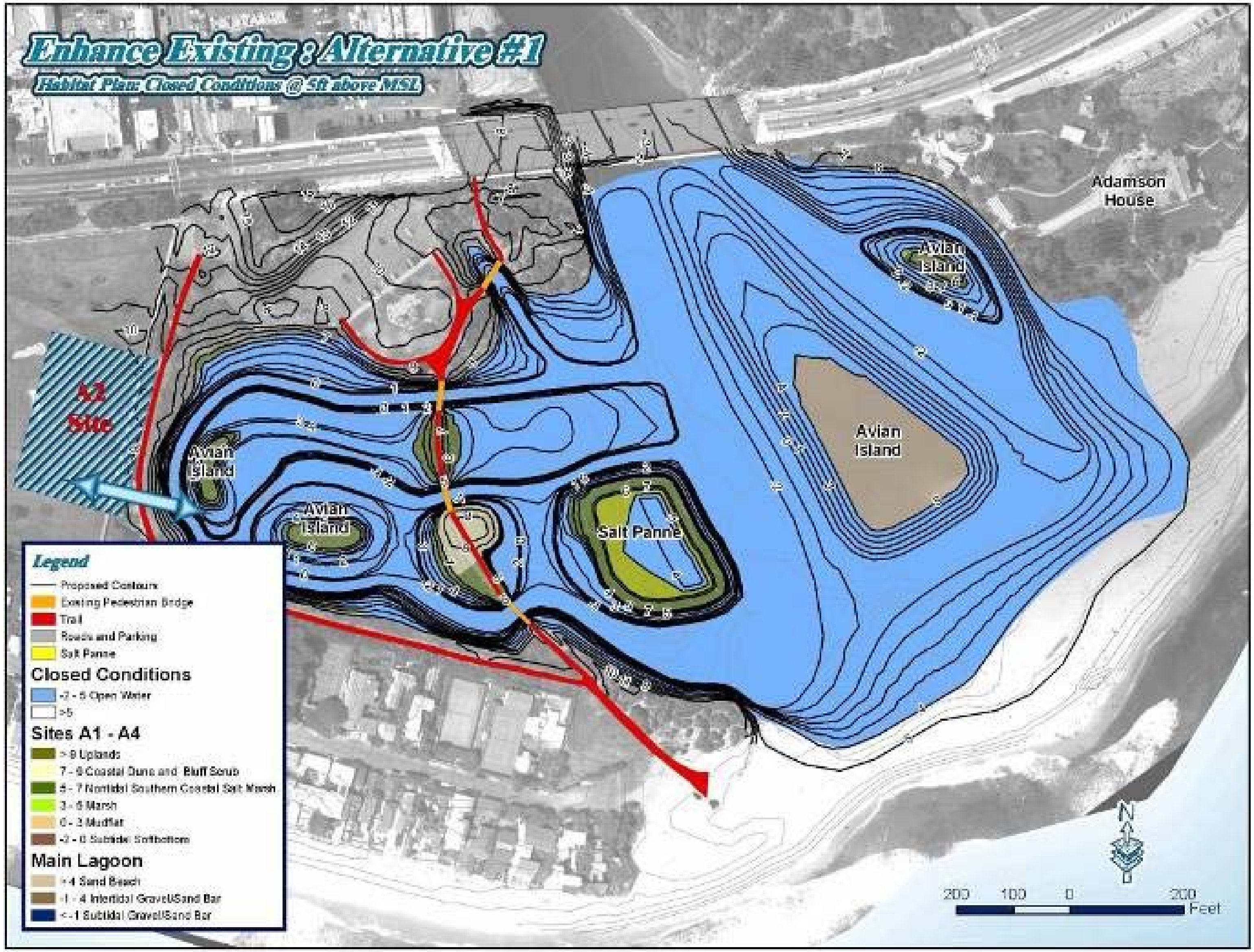
This Alternative was intended to:

- Improve circulation by expanding and deepening of existing channels in the western arms;
- Remove dead ends by connecting the A (north) channel to the C (south) Channel;
- Establish more appropriate marsh vegetation by lowering the elevation of western channels and islands to minimize upland habitat;
- Increase lagoon holding capacity during closed conditions;
- Provide additional bird habitat and minimize the need to export soils offsite by expansion of the mid-stream bar in the main lagoon body (no structural engineering is proposed to protect this bar);
- Provide unvegetated avian areas through the creation of a salt panne. The salt panne is intended to create an unvegetated area that uses a depression to capture water that will subsequently evaporate leaving behind higher salts in the soils that will minimize vegetative growth;
- Minimize cost and disruption to existing lagoon habitats.

Figure 26


Enhance Existing : Alternative #1
Habitat Plan: Open Conditions @ 1ft below MSL
Adamson House
Avian Island
Avian Island
Avian Island
Avian Island
Salt Panne
Legend
Proposed Contours
Existing Pedestrian Bridge
Trail
Roads and Parking
Salt Panne
Sites A1 - A4
> 9 Uplands
7 - 9 Coastal Dune and Bluff Scrub
5 - 7 Nontidal Southern Coastal Salt Marsh
3 - 5 Marsh
0 - 3 Mudflat
-2 - 0 Subtidal Softbottom
Main Lagoon
> 4 Sand Beach
-1 - 4 Intertidal Gravel/Sand Bar
< -1 Subtidal Gravel/Sand Bar
N
200 100 0 200
Feet

Figure 27


Enhance Existing : Alternative #1
Habitat Plan: Closed Conditions @ 5ft above MSL
Adamson House
Avian Island
Avian Island
Avian Island
Avian Island
Avian Island
Salt Panne
A2 Site
Legend
Proposed Contours
Existing Pedestrian Bridge
Trail
Roads and Parking
Salt Panne
Closed Conditions
-2 - 5 Open Water
>5
Sites A1 - A4
> 9 Uplands
7 - 9 Coastal Dune and Bluff Scrub
5 - 7 Nontidal Southern Coastal Salt Marsh
3 - 5 Marsh
0 - 3 Mudflat
-2 - 0 Subtidal Softbottom
Main Lagoon
>4 Sand Beach
-1 - 4 Intertidal Gravel/Sand Bar
< -1 Subtidal Gravel/Sand Bar
200 100 0 200
Feet

4.2.2. *Alternative 1.5 – Restore/Enhance Modified*

The Restore and Enhance Modified Alternative (Figures 28 and 29) will enhance existing conditions and restore and enhance habitat areas that have diminished functions or are in a currently degraded state. This alternative proposes significant changes to the existing lagoon configuration. The intent of this alternative is to create a footprint of a meandering channel system characteristic of more natural wetland ecosystems, such as Mugu Lagoon, the Santa Maria River Estuary, the Tijuana River Estuary, Los Penasquitos Lagoon, and others. This geometry will improve circulation for open conditions, increase tidal flow velocities in the western arms to promote scouring of fine sediments, and maximize wind-driven circulation during closed conditions.

Alternative 1.5 replaces the existing A, B, and C channels with a single channel connection to the main lagoon. The single channel is located at the south end of the lagoon and is aligned to maximize tidal circulation and minimize sediment laden storm flows in the west portion of the lagoon. This alternative proposes to install a naturalized berm along the western side of the main lagoon from the PCH bridge to the new channel opening on the south. The proposed naturalized berm will be at an elevation of approximately +2 feet msl (or 1 feet above the existing cobble berm or "speed bump") to physically separate the western arms from the path of the bed sediment load in the creek during storms, yet low enough to be inundated during closed conditions to provide for wind fetch. The naturalized berm will be constructed in a manner similar to that of the existing "speed bump," utilizing stone materials found within the lagoon. The design of the naturalized berm needs to be confirmed with additional analysis at a later stage to specify the appropriate effective crest elevation. The elevation may range from the +2 feet shown here by 1 to 2 feet vertically. The significance of constructing the berm to the appropriate elevation is that a berm that is too low may result in damage to the newly-restored marsh from sedimentation during certain flood events that may render the restoration ineffective or even reverse restoration benefits. A berm that is too high may impede the circulation of surface waters during closed conditions reducing benefits of water turnover and oxygenation.

This alternative proposes to convert significant areas of Uplands, Roads/Parking/Disturbed/Trails, Turf and Ornamental, and Riparian habitats into marsh habitats more indicative of wetland ecosystems. This alternative also proposes to relocate the parking lot to the north and to remove the lawn area to increase available habitat. The walking path through the lagoon is relocated eastward from its present alignment, but the south end of the trail ends at approximately the same location as the end of the existing trail.

Alternative 1.5 was intended to achieve:

- Tidal influence and wind driven circulation created by a single main channel with a naturalized dendritic planform more indicative of natural systems;
- Increased tidal flushing during open conditions by deepening of the west lagoon (no work is proposed in the main lagoon). This will also increase lagoon holding capacity (storage volume);
- Enhanced and increased salt marsh environment during open conditions and maximized wind fetch to enhance circulation during closed conditions;

- Permanent avian islands in A1 & A4. These islands will be designed to afford better protection from predators and will be optimized to suit avian enhancement goals;
- Expanded wetland and marsh acreage by relocating the existing parking lot into degraded upland habitat. The new parking lot will be designed to be permeable to maximize water quality enhancements through naturalized filtration/infiltration;
- Opportunities for new visitor facilities and educational resources.

Figure 28


Restore/Enhance Modified: Alternative #1.5
Habitat Plan: Open Conditions @ 1ft Below MSL
Adamson House
Avian Island
Existing Gravel Bar & Snags to Remain
A2 Site
Avian Island
Connection to A2 Site
Avian Island
Legend
Proposed Contours
Existing MSL Contours
Enhanced Parking Lot
Trails
Main Lagoon
>4 Sand Beach
-1 - 4 Intertidal Gravel/Sand Bar
Sites A1 - A4
> 9 Uplands
7- 9 Coastal Dune and Bluff Scrub
5 - 7 Nontidal Southern Coastal Salt Marsh
3 - 5 Marsh
0 - 3 Mudflat
-2 - 0 Subtidal Softbottom
200 100 0 200 Feet

Figure 29


Restore/Enhance Modified: Alternative #1.5
Habitat Plan: Closed Conditions @ 5ft Above MSL
Adamson House
Avian Island
Existing Gravel Bar & Snags to Remain
A2 Site
Avian Island
Connection to A2 Site
Avian Island
Legend
Proposed Contours
Existing MSL Contours
Enhanced Parking Lot
Trails
Closed Conditions
-4 - 5 Open Water
5 - 16 Exposed Vegetation
Main Lagoon
>4 Sand Beach
-1 - 4 Intertidal Gravel/Sand Bar
Sites A1 - A4
> 9 Uplands
7- 9 Coastal Dune and Bluff Scrub
5 - 7 Nontidal Southern Coastal Salt Marsh
3 - 5 Marsh
0 - 3 Mudflat
-2 - 0 Subtidal Softbottom
N
200 100 0 200
Feet

4.2.3. *Alternative 2 - Restore and Enhance Alternative*

The Restore and Enhance Alternative (Figures 30 and 31) intends to restore and enhance habitat areas that have diminished functions or are in a currently degraded state. This alternative is similar to Alternative 1.5 in that it creates a single sinuous channel designed to improve tidal circulation. The channel is wider and shallower than that in Alternative 1.5. The western portion of the lagoon will be designed to maximize circulation driven by tides through the channel during open conditions, a longer fetch at high water to increase wind-driven currents during closed conditions.

A new connection (North Channel) is proposed to be established to convey an appropriate source of drainage from upstream that could include either the Cross Creek storm drain, the main creek, or both. The North Channel would connect the upper end of the western arm to either the Cross Creek drain, the main creek or both under a western bent of the PCH bridge. The concept is to convey limited stormflow discharge into the upstream end of the western arms to flush fine sediment from the western lagoon. The Cross Creek storm drain may not convey sufficient stormflow to accomplish the desired flushing effect, so allowance is made to also or alternatively connect to the main creek to enhance the effect. Connection to the main creek would be designed to block bed sediment flow from entering the lagoon while permitting flows carrying suspended sediment to pass into the western arms. It is anticipated that most suspended sediment would remain in suspension and be conveyed toward the downstream end of the western arms and be discharged through the lagoon mouth into the ocean.

The proposed connection includes a weir at the upstream end of the North Channel to prevent first flush runoff from entering the west lagoon from either source. The weir enables stormflows after the first flush to be directed into the western lagoon which is anticipated is to promote the scouring of fine sediments. The connection concepts (channels, locations, planforms, cross-sections, weirs) are only envisioned to a conceptual level at this time to determine their technical feasibility at this stage. Additional engineering and analyses of the connections will be required as the project moves into the project stages of regulatory approvals and final engineering design for construction.

This alternative proposes to relocate the parking lot and remove the lawn area to accommodate the new connection and increase available habitat.

Alternative 2.0 was intended to achieve:

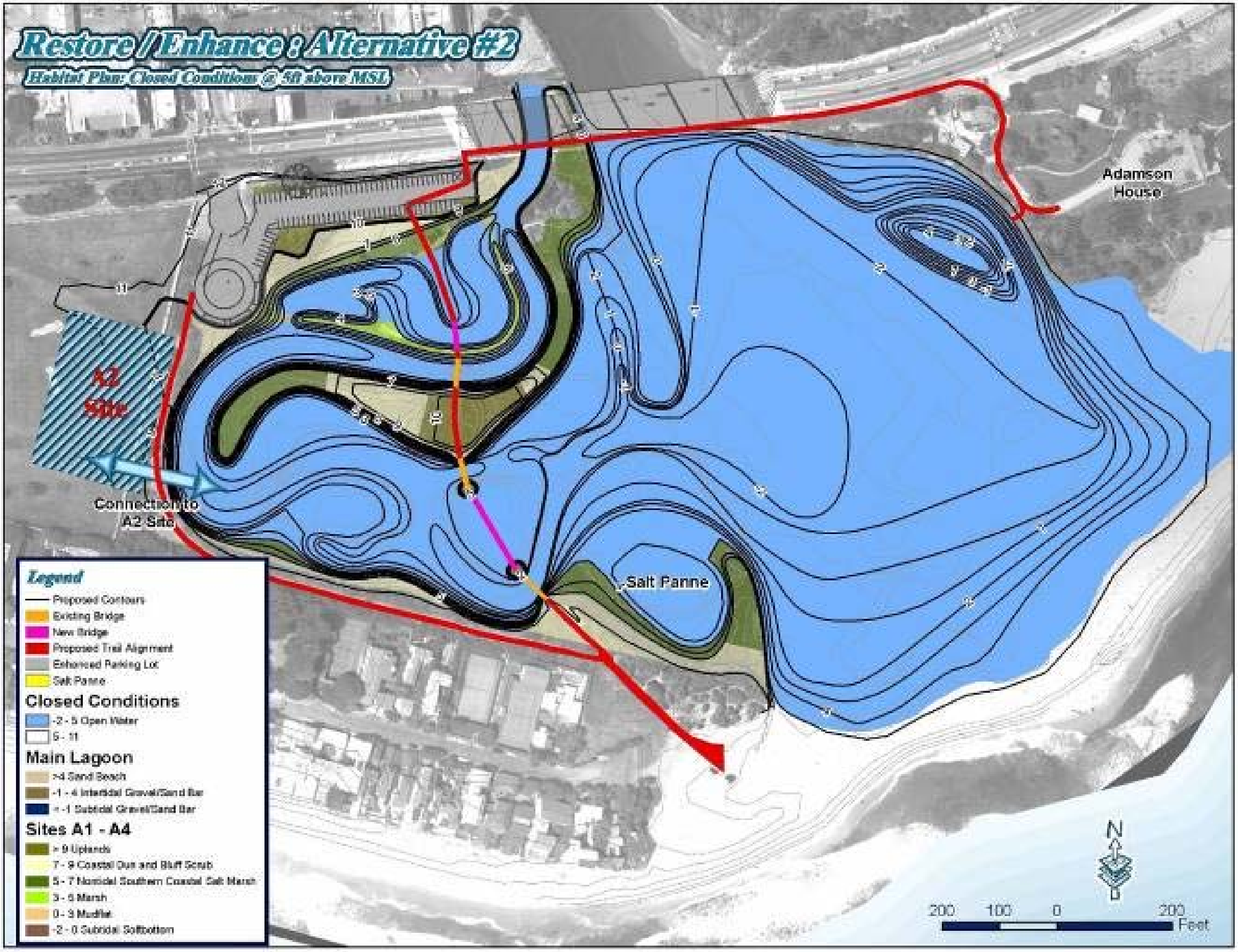
- Tidal influence created by a single sinuous main channel;
- Increased tidal flushing during open conditions by deepening of the west lagoon (no work is proposed in the main lagoon). This will also increase holding capacity (storage volume);
- Enhanced and increased salt marsh environment during open conditions and maximized wind fetch to enhance wind-driven circulation during closed conditions;
- Unvegetated avian areas through the creation of a salt panne. The salt panne is intended to create an unvegetated area that uses a depression to capture water that will subsequently evaporate leaving behind higher salts in the soils that will minimize vegetative growth;

- Expanded wetland and marsh acreage by relocating the existing parking lot into degraded upland habitat. The new parking lot will be designed to be permeable to maximize water quality enhancements through naturalized filtration/infiltration;
- Opportunities for new visitor facilities and educational resources;
- Increased flushing of sediments through the connection of the new North Channel.

Figure 30

Restore / Enhance : Alternative #2
Habitat Plan: Open Conditions @ 1ft below MSL
Adamson House
A2 Site
Connection to A2 Site
Salt Panne
Legend
Proposed Contours
Existing Bridge
New Bridge
Proposed Trail Alignment
Enhanced Parking Lot
Salt Panne
Main Lagoon
>4 Sand Beach
-1 - 4 Intertidal Gravel/Sand Bar
< -1 Subtidal Gravel/Sand Bar
Sites A1 - A4
> 9 Uplands
7 - 9 Coastal Dun and Bluff Scrub
5 - 7 Nontidal Southern Coastal Salt Marsh
3 - 5 Marsh
0 - 3 Mudflat
-2 - 0 Subtidal Softbottom
N
200 100 0 200
Feet

Figure 31



Restore / Enhance : Alternative #2
Habitat Plan: Closed Conditions @ 5ft above MSL
Adamson House
A2 Site
Connection to A2 Site
Salt Panne
Legend
Proposed Contours
Existing Bridge
New Bridge
Proposed Trail Alignment
Enhanced Parking Lot
Salt Panne
Closed Conditions
-2 - 5 Open Water
5 - 11
Main Lagoon
>4 Sand Beach
-1 - 4 Intertidal Gravel/Sand Bar
< -1 Subtidal Gravel/Sand Bar
Sites A1 - A4
> 9 Uplands
7 - 9 Coastal Dun and Bluff Scrub
5 - 7 Nontidal Southern Coastal Salt Marsh
3 - 5 Marsh
0 - 3 Mudflat
-2 - 0 Subtidal Softbottom
N
200 100 0 200 Feet

4.2.4. *Alternative 1.75 - Restore/Enhance Modified with the North Channel*

The LTAC has requested that additional analysis be performed on a variation of the Restore/Enhance Modified Alternative that includes the North Channel connection as an adaptive management tool (called the 1.75 Alternative, Figures 32 and 33). The LTAC asked for more detail to determine if the North Channel would flush fine sediments from the west lagoon in the Alternative 1.5 configuration. The North Channel may further improve flushing through the upper western arms and circulation during closed conditions. Due to the uncertainty of its beneficial effect, it would be held aside and only implemented if lagoon monitoring and further study indicated it was warranted.

Alternative 1.75 was intended to achieve:

- Tidal influence created by a single main channel with a naturalized dendritic planform more indicative of natural systems;
- Increased tidal flushing during open conditions by deepening of the west lagoon (no work is proposed in the main lagoon). This will also increase holding capacity (storage volume);
- Enhanced and increased salt marsh environment during open conditions and maximized wind fetch to enhance wind-driven circulation during closed conditions;
- Permanent avian islands in A1 & A4. These islands will be designed to afford better protection from predators and will be optimized to suit avian enhancement goals;
- Expanded wetland and marsh acreage by relocating the existing parking lot into degraded upland habitat. The new parking lot will be designed to be permeable to maximize water quality enhancements through naturalized filtration/infiltration;
- Increased flushing of sediments through the connection of the new North Channel;
- Opportunities for new visitor facilities and educational resources.

Figure 32


LTAC Requested: Alternative #1.75
Habitat Plan: Open Conditions @ 1ft Below MSL
Adamson House
Avian Island
Existing Gravel Bar & Snags to Remain
A2 Site
Avian Island
Connection to A2 Site
Avian Island
Legend
Proposed Contours
Existing MSL Contours
Enhanced Parking Lot
Trails
Main Lagoon
>4 Sand Beach
-1 - 4 Intertidal Gravel/Sand Bar
Sites A1 - A4
> 9 Uplands
7 - 9 Coastal Dune and Bluff Scrub
5 - 7 Nontidal Southern Coastal Salt Marsh
3 - 5 Marsh
0 - 3 Mudflat
-2 - 0 Subtidal Softbottom
N
200 100 0 200
Feet

Figure 33

LTAC Requested: Alternative #1.75
Habitat Plan: Closed Conditions @ 5ft Above MSL
Adamson House
Avian Island
Existing Gravel Bar & Snags to Remain
A2 Site
Avian Island
Connection to A2 Site
Avian Island
Legend
Proposed Contours
Existing MSL Contours
Enhanced Parking Lot
Trails
Closed Conditions
-4 - 5 Open Water
5 - 18 Exposed Vegetation
Main Lagoon
>4 Sand Beach
-1 - 4 Intertidal Gravel/Sand Bar
Sites A1 - A4
> 9 Uplands
7 - 9 Coastal Dune and Bluff Scrub
5 - 7 Nontidal Southern Coastal Salt Marsh
3 - 5 Marsh
0 - 3 Mudflat
-2 - 0 Subtidal Softbottom
N
200 100 0 200
Feet

5. ANALYSES OF THE ALTERNATIVES RELATIVE TO LAGOON PROCESSES

Analysis of the performance of alternatives is presented herein. The analysis is presented by discipline, with descriptions of the restoration components of each alternative that lead to anticipated positive results.

5.1. CIRCULATION

5.1.1. *Closed Conditions*

As previously stated, lagoon waters do not effectively circulate when the mouth is closed. The only identified feasible forcing mechanism to move water in the lagoon during closed conditions is to increase the circulation effects of wind. Wind-driven currents in the lagoon can be increased by increasing the forces on the water surface, and by providing appropriate downwind lagoon bathymetry to translate that energy into lateral surface currents and vertical subsurface currents.

The main approach to maximizing wind forces on water is to increase the distance over which wind blows in a constant direction (fetch). The existing fetch could be increased by aligning the west arm(s) in the direction of the wind (east to west), lengthening the lagoon surface water area and maintaining deep enough water along the east shore to allow wind waves to reach the shore unattenuated. Increasing the channel length and orientation will increase the fetch and the heights of wind generated waves thus increasing surface water movement across the lagoon.

Coupled with increasing the fetch and wind wave heights, the lagoon boundary at the downwind end needs to be shaped to conserve wind wave energy and translate it into effective horizontal and vertical surface currents. The lagoon bed must remain relatively deep at the east and south shores to reduce friction losses to wind waves across the surface, and to promote a lateral surface current toward the southeast and a return current toward the west. As water surface elevations rise at the east shore from wind wave set-up, consequently slightly dropping the water surface in the western arms, a return current could occur clockwise toward the west to restore hydraulic equilibrium. Clearing obstructions to flow along the south shore of the lagoon will reduce bed friction losses of the current.

The restoration approach to improve circulation under closed conditions includes the following:

Alternative 1

- **Components:**
  1. Channel widening and deepening and the removal of dead ends.
- **Theorized results:**
  1. Slight improvement of water movement through the western arms compared to existing conditions.
- **Expected results:**
  1. The basic channel planform of multiple and looped channels will still exist thus reducing the flow velocities throughout the entire western lagoon, and closed stagnant conditions will persist or even be exacerbated with this design.

Alternative 1.5

- **Components:**
  1. Reconfiguration of the wetland hydraulic system to provide more open water surface area during closed conditions increasing the wind fetch.
  2. Fewer obstacles to currents along the south lagoon shore.
- **Theorized results:**
  1. Increased wind stress on the water surface and increased water circulation from wind-driven currents.
  2. Maximum probability of a return current from the east shore to the west arms should occur.
- **Expected results:**
  1. Wind-generated waves will increase in size and thus cause amplified effects of a higher water surface and greater wind-induced current along the east shore.
  2. More of a return current from the east shore toward the west shore will occur compared to existing conditions, although its magnitude can only be estimated and cannot be accurately quantified at this time.

Alternative 1.75

- **Components:**
  1. Alternative 1.75 possesses the same components as Alternative 1.5 of a reconfigured wetland hydraulic system to provide more open water surface area during closed conditions increasing the wind fetch.
  2. Fewer obstacles to currents along the south lagoon shore.
- **Theorized results:**
  1. Similar to Alternative 1.5, with the addition of possible return currents through the North Channel as well as along the southern lagoon shore.
- **Expected results:**
  1. Similar to Alternative 1.5, with the addition of possible return currents through the North Channel, although the magnitude of the beneficial effect is uncertain.

Alternative 2

- **Components:**
  1. Alternative 2 also possesses a reconfigured wetland hydraulic system to provide more open water surface area during closed conditions to increase the wind fetch, but it provides a reduced fetch from alternatives 1.5 and 1.75 due to an exposed northwestern peninsula;
  2. A southern salt panne along the south shore that partially blocks return currents.

- **Theorized results:**
  1. Increased wind stress on the water surface and increased water circulation from wind-driven currents.
  2. Reduced probability of a return current to the west from Alternatives 1.5 and 1.75.
  3. Possible return current through the North Channel.
- **Expected results:**
  1. Wind-generated waves along the east shore are essentially the same as for Alternatives 1.5 and 1.75.
  2. A salt panne is proposed along the southern lagoon boundary for this option that would reduce the return current compared to the other alternatives.
  3. Possible return current through the North Channel; the magnitude of the beneficial effect is uncertain.

Alternatives 1.5, 1.75, and 2 include an increased wind fetch. The fetch direction is longest during closed conditions and most closely aligned with the wind direction in Alternatives 1.5 and 1.75. Alternative 1 does not increase the wind fetch and benefit, other than the ancillary effect that wider channels and lower island tops may have to reduce sheltering of the channel to the wind. Calculations presented in Table 4 indicate that Alternatives 1.5 (and 1.75) and 2 may slightly increase the wind driven circulation over existing conditions or Alternative 1.

Table 4. Wind Induced Circulations
(Lagoon Water Level at +5.0 ft MSL)

Wave Parameters	Existing	Alt. #1	Alt.#1.5	Alt. #2.0
Height (ft)	0.12	0.11	0.14	0.14
Period (s)	0.65	0.64	0.72	0.72
Induced Longshore Current (fps)	0.91	0.92	1.04	1.04

Increasing wind-driven circulation is difficult to predict given available technologies for analyses, and considering the relatively small-scale of the Malibu Lagoon system compared to larger systems studied more extensively and serving as the bases of existing models. Thus the prediction of improved wind-driven circulation is only a rough estimate, but is supported by observations made and data recorded at the site in summer of 2004. Clearly the circulation effects of wind will improve with the reconfigured lagoon, but the extent of that circulation improvement is very difficult to quantify with existing available and applicable technology. More extensive analyses could occur, but they may be cost-prohibitive at this stage.

Conclusion for Circulation Under Closed Conditions: Alternatives 1.5 and 1.75 provide the greatest potential for wind-induced circulation to occur throughout the lagoon under closed conditions. Due to the uncertain magnitude of benefits of the North Channel, Alternative 1.5 is determined to perform superior to other alternatives. This conclusion acknowledges that the North Channel may further improve circulation if lagoon monitoring and further analyses indicate it is warranted as an adaptive management device.

5.1.2. *Open Conditions*

Currently, there are three channels in the west lagoon that are narrow, relatively shallow and looped in planform. This channel configuration impedes water flow through the west lagoon and results in dead spots of flow where essentially no water movement occurs. Promoting circulation in the west lagoon under open conditions requires simplifying channel planform to being one main (first-order) channel and possibly several smaller ones branching off of it (higher-order channels). The single first-order channel allows efficient water movement because water is forced through one path along its entire length. All hydraulic energy is maintained within the channel thus maximizing momentum throughout its length and scouring forces on the bed. As water penetrates through one main channel it moves more rapidly than through the three channels that presently exist. This fact is confirmed with observations made at the lagoon in 2004 and numerical modeling as discussed below.

The following points summarize the restoration approach to improve circulation under open conditions:

Alternative 1

- **Components:**
  1. Channel widening and deepening and the removal of dead ends to minimize obstructions and reduce friction losses to tidal flows.
- **Theorized results:**
  1. Slight improvement of water movement through the western arms compared to existing conditions but flow velocities of tidal currents will not be maximized to promote scour of fine sediments.
- **Expected results:**
  1. Numerical modeling indicates that tidal flow velocities and the area of water movement in the channels for Alternative 1 is the same as or less than for existing conditions, and are less than those for Alternatives 1.5, 1.75 and 2.

Alternative 1.5

- **Components:**
  1. First-order stream channel and few second order channels;
  2. The main channel for this alternative and that of Alternative 1.75 is narrower and deeper than that for Alternative 2 and its length is shorter;
- **Theorized results:**
  1. Increased tidal flow velocities into the western lagoon;
  2. Deeper penetration of tidal currents into the western lagoon;
- **Expected results:**
  1. Numerical modeling indicates tidal currents are higher throughout the western lagoon for this alternative than for any other scenario except Alternative 1.75.
  2. Tidal currents penetrate farther upstream for this alternative than for any other scenario except Alternative 1.75.

Alternative 1.75

- **Components:**
  1. First-order stream channel and few second order channels.
  2. The main channel for this alternative and that of alternative 1.5 is narrower and deeper than that for Alternative 2 and its length is shorter.
  3. The North Channel is included.
- **Theorized results:**
  1. Increased tidal flow velocities into the western lagoon.
  2. Deeper penetration of tidal currents into the western lagoon.
  3. Relatively high outgoing flow velocities from the western arms during storm flows from the North Channel.
- **Expected results:**
  1. Similar tidal flow velocity to Alternative 1.5.
  2. Tidal current penetration is similar to Alternative 1.5.
  3. Storm flows from the Cross Creek drain may not be sufficient to increase flow velocities in the west lagoon and the effectiveness of capturing flows from the main creek remains in question, thus the beneficial effect of the North Channel is uncertain.

Alternative 2

- **Components:**
  1. First-order stream channel and few second order channels.
  2. The main channel is wider and shallower in cross-section than for alternatives 1.5 and 1.75.
  3. The main channel is slightly longer than that for Alternatives 1.5 and 1.75.
  4. The North Channel is included.
- **Theorized results:**
  1. Increased tidal flow velocities into the western lagoon.
  2. Increased tidal discharge into the western arms, but with slower velocities due to increased friction compared to Alternatives 1.5 and 1.75.

3. Relatively high outgoing flow velocities from the western arms during storm flows from the North Channel.

- **Expected results:**
  1. Numerical modeling indicates tidal currents are higher throughout the western lagoon for this alternative than for existing conditions and Alternative 1, but are lower than those of Alternatives 1.5 and 1.75.
  2. Tidal discharge into the lagoon is not greater, but is the same as that for Alternatives 1, 1.5, and 1.75 because the incoming discharge is limited by the sill at the lagoon mouth and all alternatives convey the same tidal prism into the western arms.
  3. Storm flows from the Cross Creek drain may not be sufficient to increase flow velocities in the west lagoon and the effectiveness of capturing flows from the main creek remains in question, thus the beneficial effect of the North Channel is uncertain.

Increasing circulation in the west lagoon under open conditions requires simplifying channel planform to one first-order channel and several second-order or higher-order channels. The single first-order channel promotes better hydraulics, as indicated by the results of hydraulic modeling as discussed below. All hydraulic energy is maintained within the channel thus maximizing scouring forces on the bed. Water will be able to penetrate farther into the marsh more rapidly, and drain more efficiently through one main channel than the three channels that presently exist. It is expected that the increased velocity of tidal currents will more effectively scour fine sediments from the channel that may have been deposited by previous storm flows, thereby keeping the channel freer of fine-grained sediments than under existing conditions. Nutrients bound to fine grained sediments are a contributor to eutrophication in the lagoon (Sutula et. al., 2004). Removal of these sediments by scour will reduce eutrophication as well as sediment accretion in the west lagoon.

Alternatives 1.5, 1.75, and 2 include a single first-order stream channel and few second order channels to maximize hydraulic efficiency. Alternative 1 maintains the existing channel network with widening and deepening and the removal of dead ends to minimize obstructions and reduce friction losses to tidal flows. While this may improve water movement through the western arms compared to existing conditions, it may not maximize flow velocities to promote scour of fine sediments.

Analysis of circulation was done using a numerical computer model. Modeling was performed using a one-dimensional numerical model to estimate flow velocities for existing and restored conditions. The computer program uses input data of recorded water levels in the lagoon, lagoon bathymetry and topography, ocean tides and creek flow to predict water surface elevations and flow velocities throughout the lagoon. Data used for modeling of tides were water surface elevations recorded by the Tapia gage at PCH bridge in 2002, along with ocean tide data for the same period recorded by National Oceanic and Atmospheric Administration in Santa Monica Bay. Stream flow data were obtained from the Los Angeles County stream flow gage on Malibu Creek at the confluence of Cold Creek. Slides A7-A15 in Appendix 1 shows the model set-up for the lagoon, and predicted tidal and storm flow velocities for existing conditions and each restoration case. The values on the Figures refer to flow velocities in feet per second, with blue numbers representing inflow velocities (tidal flooding) and red numbers representing outflow (tidal ebbing) velocities.

Tidal flow velocities for existing and restored conditions for all alternatives are shown in Tables 3 and 4 below. The matrices show water flow velocities through the western arms for:

1. Ebbing tidal flows and
2. Flooding tidal flows.

The information is presented as flow velocities in the vicinity of the existing C Channel from the upper ends (inland ends) of the western arms for each alternative through the middle-reaches, and to the lower reaches (seaward ends) of the arms. The circulation objectives of the project are to:

- increase tidal flow velocities to generate increased circulation and water penetration into and out of the western arms, and
- increase storm velocities out of the western arms to promote removal of sediment deposited by storm flows into the western arms.

For both ebbing and flooding tides, existing conditions possess very low flow velocities at the upper ends of the western arms, and increased velocities downstream to a constriction at the footbridge, then decreased velocities at the main lagoon. Alternative 1 shows a similar pattern, without the constriction at the footbridge and overall lower velocities than existing conditions. Alternatives 1.5 and 1.75 result in higher tidal flow velocities throughout the entire reach, even in the more middle and upper portions of the site. The average value of flow velocity is highest for these two scenarios indicating more effective water movement through the site. Alternative 2 also shows higher tidal flow velocities than presently exist, but they are not as high as for Alternatives 1.5 and 1.75 due to its broader channel cross-section.

Another objective of this project is to not modify the temporal pattern of natural openings and closures of the lagoon mouth. As shown in Tables 5 and 6, flow velocities of incoming flooding tides at the lagoon generally exceed those for outgoing ebbing tides. This is indicative of a "flood-tidal dominant system" that experiences net movement of coastal sediment (sand) into the lagoon causing the mouth to be unstable and close relatively soon after opening. This compares to ebb-dominated systems that are more effectively flushed of sand causing their mouths to be more stable and remain open for longer time periods. The stability of the Malibu Lagoon mouth is not modified by any of these alternatives and it should experience similar conditions of openings and closures as presently occur.

Table 5. Results of Circulation Modeling – Ebbing Tides

Alternative	Flow Velocity (in Feet Per Second)					
	Upper Reach	**Upper Mid-Reach**	**Mid-Reach**	**Lower Mid-Reach**	**Lower Reach**	**Average of Reaches**
Existing	0.07	0.06	0.08	0.49	0.14	0.17
1	0.01	0.02	0.03	0.11	0.13	0.06
1.5	0.09	0.76	0.54	0.40	0.27	**0.41**
1.75	0.09	0.76	0.54	0.40	0.27	**0.41**
2	0.43	0.19	0.10	0.05	0.12	0.18

Table 6. Results of Circulation Modeling – Flooding Tides

Alternative	Flow Velocity (in Feet Per Second)					
	Upper Reach	**Upper Mid-Reach**	**Mid-Reach**	**Lower Mid-Reach**	**Lower Reach**	**Average of Reaches**
Existing	0.19	0.29	0.34	1.05	0.26	0.43
1	0.02	0.01	0.03	0.15	0.17	0.08
1.5	0.34	0.45	0.82	0.58	0.36	**0.51**
1.75	0.34	0.45	0.82	0.58	0.36	**0.51**
2	0.88	0.48	0.16	0.10	0.20	0.40

In summary, both incoming and outgoing tidal currents are higher for the lagoon with a single main arm (Alternatives 1.5, 1.75 and 2) than for existing conditions and Alternative 1, and water movement is maintained throughout the entire length of the channel like more of a natural pattern. This increased circulation throughout the entire length of the western arms will lead to increased oxygenation of water and thus greater contact of oxygenated water with the bed, potential removal of sediments, and increased vertical and horizontal movement of water. Water flow velocities are higher and extend over a longer reach of the future western arm for Alternatives 1.5 and 1.75 due to the smaller cross-section throughout the channel.

5.1.3. *North Channel*

Another important option to consider for circulation at the western lagoon is capturing storm flows from the Cross Creek storm drain and/or the main creek and routing them through a new North Channel to the upper end of the west lagoon. This new North Channel is proposed to be situated at the west end of the PCH bridge and within the outlet channel from the Cross Creek drain to only capture drainage from either Cross Creek, the main creek, or both. A removable weir board is proposed to be placed at the upstream end of the North Channel to completely block the Channel from receiving storm flows during the first flush. The weir boards could be removed after the first flush to allow storm flows from either the Cross Creek Drain, the main creek, or both into the North Channel to scour sediments. Flows to the new North Channel are intended to effectively scour fine sediments from the new western arm toward the sea. The weir board provides flexibility for managing the North Channel and provides the option to entirely close the Channel off if it is determined to be undesirable or unnecessary at some future date.

The weir could also be lowered in the dry season to allow for potentially additional circulation through the North Channel from the main lagoon under closed conditions. Under westerly wind condition, water mass will move from the west lagoon to the main lagoon area to form a super-elevation in the eastern bank. The North Channel can theoretically serve as a conduit for the water to return to the west lagoon to supplement any return flow along the southern perimeter of the lagoon. This weir concept would require maintenance actions to raise and lower the crest seasonally.

The potential storm flow discharge from the Cross Creek Drain is estimated to provide a basis for analyses. The estimates are based on assumptions that may or may not prove accurate during storms. Observations by Heal the Bay (HtB) staff (Shuman, Personal Communication, 2005) indicate that stormflows from the drain during severe storms of January and February of 2005 were minimal. This indicates that stormflows from the Cross Creek drain may not effectively scour sediments from the western arms, and that the North Channel should be conceived to also possibly convey a portion of stormflows from the main creek. This lends flexibility to the North Channel for future design, analyses and implementation.

Cross Creek storm drain drains 22 acres of relatively flat and somewhat urbanized area in the City of Malibu (provided by Malibu City Engineer Yugal Lall on 10/19/04). Runoff from the small watershed during a 5-year storm is estimated to generate a peak discharge of 72 cubic feet per second (cfs) according to standard hydrologic calculations specified by LA County. Considering that less discharge may occur from the Drain during a storm based on HtB measurements, this discharge value is assumed to represent potential flows from the main creek as well for purposes of this analysis. Stormflows from the main creek could far exceed the approximate 72 cfs estimate, but this value is a representative discharge utilized for analyses. Greater discharges may not be desirable as they could damage the marsh channel by erosion, and lower discharges may be insufficient to produce the desired scouring effect.

A simplifying assumption of a triangle-shaped hydrograph with the peak flow of 72 cfs was input into the one-dimensional model described above and routed through the North Channel and into the west lagoon during an ebbing tide to quantify the range of flow velocities through the site during idealized conditions. This idealized case is not anticipated to occur frequently, but roughly on the order of every 5 years to reduce the build-up of fine sediments in the upper western arms. The resulting velocities for Alternatives 1.5 (if a future North Channel component were implemented), 1.75 and 2 are shown in Figures 34 and 35, and Tables 7 and 8. Blue numbers in the figures represent ebb flow velocities without connection to the North Channel, while numbers in red represent ebbing/stormflow velocities with connection to the North Channel.

Tables 5 and 6 show that storm flood velocities also vary between alternatives, and that effects of a North Channel increase outgoing storm flow velocities. Storm flows are the primary sediment source to the western arms. Alternatives 1.75 and 2 show the effects of the North Channel, with the highest outgoing flood flow velocities of any alternatives. This beneficial effect is maximized for Alternative 1.75 that possesses the highest outgoing flood flow velocities of any alternatives. The overall channel cross-sectional area is larger for Alternative 2 than for Alternative 1.75 causing flow velocities to be lower. None of the alternatives possess storm flow velocities during a 5-year storm that are high enough to cause damage from erosion.

Table 7. Results of Circulation Modeling – Storm Flows Into Western Arms (5-Year Storm)

Alternative	**Flow Velocity (in Feet Per Second)**					
	Upper Reach	**Upper Mid-Reach**	**Mid-Reach**	**Lower Mid-Reach**	**Lower Reach**	**Average of Reaches**
Existing	0.18	0.29	0.34	1.07	0.10	**0.40**
1	0.09	0.01	0.04	0.18	0.12	0.09
1.5	0.27	0.0	0.70	0.36	0.30	0.33
1.75	0.27	0.0	0.70	0.36	0.30	0.33
2	0.70	0.55	0.18	0.12	0.23	0.36

Table 8. Results of Circulation Modeling – Storm Flows Out of Western Arms (5-Year Storm)

Alternative	**Flow Velocity (in Feet Per Second)**					
	Upper Reach	**Upper Mid-Reach**	**Mid-Reach**	**Lower Mid-Reach**	**Lower Reach**	**Average of Reaches**
Existing	0.06	0.07	0.09	0.65	0.06	0.19
1	0.01	0.02	0.06	0.19	0.41	0.14
1.5	0.06	0.18	0.39	0.29	0.19	0.22
1.75	0.82	0.73	0.90	0.67	0.41	**0.71**
2	0.43	0.76	0.31	0.11	0.22	0.37

As shown in the figures, flow velocities through the western arm are higher with the North Channel than without it. This indicates greater potential for periodic scour of accumulated sediments from the western lagoon during stormflow through the North Channel. This opportunity is significant as it appears to be the only unengineered forcing mechanism available to address the issue of problematic sedimentation at this location.

Figure 34 – Alternative #1.5
(Ebbing Velocity Comparison of with/without 5-yr Drain Flow)

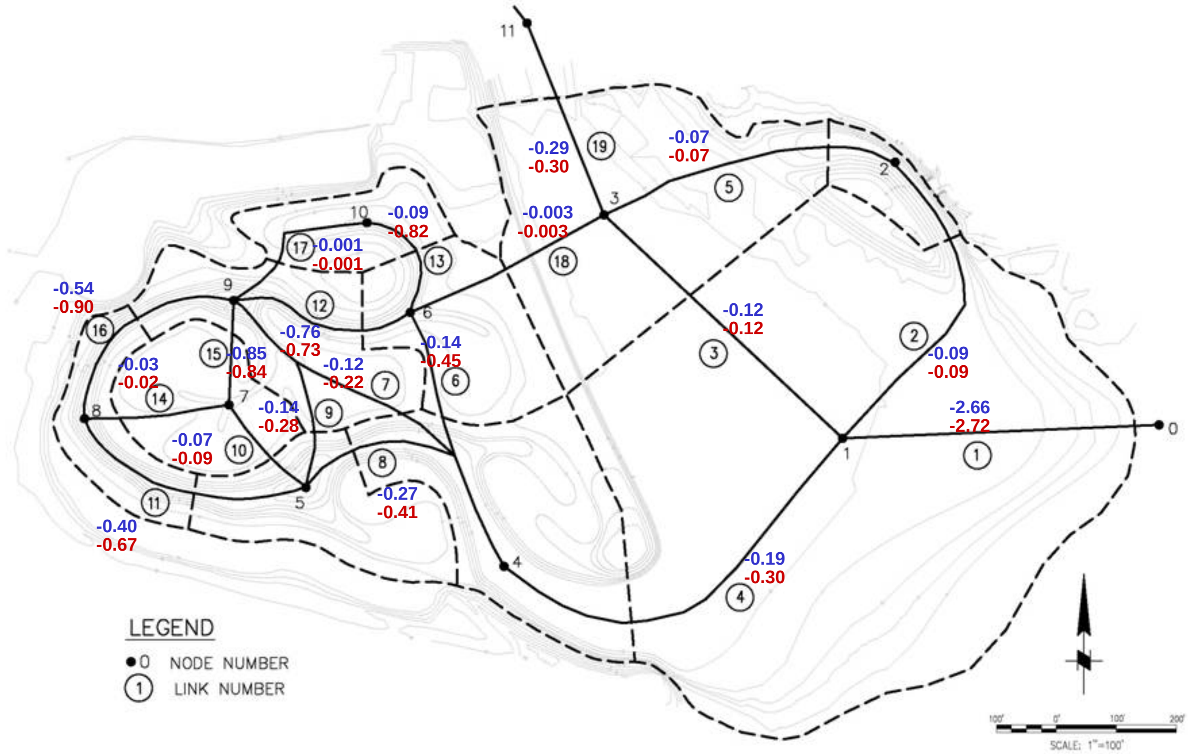
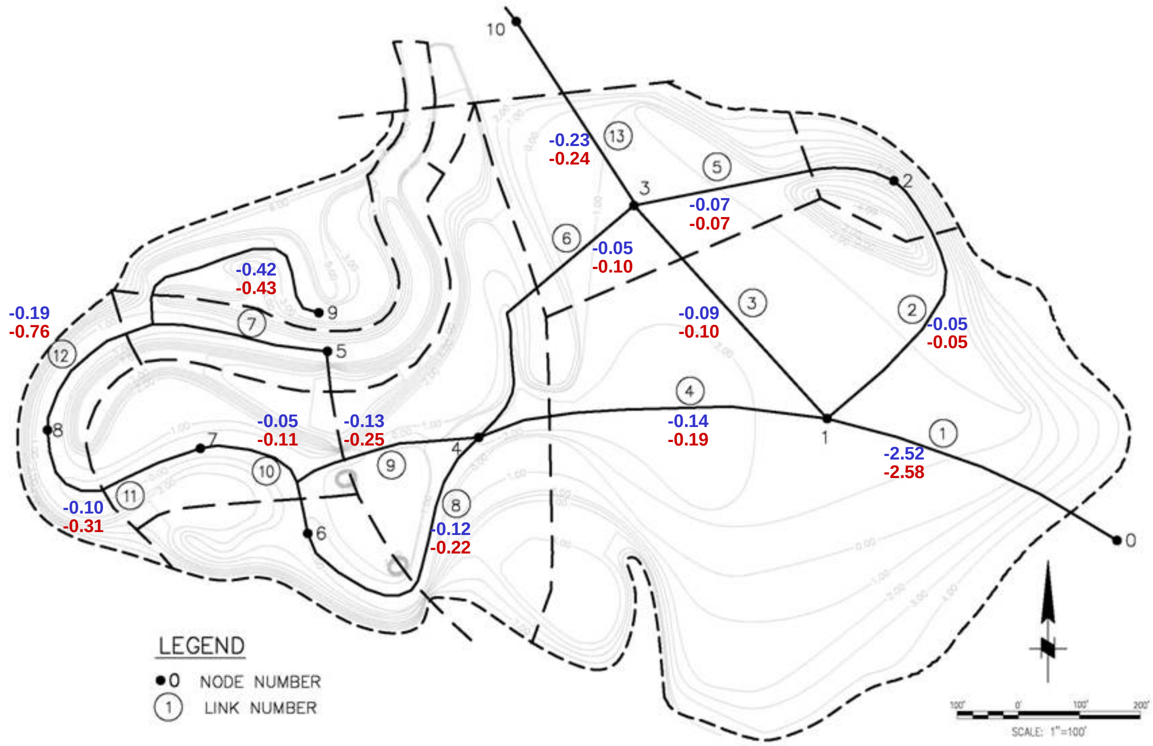


Figure 35 – Alternative #2
(Ebbing Velocity Comparison of with/without 5-yr Drain Flow)



While the North Channel does appear to theoretically provide benefits, it is not without its detriments. Water quality at the sensitive western arm portion of lagoon could potentially be compromised by flows from the North Channel. To understand potential water quality ramifications of using stormflows to flush the western arms, stormflows were sampled on October 20, 2004 following the first significant storm of the season (first flush) at the Cross Creek Drain outlet and the PCH Bridge at the main lagoon. Readings were taken to determine bacterial loads in the creek and in the runoff discharged from the drain. Sample results are summarized in Table 9. The levels of all three indicators at both sampling sites are more than an order of magnitude higher than the State AB411 criteria. Although still in excess of State criteria, the levels of enterococcus and E. coli at the PCH Bridge were an order of magnitude lower than those measured at the Cross Creek Drain.

For comparison, URS Greiner Woodward Clyde conducted a sampling effort of surface water and groundwater contributing to receiving waters in the fall and early winter of 1999 for nutrients and bacteria in the Malibu Lagoon (URSGWC, 2000). The consultants sampled over 20 locations on 6 different occasions from August 2, 1999 to November 29, 1999. The sampling began during lagoon closure and continued through the sand bar breach and lagoon opening. The sampled locations included 3 storm drains discharging directly to the lagoon, including the North Channel drain (station ID SD-2). The nitrogen species (ammonia, nitrate, TKN (total organic nitrogen) concentrations in the effluent from all 3 storm drains are detectable in some samples, but typically below 10 mg/L. The main lagoon sampling site is slightly lower for the N species sampled. Sample site SD-2 (North Channel) ammonia and TKN values exceed 10 mg/L for 3 of the 6 sampling efforts, all of which occur in November during winter rain runoff events. The North Channel sampling also displayed the highest total coliform, fecal coliform and E. coli values for the November sampling relative to the other 2 storm drains, and was an order of magnitude higher than the main lagoon sample site (L-1).

The nutrient and bacteria concentration differences between the Cross Creek Drain and the main lagoon are the result of a dilution effect due to the large volume of water within the Central Lagoon (between approximately 30 and 90 acre-feet depending on tidal stage) relative to the approximate 1 cfs flow discharge from the North Channel that occurred on the day of water sampling in 2004. Cross Creek Drain will contribute relatively poor-quality water to the lagoon, but this effect may only incrementally affect water quality in an adverse way, and may be offset by the benefits of increasing water flow and circulation. The effects of potential bacteria and nutrient loads to the west arms as part of the North Channel should be further evaluated.

With regards to nutrients, the lagoon and west arms are so nitrogen-enriched that the additional contribution from this storm drain on a seasonal or annual basis is insignificant. The slight (if any) increase in the standing biologically available N concentrations in the west arms as a result of this hydrologic change will not increase biological production.   However, the literature consistently supports the fact that increased water circulation will decrease water temperatures, decrease light availability and exponentially decrease biological production at the base of the food chain in eutrophic environments (Monbet 1992, Wetzel 1975, Cloern 1996, Caffrey 2003, etc).

Future sampling may need to be performed to determine if subsequent runoff events are found to have lower bacterial levels. Although this runoff is currently discharging into the lagoon north of the PCH Bridge, the introduction of pollutants into the western arms through the new North Channel may be a cause for concern. These pollutants may be more concentrated in the first flush that is envisioned to be conveyed directly to Malibu Creek and not into the new North Channel.

Table 9. Bacteria Sampling Results

Location	Enterococcus cfu/100ml	Total Coliform cfu/100ml	E.coli cfu/100ml
Cross Creek Drain	19,180	>241,920	155,307
PCH Bridge	4,190	>241,920	11,870
State AB411 Criteria	104	10,000	400

Conclusion for Circulation Under Open Conditions: Alternatives 1.5 and 1.75 provide the greatest tidal flushing and water turnover under open conditions than other alternative configurations. Alternatives 1.75 and 2 theoretically provide the greatest potential for storm flow flushing of sediment from the western lagoon. The magnitude of North Channel scouring effect is uncertain and requires further study. Due to this uncertainty, it is concluded at this time that

Alternative 1.5 performs superior to all other alternatives under open conditions to improve circulation.

5.2. SEDIMENTATION

The western arms experience sedimentation of fine-grained particles and are relatively high in channel bed elevation. Sutula et.al. (2004) showed that portions of the western arms included up to 25% silts and 15% clays (Figure 13 on page 20). The mouths of the western arms are situated and oriented into the flow path of the main lagoon. This enables the arms to receive sediment-laden storm flows. They are also sheltered from scouring by tides or storm flows due to their lack of hydraulic connectivity so deposited sediment is not readily scoured and removed. Potential solutions to this problem involve reducing their exposure to receiving sediment and providing better scouring capacity of frequent flows to remove any deposited fine sediment.

The following points summarize the restoration approach to reduce sedimentation in the western lagoon:

Alternative 1

- **Components:**
  1. Channel widening and deepening and the removal of dead ends to maximize flushing.
- **Theorized results:**
  1. Slight improvement of water movement through the western arms compared to existing conditions to promote increased scour of fine sediments.
- **Expected results:**
  1. Numerical modeling indicates that tidal flow velocities are the same as existing conditions and are insufficient to scour sediments, and are lower than those for Alternatives 1.5, 1.75 and 2.

Alternative 1.5

- **Components:**
  1. One main west lagoon channel connecting to the creek.
  2. The channel opening to the west arms is moved south and angled out of the path of floods on the main creek.
  3. The main channel for this alternative and that of Alternative 1.75 is narrower and deeper than that for Alternative 2 and its length is shorter.
- **Theorized results:**
  1. Less sediment delivered to the western lagoon during floods.
  2. The western lagoon is more protected from sediment delivery by storm flows.
  3. Higher tidal flow velocities to scour sediment from the western lagoon.
- **Expected results:**
  1. Numerical modeling indicates sediment delivery to the western arms will occur, but will be lower in magnitude than for existing conditions and Alternative 2.
  2. Tidal currents are highest throughout the western lagoon for this alternative than for any other scenario except Alternative 1.75, but are insufficient to induce appreciable scour of fine sediments.

Alternative 1.75

- **Components:**
  1. One main west lagoon channel connecting to the creek.
  2. The channel opening to the west arms is moved south and angled out of the path of floods on the main creek.
  3. The main channel for this alternative and that of Alternative 1.5 is narrower and deeper than that for Alternative 2 and its length is shorter.
  4. The North Channel is included.
- **Theorized results:**
  1. Reduced sediment delivery from storm flows on the creek.
  2. Greater protection of the western arms from direct sediment input from the creek.
  3. Higher tidal flow velocities to scour sediments from the western lagoon;
  4. Relatively high outgoing flow velocities from the western arms during storm flows from the North Channel.
- **Expected results:**
  1. Same as Alternative 1.5
  2. As currently designed, the beneficial flushing effect by storm flow conveyed through the North Channel is uncertain and flows may or may not be sufficient to scour sediments.

Alternative 2

- **Components:**
  1. One main west lagoon channel located in the center of the lagoon and oriented at 90 degrees to the creek, similar to existing conditions.
  2. The main channel is wider and shallower in cross-section than for Alternatives 1.5 and 1.75.
  3. The North Channel is included.
- **Theorized results:**
  1. Higher tidal flow velocities to scour sediments from the western lagoon.
  2. Increased tidal discharge from the western arms, but with slower velocities due to increased friction compared to Alternatives 1.5 and 1.75 yet sufficient to induce scour.
  3. Relatively high outgoing flow velocities from the western arms during storm flows from the North Channel.
- **Expected results:**
  1. Numerical modeling indicates that reduced sediment will be delivered to the lagoon compared to existing conditions, but more than will be delivered than for Alternative 1.5 due to the more direct exposure of Alternative 2 to creek storm flows.
  2. Modeling indicates tidal currents are higher than for existing conditions and Alternative 1, but lower than for Alternative 1.5 and tidal currents alone are insufficient to appreciably scour sediment.

3. As currently designed, the beneficial flushing effect by storm flow conveyed through the North Channel is uncertain and flows may or may not be sufficient to scour sediments.

5.2.1. *Reduced Sediment Trapping*

Reducing the western arms exposure to sediment delivery by storms requires the mouths to be moved farther downstream, reorienting the openings to face more directly downstream than perpendicular to the main flow, and improving the hydraulic efficiency of the channels. Preferably, only one mouth and one main channel would exist in a future configuration rather than the three that presently exist. A single main channel will maximize flow velocities and scour potential.

Alternatives 1.5 and 1.75 provide one main opening that is moved farther downstream and oriented away from the effective creek flow path. The opening is also partially protected from direct exposure to the main creek by a low, naturalized berm along the west creek bank from the highway to the south portion of the main lagoon. These alternatives also include a single main lagoon arm extending upstream to maximize flow velocities through the channel. Alternative 2 includes a single main arm located at the central lagoon and oriented into the effective creek flow path. Due to its location and position, Alternative 2 will entrain more sediment and transport it into the west lagoon than Alternatives 1.5 and 1.75. However, it also includes a single main channel which will help to increase tidal flow velocities and associated scour potential. Alternative 1 includes the existing footprint with larger openings and channel cross-sections. This configuration does not provide any benefits to reduced sediment trapping.

5.2.2. *Increased Sediment Expulsion*

Increasing the ability of the western arms to expel sediment deposited by storm flows requires increasing the velocity of water moving through the west lagoon. As discussed above, improved hydraulic efficiency (conveyance) of the channel will result by creating one main channel with few tributaries within the western arms. This is accomplished by limiting the channel network to one first-order main channel and only a few smaller second or higher-order channels. Simplifying the path of flows allows water to more readily penetrate upstream and return downstream, and to retain higher flow velocities than presently occurs at the site. Higher tidal flow velocities will exert greater shear stresses on the bed. Figure 36 shows the ebbing flow velocities needed to scour and transport silts and sands. Tidal flows can scour sand-sized sediments, but are insufficient to cause appreciable bed scour of finer-grained sediments such as silts and clays due to effects of particle cohesion.

Figure 36

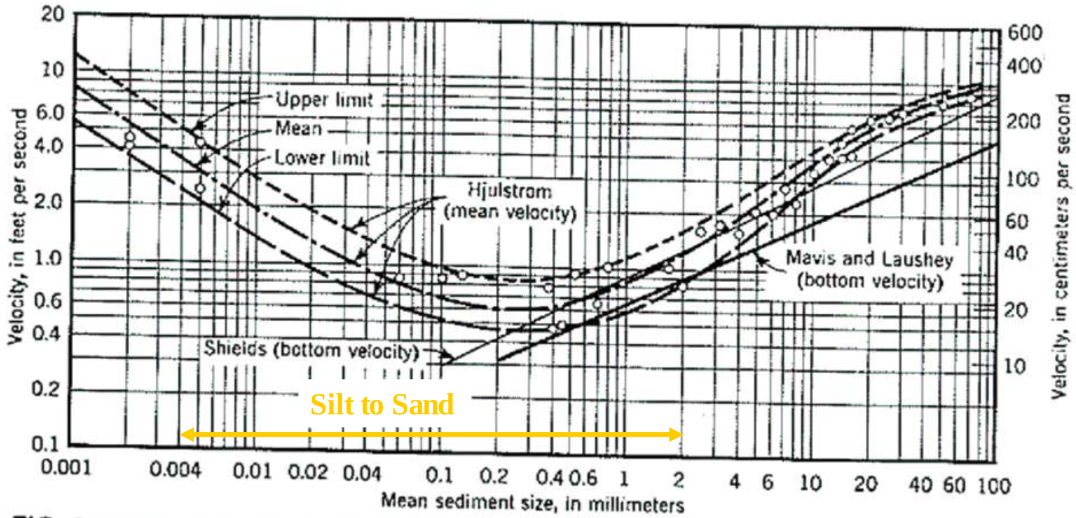


FIG. 2.46.—Critical Water Velocities for Quartz Sediment as Function of Mean Grain Size

Classification	Clay	Silt	Very Fine Sand	Sand
Grain Size (mm)	0.001- 0.004	0.004 – 0.063	0.063 – 0.125	0.125 – 2

As described above, routing the storm flows from the Cross Creek Drain and/or the main creek through the new North Channel may increase scour velocities in the west lagoon, although the magnitude of this effect is uncertain. Concentrating both storm drain and tidal flows together through one main channel will maximize bed scour of fine sediments thus leaving the coarsest grain sizes possible in the west lagoon. Appendix 3 provides detailed analyses of sediment deposition and flushing in the western lagoon under existing conditions and for the alternatives.

Conclusion for Sedimentation: Alternatives 1.5 and 1.75 provide the greatest reduction of sediment delivery from the main creek during storms. No alternatives have the ability to flush the fine-grained sediment out of the western lagoon by tides alone. Alternatives 1.75 and 2 theoretically provide the greatest potential for storm flow flushing of sediment from the western lagoon, but the magnitude of this effect is uncertain and requires further study. Due to this uncertainty, it is concluded at this time that Alternative 1.5 performs superior to all other alternatives at reducing sedimentation.

5.3. NUTRIENT-CYCLING

The extreme nutrient enrichment in Malibu Lagoon has been discussed in Section 3.3. The City of Malibu's reliance on septic systems for wastewater treatment and releases from the Tapia wastewater treatment plant in the upper Malibu Creek Watershed are the primary sources of nutrients to the lagoon (Ambrose and Orme, 2000; Sutula et. al., 2004; CH2MHill, 2000). The success of any physical restoration alternatives that reconfigure the geometry and hydrodynamics of the lagoon are limited on the benefit they will have on the chemical water quality issues inherent with this site. The commitment and adoption of long-term pollutant source reduction efforts will have the greatest benefit to the water quality, nutrient cycling and eutrophication issues present at Malibu Lagoon.   The physical components of each alternative are analyzed below, with attention paid to the potential benefit the physical modification may have on the future water quality of the Malibu Lagoon.

5.3.1. *Reducing Fine Sediment Storage*

Sutula et.al. (2004) have identified that sediment release may contribute as much as 17% of the summer lagoon biologically available nitrogen load. Nitrogen is the nutrient that could potentially limit biological growth in Malibu Lagoon, though at present the levels are too high to restrict productivity rates (Tetra Tech, 2002; Sutula et. al., 2004). The summer sediment regeneration of nitrogen (and phosphorous) is the only source of nutrients that can be impacted by physical restoration design efforts, again comprising 17% of the available summer supply in the west arm of the lagoon.   Nitrogen concentrations adhered to sediments decrease with increasing grain size. Therefore, restoration alternatives were designed with varying degrees of physical components to enhance flow velocities in the western arms, remove fines accumulated in the summer months and deposit relatively coarser bed sediments following the elevated winter flow conditions than existing conditions allow.

The following points summarize the restoration approach to increase nutrient cycling at the lagoon:

Alternative 1

- **Components:**
  1. Widening and deepening of west arm channels from existing conditions.
  2. West arm channels remain oriented perpendicular to Malibu Creek flow patterns.
  3. Channelization of the main lagoon to increase scour and provide an avian island.
- **Theorized results:**
  1. Improved circulation may flush sediment from the western arms to reduce accumulation of fines.
  2. Sediment delivery to the western arms should remain the same as existing conditions.
  3. Increased scour will occur in the main lagoon during storm flows. Course sediment deposition will continue in the main lagoon.
- **Expected results:**
  1. Sedimentation of fines will increase compared to existing conditions due to decreased tidal velocities leading to more nutrient storage in the western arms (Appendix 1, Slide A8).
  2. Opportunities to capture flow energy from winter storm runoff is not maximized by this configuration and thus fine sediment and nutrients delivered to the western arms will remain and not be removed.
  3. The main lagoon retains the character of having coarse bed sediments.

Alternatives 1.5

- **Components:**
  1. A single hydrologic connection of the west arms to the main channel at the southern end of the lagoon that is protected from directly receiving sediment from the creek by being oriented northwest to southeast.
  2. Areas adjacent to the main channel in west arms are lowered in elevation.
  3. Existing conditions are maintained in the main channel.
- **Theorized results:**
  1. Less fine sediment and nutrients will be delivered to the western arms. Hydrologic energy will dissipate as water flows into the west arms but the single channel will increase the transport capacity of water and sediment. Sediments will be courser than present conditions in the western arms.
  2. Deposition of fine sediments on surrounding lower areas in the west arms will occur when flows exceed the capacity of the channel in west arms. There is low potential for summer fines accumulation to be removed during winter flows or tidal exchange.
  3. Increased horizontal and vertical water exchange.
  4. Increased frequency of contact of oxygen-rich water to bed sediments (enhances denitrification).
  5. Coarse sediment deposition will continue in the main lagoon.
- **Expected results:**
  1. Less fines and nutrients will be delivered to the west lagoon during winter stormflows and sediments will be coarser than present.
  2. Fines and nutrients may continue to exist in intertidal areas.
  3. Improved circulation will increase horizontal and vertical water exchange.
  4. Improved circulation will increase the frequency of oxygen rich water to bed sediments.
  5. Coarse sediment will continue to occupy the bed of the main lagoon.

Alternative 1.75

- **Components:**
  1. A single hydrologic connection from the west arms to the main channel at the southern end of the lagoon that is protected from directly receiving sediment from the creek by being oriented northwest to southeast.
  2. Areas adjacent to the main channel in west arms are lowered in elevation.
  3. Existing conditions are maintained in the main channel.
  4. A new hydrologic connection is installed at Highway 1 (North Channel).
- **Theorized results:**
  1. Less fine sediment and nutrients will be delivered to the western arms. Hydrologic energy will dissipate as water flows into west arms but the single channel will increase the transport capacity of water and sediment. Sediments will be courser than present conditions in the western arms and summer fine-grained and organic-rich sediments will be scoured.
  2. Deposition of fine sediments on surrounding lower areas will occur when flows exceed the capacity of the channel in the west arms. Low potential will exist for

summer fines accumulation to be removed from these intertidal areas during winter flows or tidal exchange.
3. Course sediment deposition will continue in the main lagoon.
4. Increased horizontal and vertical water exchange.
5. Increased frequency of contact of oxygen rich water to bed sediments (enhances denitrification).
6. The North Channel will increase storm flows to western arms, increase the transport capacity of flows, and increase the scour potential of summer fines.

- **Expected results:**
  1. Same as Alternative 1.5
  2. As currently designed, the beneficial flushing effect by storm flow conveyed through the North Channel is uncertain and flows may or may not be sufficient to scour sediments.

Alternative 2

- **Components:**
  1. A single hydrologic connection is provided from the west arms to the main channel that is oriented northwest to southeast.
  2. The channel geometry of the west arm is wider and shallower than that for Alternatives 1.5 and 1.75.
  3. A new hydrologic connection is provided at Highway 1 (North Channel).
  4. Deepening of the main lagoon.
- **Theorized results:**
  1. Orientation of the channel connecting west arms to the main channel will maximize the hydrologic energy conservation from winter storm flows and increase sediment transport capacity of flows entering and exiting the west arms. Sediments will be courser than present conditions in the western arms.
  2. Though scour in the west channel will be lower than in the west channels in Alternatives 1.5 and 1.75, a more uniform channel scour may result in a greater area of the west arm having larger grain size deposition and being subject to removal of accumulated summer organic materials.
  3. Increased horizontal and vertical water exchange.
  4. Increased frequency of contact of oxygen rich water to bed sediments (enhances denitrification).
  5. Flushing of the western arms of fines and nutrients by stormflows from the North Channel.
  6. Potential loss of sediment transport capacity in the main lagoon and aggradation.

- **Expected results:**
  1. Sediments will be courser than present conditions in the western arms as evidenced by numerical modeling results.
  2. An incrementally larger area of the west arm will have larger grain sizes in the bed compared to other alternatives (benefits are considered similar to or slightly greater than for Alternatives 1.5 and 1.75).
  3. Increased horizontal and vertical water exchange.
  4. Increased frequency of contact of oxygen rich water to bed sediments (enhances denitrification).
  5. As currently designed, the beneficial flushing effect by storm flow conveyed through the North Channel is uncertain and flows may or may not be sufficient to scour sediments.

5.3.2. *Maintaining and Not Increasing the Seasonal Period of the Closed Lagoon*

Two years of research (Sutula et. al, 2004) suggest that submerged aquatic vegetation (SAV) and algae growth are less rapid or extensive if lagoon closure does not occur earlier than normal in the year limiting its ability to utilize optimum growing conditions. However, observations by the project team show that the lagoon closed in July in 2004 (relatively later in the year) and SAV growth was still extensive, suggesting a possibly more complex relationship. Increasing the tidal prism throughout the lagoon will benefit the site because:

1. Increasing the frequency of sediment water contact with oxygenated seawater will provide oxygen to the surface sediments and increase the potential for dentrification (discussed below);
2. Increased turnover of lagoon water improves water quality;
3. More water in the lagoon leads to better water mixing and exchange than present; and
4. Increasing water storage will further dilute the concentrations of nutrients loaded to the system every year from key sources and could eventually reduce the degree of eutrophication.

The approach to maintaining and not reducing the period of time the lagoon is open is by maintaining or only slightly increasing the lagoon’s tidal prism, or volume of seawater exchange between mean high and low tides. The method to slightly increase the tidal prism is to reconfigure the lagoon to expand the storage area between approximately –3 feet and +3 feet relative to msl (roughly the mean low and high tidal elevations in Southern California, respectively, for a mean range of approximately six feet). The mean tidal elevations and tide range is compressed for Malibu Lagoon because the sill at the mouth truncates (perches) low tides in the lagoon and decreases the tidal range to approximately three feet (from 0 feet to +3 feet msl). Alternatives 1.5, 1.75 and 2 increase the tidal prism slightly (less than five percent) over existing conditions and should maintain the opening for the same time period as presently occurs. Alternative 1 does not appreciably increase the tidal prism, although the western lagoon is lowered in elevation, because a large and high nesting island is proposed in the main lagoon to offset lowering elsewhere. The alternatives do not expand the lagoon storage capacity sufficiently (less than one percent of storm runoff volume for a five-year storm) to cause it to breach more or less frequently than presently occurs.

Conclusion for Nutrient Cycling: Alternatives 1.5 and 1.75 will receive less direct sediment and nutrients delivery to the western arms, will experience greater vertical and horizontal water exchange, and will increase the time of oxygen rich water contact with the bed sediment from improved circulation under all conditions. Alternatives 1.75 and 2 theoretically provide the greatest potential for storm flow flushing of sediment from the western lagoon, but the magnitude of this effect is uncertain and requires further study. Due to this uncertainty, it is concluded at this time that Alternative 1.5 performs superior to all other alternatives at reducing sedimentation.

5.4. EUTROPHICATION

The most effective way to reduce primary production in Malibu Lagoon will be through source control of the primary nutrient loads, watershed sources and adjacent septic systems which are all outside the scope of this project. However, there are physical alterations that can be made to Malibu Lagoon to decrease the biological production rates for a given standing nutrient supply. As discussed in Section 3.1, circulation has a profound effect on the availability of nutrients and the resulting primary production rates that lead to eutrophic conditions. Improving circulation to the western lagoon during open conditions will increase the frequency that oxygen-rich waters interact with the surface sediments thereby increasing the potential for denitrification (net loss of the limiting nutrient N from the surface sediments). Benefits of enhancing wind mixing during closed conditions and modifying channel geometry to reduce eutrophication are described below.

5.4.1. *Wind Mixing During Closed Conditions*

In the closed summer lagoon, the mechanical water mixing energy of tides and fresh water inflow are virtually eliminated, leaving wind mixing as the only forcing mechanism. Maximizing the surface water circulation generated by wind during closed conditions will accomplish three goals:

1. Reduction of daily maximum surface water temperatures (decreased primary productivity rates);
2. Introduction of atmospheric oxygen into the surface layer of the water column for higher dissolved oxygen levels in the water; and
3. Deepening of the surface water mixing zone and potentially alleviating stratification to a certain extent.

5.4.2. *Channel Geometry and Impacts to Open and Closed Conditions*

The presence of narrow deep channels in Malibu Lagoon results in decreased horizontal water exchange (an existing problem in the western arms), stratification, and concentration of organic detritus on the channel beds due to their small surface area. Stratification limits the reservoir of oxygen available for respiration of bacteria in the bottom waters, and narrow channels exacerbates stratification as well as concentrating the organic matter to be respired into a much smaller area.

Also, increasing the period of time that intertidal areas are subaerial and exposed to the atmosphere oxygenates the soil and pore waters. Alternatives that propose flatter slopes of intertidal areas during open conditions will increase the area of mudflat exposed to the air. This effect will enhance denitrification in the soil and soil moisture.

Finally, minimizing narrow deep channels in Malibu Lagoon will accomplish three goals from a water quality perspective:

1. Reduced stagnation of waters by improving the horizontal water mixing and exchange in all directions during closed conditions. This exchange may be enough to eliminate stratification measured by the project team in October of 2004 and increase oxygen availability in the bottom waters. This would increase nitrogen removal via denitrification by the processes described in the Denitrification section (section 3.5.1).
2. Maximized surface mixing by wind as described above.
3. Improved tidal exchange and mixing in these areas during open conditions.

The following summarizes the restoration approach to reduce eutrophication under closed conditions:

Alternative 1

- **Components:**
    1. Deepening of existing channels.
    2. Channelization in the main lagoon.
- **Theorized results:**
    1. Tidal flushing of west arms during open conditions may slightly improve over existing conditions.
    2. No improvement to closed condition circulation, which may decrease water quality in the main lagoon relative to existing conditions due to channelization and potential stagnation.
- **Expected results:**
    1. Tidal flushing is not improved in this alternative than existing conditions.
    2. Deeper and narrower channels will exacerbate stratified conditions during closed conditions.
    3. The relatively small bed surface areas of channels will concentrate organic matter detritus into smaller areas in shallow sediments, increasing anoxic conditions in bottom waters during closed conditions.

Alternative 1.5

- **Components:**
    1. A single channel configuration in the west arms with lower elevations of adjacent intertidal areas relative to Alternative 1, with the maximum water surface area during closed conditions relative to other alternatives and existing conditions.
    2. Existing conditions remain in the main lagoon.
- **Theorized results:**
    1. Improvement to closed condition circulation by expanding the open water surface subjected to wind mixing.
    2. Open water conditions in the west arms will improve horizontal and vertical water exchange.

3. Increased frequency of tidal flushing and oxygenated water/sediments interactions in the west arm during open conditions but not as optimal as Alternatives 1.75 and 2 that possess the North Channel connection.

- **Expected results:**
  1. Circulation during closed conditions will improve horizontal and vertical water exchange.
  2. Increased frequency of tidal flushing will oxygenate water/sediments interactions in the west arm during open conditions.
  3. The main lagoon remains unchanged.

Alternative 1.75

- **Components:**
  1. A single channel configuration in the west arms with lower elevations of adjacent intertidal areas relative to Alternative 1, with the maximum water surface area during closed conditions relative to other alternatives and existing conditions.
  2. Existing conditions remain in the main lagoon.
  3. The North Channel is added to the lagoon configuration.
- **Theorized results:**
  1. Improvement to closed condition circulation by expanding the open water surface subjected to wind mixing.
  2. Open water conditions in the west arms will improve horizontal and vertical water exchange.
  3. Maximum frequency of tidal flushing and oxygenated water/sediments interactions in the west arm during open conditions.
  4. The North Channel adds water movement from water slope variations as wind pushes water east and west arms will fill with water from both the southern perimeter and the North Channel.
- **Expected results:**
  1. Same as Alternative 1.5.
  2. As currently designed, the beneficial flushing effect by storm flow conveyed through the North Channel is uncertain and flows may or may not be sufficient to scour sediments.

Alternative 2

- **Components:**
  1. A wider single channel is proposed through the west lagoon than for Alternatives 1.5 and 1.75.
  2. The North Channel hydrologic connection is proposed between the main lagoon and the west arm.
- **Theorized results:**
  1. A slightly wider channel in the west arm will enhance horizontal water exchange at depth.
  2. Improved circulation and water exchange during closed conditions will occur from existing conditions and Alternatives 1 and 1.5 due to the North Channel connection.

3. Connection to the North Channel and removal of constrictions at downstream ends of western arms will improve the frequency of tidal and stream flow interactions (oxygen rich water) with the west arms, maximizing the potential for denitrification in shallow sediments.

- **Expected results:**
  1. A slightly wider channel in the west arm will enhance horizontal water exchange at depth, but only incrementally over Alternatives 1.5 and 1.75.
  2. Improved circulation and water exchange during closed conditions will occur from existing conditions and Alternatives 1 and 1.5 due to the North Channel connection, but the magnitude of this benefit is uncertain, and a barrier in the west lagoon dissects it from the main lagoon, preventing complete mixing.
  3. Connection to the North Channel and removal of constrictions at downstream ends of western arms should improve the frequency of tidal and stream flow interactions (oxygen rich water) with the west arms, maximizing the potential for denitrification in shallow sediments, but the magnitude of this effect is unknown.

Conclusion for Eutrophication: Alternatives 1.5 and 1.75 will maximize wind mixing during closed conditions, while channel configurations maximize frequency of oxygen rich water exchange in all areas of lagoon during open conditions. These conditions enhance the potential for denitrification. While the North Channel may theoretically provide additional circulation during closed conditions, it is not possible at this time to accurately quantify the circulation benefit gained from his additional feature, and therefore the magnitude of this effect is uncertain and requires further study. Due to this uncertainty, it is concluded at this time that Alternative 1.5 performs superior to all other alternatives at reducing eutrophication in the western lagoon.

5.5. HABITAT AND JURISDICTIONAL WETLANDS

The evaluation of habitat differences for the four alternatives includes a consideration of both the extent of impact to existing lagoon habitat resources as well as the habitat benefits that each alternative would provide.

5.5.1. *Impact to Existing Habitat*

The existing habitat acreages are summarized on Figure 25 (p. 34). Existing vegetation that has developed in the study area is the result of numerous interacting factors including natural and human induced physical, chemical, and biologic forces. These include variable soil conditions, variable inundation regimes, fluctuating nutrient loading, dynamic sedimentation and erosion environments, as well as vegetation trampling and restoration efforts. However, predictive habitat development modeling used in the present effort relies on simplified assumptions driven by physical hydrologic environmental conditions based on elevation. Modeling takes into account the relative frequency of disturbance resulting from annual hydrologic cycles, but it does not consider less predictable effects. Modeling employed for the current study is static and determinant relative to the outcome of vegetation development and as a result the modeling does not address serial habitat succession following disturbances. Further, modeling employed does not address alternative outcomes based on anthropogenic factors such as restoration efforts, or differential soil and drainage environments that may exist on-site or which may be developed during final design phases of restoration planning.

Because of the coarse nature of habitat modeling using physical environmental factors, it is not possible to fully predict habitat outcomes to the same degree as would be represented in a natural habitat mosaic. As a result, predicted habitat outcomes are simplified from those represented under existing conditions. This simplification is accomplished by combining existing mapped vegetative communities into fewer more general modeled habitat classes that can be more accurately predicted based on physical environmental conditions. Vegetation classes were combined as demonstrated in Table 10, Figures 37, 38 and 25 (p. 36).

Table 10. Mapped Vegetative Communities and Modeled Habitat Outputs

Mapped Vegetative Communities	Modeled Habitat Outputs
Brackish Marsh Coastal and Valley Freshwater Marsh	Marsh
Disturbed Habitat	Disturbed Habitat
Mudflat	Mudflat
Non-native Grassland	Non-native Grassland
Open Water	Unveg. Mud Bottom Unveg. Sand and Gravel Bottom
Sand Beach/Sand Bar	Intertidal Gravel/Sand Bar Supratidal Sand/Gravel Beach
Southern Coastal Salt Marsh Salt Panne	Alkali Meadow
Southern Sycamore-Alder Riparian Woodland Southern Willow Scrub Mulefat Scrub	Riparian Woodland
Urban Developed	Urban Developed
Venturan Coastal Sage Scrub Mixed Scrub Baccharis Scrub Atriplex Scrub	Coastal Dune/ Bluff Scrub

Figure 37


Existing Situation
Habitat Plan (No Project): Open Conditions @ 1ft below MSL
Adamson House
Legend
Existing Habitats
Roads and Parking
Trails and Disturbed Habitat
Riparian Habitats
Uplands
Coastal Dune and Bluff Scrub
Alkali Meadow
Freshwater Marsh
Brackish marsh
Mudflat
Subtidal Softbottom
Subtidal Gravel/Sand Bar
Intertidal Gravel/Sand Bar
Sand Beach
Ornamental Landscape OR Unvegetated
N
200 100 0 200
Feet

Figure 38


Existing Situation
Habitat Plan (No Project): Closed Conditions @ 5ft above MSL
Adamson House
Legend
Closed Conditions
-4 - 5 - Open Water
>5
Existing Habitats
Roads and Parking
Trails and Disturbed Habitat
Riparian Habitats
Uplands
Coastal Dune and Bluff Scrub
Alkali Meadow
Freshwater Marsh
Brackish marsh
Mudflat
Subtidal Softbottom
Subtidal Gravel/Sand Bar
Intertidal Gravel/Sand Bar
Sand Beach
Ornamental Landscape OR Unvegetated
N
200 100 0 200
Feet

For purposes of analysis, the anticipated habitat characteristics were modeled for each restoration alternative. GIS spatial tools were utilized to predict future habitat/vegetative communities using ground surface elevation and associated lagoon inundation frequencies and water levels. This analysis enables the comparison between existing conditions and predicted future outcomes for each restoration alternative during open and closed conditions. Existing conditions and predicted outcomes for each restoration alternative at low tide open condition (-1 foot msl water level) are shown in Table 11. Percent change in vegetative communities is also demonstrated. Each of the restoration alternatives shows an increase in the percentage of marsh habitat. In addition, the restoration alternatives result in a decreased amount of non-marsh and disturbed acreage.

Notwithstanding the benefits of evaluating likely habitat results using inundation frequencies, water levels, and ground surface elevations, it is recognized that Malibu Lagoon is characterized by alternating hydrologic states. The timing of changes between open and closed conditions and rate and elevation to which water pools under closed conditions cannot be predicted on a highly accurate basis. For this reason, the habitat composition predicted to occur within an elevation range that is most substantially affected by alternating hydrologic conditions (i.e., mudflats and marsh) are likely to be characterized by a dynamic mosaic through time and would be expected to evolve based on long-term climatic and run-off patterns. Given this condition, one likely state of habitat composition has been presented in Tables 11-14. However, it is most appropriate to consider mudflat and marsh as a single habitat complex comprising the elevation range from 0-5 feet msl within quiescent waters of the lagoon. As such, comparisons of alternatives should not only consider the presented distribution of habitats under the various alternatives, but also, the cumulative area of the mudflat and marsh complex presented in the subsequent tables.

Table 11. Entire Lagoon: Open Conditions at Water Level of 1 ft below MSL

Entire Lagoon-Open Condition, -1' water level						
		Existing	**1**	**1.5**	**2**	**1.75**
Habitat Type	**Eleva-tion**	**Acres**	**Acres**	**Acres**	**Acres**	**Acres**
Subtidal Gravel/Sand Bar	-2 - -1	0.13	5.30	0.00	7.46	0.00
Intertidal Gravel/Sand Bar	-1 - 4	12.55	6.81	10.25	6.24	10.25
Sand Beach	4 - 6	1.95	2.91	4.45	1.38	4.45
Subtidal Softbottom	-2 - 0	0.51	3.59	0.29	2.24	0.29
Mudflat*	0 - 3	4.77	4.06	5.59	6.37	5.04
Marsh*	3 - 5	.98	2.37	5.08	3.17	5.86
Alkali Meadow	5 - 7	4.95	1.68	3.28	2.02	3.37
Riparian	varies	1.97	1.63	0.41	0.13	0.35
Impounded Brackish Pond**	-2 - 5	0	0	0	0	0
Wetland Habitat		**27.81**	**28.34**	**29.63**	**29.03**	**29.59**
Coastal Dune/Bluff Scrub	7 - 9	1.32	1.91	1.22	1.81	1.11
Uplands/Non-Native Grassland	>9	0.54	0.01	1.09	1.25	1.09
Roads/Parking/Disturbed/ Trails		2.03	1.98	0.40	0.35	0.40
Turf & Ornamental		0.89	0.34	0.54	0.15	0.39
Non-wetland habitat		**4.78**	**4.25**	**3.25**	**3.56**	**2.99**
Total Area		**32.59**	**32.59**	**32.59**	**32.59**	**32.59**
Wetland change from existing		**0.00%**	**1.92%**	**6.54%**	**4.38%**	**6.42%**

* See textual discussion of the relationship of these habitats elements to hydrologic conditions of the lagoon. Acreage values should be viewed as a total habitat estimate for a complex of mudflat/ marsh.

** Impounded brackish pond is the closed lagoon alternate state for habitats below the 5 foot msl elevation.

During closed, high water conditions (5 foot msl water level), more of the lagoon is submerged in all of the alternatives than in the existing configuration as shown in Figure 44. The decrease of exposed acreage in the alternatives, from that observed under existing conditions, is a result of the lowering of ground elevation to increase available marsh habitat (and wind fetch for circulation) as proposed for the restoration alternatives. Under closed conditions, lower elevation marsh and unvegetated mudflats/gravel bars, etc. are submerged if they occur below the pool elevation of the brackish water impoundment. As such, these environments are incorporated into an Impounded Brackish Pond habitat class. While these areas are nominally considered brackish pond during closed conditions, it should be noted that a significant portion of the habitat is only slightly below the +5 foot inundation elevation used in the open condition analyses (Figure 43), and while the ground surface elevation is used for purposes of analyses, these areas would typically support some emergent vegetation, and shallow habitat suitable for use by wading marsh and shorebirds, as well as dabbling waterfowl. Alternatives with the most extensive habitat falling between +3 and +5 foot msl are Alternatives 1.75 followed by Alternative 1.5, however, all alternatives have greater habitat in this zone than do the existing conditions (Table 11).

Table 12. Entire Lagoon: Closed Conditions at Water Level of 5 ft above MSL

Entire Lagoon-Closed Condition, 5' msl water level						
		Existing	**1**	**1.5**	**2**	**1.75:**
Habitat Type	Elevation	Acres	Acres	Acres	Acres	Acres
Subtidal Gravel/Sand Bar	-2 - -1	Submerged	Submerged	Submerged	Submerged	Submerged
Intertidal Gravel/Sand Bar	-1 - 4	Submerged	Submerged	Submerged	Submerged	Submerged
Sand Beach	4 - 6	Submerged	Submerged	Submerged	Submerged	Submerged
Subtidal Softbottom	-2 - 0	Submerged	Submerged	Submerged	Submerged	Submerged
Mudflat	0 - 3	Submerged	Submerged	Submerged	Submerged	Submerged
Marsh	3 - 5	Submerged	Submerged	Submerged	Submerged	Submerged
Alkali Meadow	5 - 7	4.95	1.68	3.28	2.02	3.37
Riparian	varies	1.97	1.63	0.41	0.13	0.35
Impounded Brackish Pond*	-2 - 5	20.89	25.04	25.95	26.87	25.88
Wetland Habitat		**27.81**	**27.36**	**29.63**	**28.77**	**30.11**
Coastal Dune/Bluff Scrub	7 - 9	1.32	2.06	1.25	2.46	1.12
Uplands/Non-Native Grassland	>9	0.54	0.78	0.58	0.22	0.25
Roads/Parking/Disturbed/Trails		2.02	2.02	1.13	1.13	1.13
Turf & Ornamental		0.89	0.38	0.00	0.00	0.00
Non-wetland habitat		**4.78**	**4.25**	**3.25**	**3.56**	**2.99**
Total Area		**32.59**	**32.59**	**32.59**	**32.59**	**32.59**
Wetland change from existing		**0.00%**	**1.92%**	**6.54%**	**4.38%**	**6.42%**

* Impounded brackish pond is the closed lagoon alternate state for habitats below the 5 foot msl elevation.

To further clarify the gains and losses of habitats, it is worthwhile examining the habitats anticipated under each alternative and the existing conditions within the various regions of the lagoon. The west lagoon (A1) and east lagoon near the Adamson House (A4) have been separated to permit the evaluation of vegetative community changes in each area of these areas (Tables 13 and 14). Habitats are presented for an open lagoon system since this condition allows for the greatest distinction in habitat classes. Under a closed condition, all habitats below an elevation of +5 foot msl would be considered impounded brackish pond.

To assist in clarifying how habitats differ for the alternatives, each table includes not only the area of each habitat, but also the change in overall wetland habitat. In the west and east lagoon areas, it is clear that an increase in wetlands occurs under some alternatives, while for the main lagoon, the amount of wetland habitat does not change substantively even though changes to the landform are contemplated. This is the case since both the existing habitat and the proposed resultant habitat under the various alternatives fall within the broader wetland habitat category.

For the west lagoon (A1), gains in habitat are greatest under Alternative 1.75, followed by Alternative 1.5 and 2 with very limited gains being seen in Alternative 1. As a percentage of the total, these patterns of wetland gain are reversed in the much smaller A4 area where Alternative 1 and 2 show similar gains and Alternatives 1.5 and 1.75 show approximately half as much wetland gain. However, on an area basis, the 1.54-acre A4 area accounts for a very limited extent of habitat so the quality of enhancement may be far more important than the quantity (total area) of expanded wetland. In the case of Alternatives 1 and 2 a fully isolated island environment would be created, while under Alternatives 1.5 and 1.75, a partially isolated island environment would be created. In both cases, a water barrier would exist between the east bank and a small island during closed conditions. However under open conditions, greater island isolation would exist under Alternatives 1 and 2.

Table 13. Habitat Changes at West Lagoon (A1)

A1 West Lagoon					
	Existing	1	1.5	2	1.75
Habitat Type	**Acres**	**Acres**	**Acres**	**Acres**	**Acres**
Wetlands and Waters					
Subtidal Gravel/Sand Bar	0.00	0.00	0.00	0.00	0.00
Intertidal Gravel/Sand Bar	0.00	0.00	0.00	0.00	0.00
Sand Beach	0.00	0.00	0.00	0.00	0.00
Subtidal Softbottom	0.51	3.25	0.24	1.84	0.24
Mudflat*	4.02	3.43	4.59	5.77	4.07
Marsh*	0.80	1.99	4.86	2.76	5.61
Alkali Meadow	4.50	1.48	2.88	1.95	2.97
Riparian	1.93	1.62	0.39	0.13	0.34
Upland Habitats					
Coastal Dune/Bluff Scrub	1.25	1.90	1.21	1.81	1.10
Uplands/Non-Native Grassland	0.54	0.01	1.09	1.25	1.09
Roads/Parking/Disturbed/Trails	2.02	1.98	0.40	0.35	0.40
Turf/Ornamental	0.38	0.28	0.28	0.08	0.13
Total Area	**15.95**	**15.95**	**15.95**	**15.95**	**15.95**
Percent Wetland Habitat	**73.73%**	**73.77%**	**81.33%**	**78.14%**	**82.92%**
Wetland Change from Existing	**0.00%**	**0.03%**	**10.30%**	**5.97%**	**12.45%**

* See textual discussion of the relationship of these habitats elements to hydrologic conditions of the lagoon. Acreage values should be viewed as a total habitat estimate for a complex of mudflat/ marsh.

Table 14. Habitat Changes at East Lagoon (A4)

A4 Adamson					
	Existing	1	1.5	2	1.75
Habitat Type	**Acres**	**Acres**	**Acres**	**Acres**	**Acres**
Wetlands and Waters					
Subtidal Gravel/Sand Bar	0.00	0.00	0.00	0.00	0.00
Intertidal Gravel/Sand Bar	0.00	0.00	0.00	0.00	0.00
Sand Beach	0.00	0.00	0.00	0.00	0.00
Subtidal Softbottom	0.00	0.34	0.05	0.40	0.05
Mudflat*	0.35	0.56	0.62	0.58	0.57
Marsh*	0.18	0.38	0.22	0.41	0.24
Alkali Meadow	0.39	0.20	0.38	0.07	0.38
Riparian	0.04	0.00	0.01	0.00	0.01
Upland Habitats					
Coastal Dune/Bluff Scrub	0.07	0.00	0.00	0.00	0.00
Uplands/Non-Native Grassland	0	0.00	0.00	0.00	0.00
Roads/Parking/Disturbed/Trails	0	0.00	0.40	0.00	0.00
Turf/Ornamental	0.51	0.06	0.27	0.07	0.27
Total Area	**1.54**	**1.54**	**1.54**	**1.54**	**1.54**
Percent Wetland Habitat	**62.34%**	**96.01%**	**82.50%**	**95.06%**	**82.50%**
Wetland Change from Existing	**0.00%**	**54.01%**	**32.34%**	**52.49%**	**32.34%**

* See textual discussion of the relationship of these habitats elements to hydrologic conditions of the lagoon. Acreage values should be viewed as a total habitat estimate for a complex of mudflat/ marsh.

5.5.2. *Jurisdictional Wetland Impacts*

Each of the three alternatives would result in somewhat differing habitat and jurisdictional wetland impacts. These differing impacts do not consider construction work area requirements, as these are not fully identifiable at this time. Rather, the defined areas represent the extent of habitat that would be altered to modify elevations or which would otherwise be converted to a differing habitat under the project. Habitat changes and respective habitats are illustrated in Figures 27 through 34 and are quantified in tables in Tables 11 through 14.

Alternative 1 was designed to be the least expensive option and therefore envisions placing dredged sediments into the central lagoon. This placement of materials can skew the impact evaluation when the entire lagoon is assessed as a single unit. Therefore, the west arms have been isolated during analyses as this is the habitat of concern that would be most impacted by restoration actions. While Alternative 1 reflects an enhancement of the existing lagoon and would be expected to have a relatively minor impact to the lagoon, the proposal to enhance habitat conditions under this alternative would result in changes in elevation for much of the vegetated islands and shoreline of the lagoon and also includes modification to the central gravel shoal in the main lagoon. As a result, the extent of construction impact from this alternative is similar to that of Alternative 2 that also includes substantial work within the main lagoon. For Alternatives 1.5 and 1.75, the extent of work is similar and, as a result of limited work in the main lagoon, these alternatives have substantively smaller construction footprints than do the other alternatives (Figure 27-34). If only impacts to the western lagoon are considered, construction impacts are least for Alternative 1, slightly greater for Alternative 1.5, and still greater for the other two alternatives.

Jurisdictional wetland impacts will occur from each alternative as a result of reworking existing wetlands and uplands to either restore or create new wetland and upland habitats. As such, impacts will occur throughout much of the entire lagoon, but will be compensated by the benefits that will result from overall project improvement. The degree of impact from the different alternatives generally follows the trend of impacts to lagoon habitats. Essentially more excavation will occur with Alternative 2 as the west arm channel is larger and deeper than other alternatives, and the bar at the main lagoon is removed thus causing a greater level of impact. For Alternative 1, the footprint of change within the west lagoon may be less than that occurring for the other alternatives, however this alternative includes deepening and expansion of the main lagoon channels and reduction of upland elevations with deposition of material on the central lagoon shoal. As a result, this alternative would also result in extensive construction period modification to existing wetland habitats. The least impacting alternatives if overall earthwork and construction impacts are considered are Alternatives 1.5 and 1.75 as less extensive excavation will occur combined in the western arms and the main lagoon. These conclusions are presented in more detail in Table 16 in Section 5.8.

5.5.3. *Habitat Benefits*

Habitat enhancement focuses on opportunities to enhance aquatic habitat conditions, enhance marsh vegetation diversity and persistence, improve habitat connectivity, provide suitable tidewater goby habitat, maintain steelhead migration habitat, enhance avian habitat, and reduce terrestrial predator encroachment. In addition, the reduction of mosquito vectors has been included under habitat enhancements.

Aquatic Habitat Enhancement

The opportunities for improving aquatic habitat conditions within the lagoon are inextricably tied to opportunities and constraints to manage lagoon hydrology, modify lagoon basin morphology, and enhance water quality. Each of the alternatives differ in their capacity to address habitat conditions through physical site modifications. Key to improvements of the aquatic system are improvements resulting in reduced eutrophication within the system and to reduce anoxia resulting from eutrophication and inadequate water circulation. These opportunities are addressed in detail previously under respective sections on **Circulation** and **Eutrophication** and thus are not reiterated here.

Marsh Vegetation Enhancement

Malibu Lagoon is a seasonally closed estuary and therefore should not have a well-developed salt marsh community as a restoration goal. The enhancement of marsh habitat conditions is limited by the relatively small area of the lagoon as well as the relatively large amount of unseasonal freshwater that enters the lagoon during drier months. Because vegetation conditions are defined substantially by soil chemistry, and soil chemistry is significantly influenced by inundation frequency and water salinity, the absence of effective control mechanisms for these conditions restricts lagoon vegetation enhancement opportunities. As nuisance flows of imported water are eliminated from the watershed, evaporation will assist to control salinity levels within the lagoon during summer-closed conditions.

Opportunities for marsh enhancement are controlled principally by the opportunities to alter the lagoon topography to enhance drainage and slopes under open conditions and to optimize substrate elevations under closed conditions. Under the various alternatives, Alternatives 1.5, 1.75 or 2 provide the greatest potential for reworking site conditions to achieve desired vegetation improvements. Alternative 1 has the least capacity to accomplish desirable changes as it maintains, to a great extent, the existing lagoon planform, while providing for slight modification to site elevations. Alternative 1, while resulting in some improvements to the circulation and habitat quality within the lagoon, in fact, results in only a minor increase of the overall wetland habitat.

To improve the habitat characteristics of the site, it is desirable to restore as much of the lagoon to a natural vegetation condition as possible. For a seasonally closed estuary, the natural conditions include the presence of low-growing alkaline meadow and marsh vegetation in the more saline environments with a transition to brackish and ultimately freshwater marsh vegetation in upper lagoon areas. The vegetation is typically transitory seasonally and interannually as a result of episodic scour events and nutrient-poor sandy soils. Surrounding upland vegetation is typically dominated by an open scrubland transition indicative of past flood events, and coastal dune vegetation intergrading with scrub habitats where shifting and nutrient-poor sands blow into the coastal limits of scrub habitat.

For Malibu Lagoon, the stabilization of the system and the import of fill materials have resulted in a loss of much of the suitable soil environment and environmental dynamics that sustained the natural lagoon environment. To foster the return of these conditions, it is desirable to focus on the development of the low alkali marsh/meadow and seasonally inundated habitat restoration in areas that have been historically displaced by upland fills.

Improve Habitat Connectivity

Habitat connectivity is a goal established to promote the transit through and use of all available areas of the lagoon by desirable aquatic and terrestrial species under both open and closed lagoon conditions. Improvement defines conditions that maximize continuity of similar habitats and minimizes impediments between areas such as weirs, sills, bridges and trails, etc. Under all of the alternatives, conditions are improved for habitat connectivity except for the closed lagoon condition of Alternative 1.5 where a narrow finger of habitat along a channel corridor extends along the northern portion of the western arm without being linked back to the main lagoon. This long channel is effectively a dead-end and would not be expected to support a significant regular interchange with the remainder of the lagoon. The elongated channel system has been linked back to the main lagoon under Alternatives 1.75 and 2 by the inclusion of a North Channel. For habitat connectivity, the best conditions are achieved for Alternatives 1.75 and 2 with less improvement being observed for Alternative 1 and Alternative 1.5.

Provide Suitable Tidewater Goby Habitat

A healthy population of tidewater gobies currently exists in the lagoon, however this population remains at risk of extirpation during large-scale storm events. This is especially true as refugia habitats away from the main lagoon silt-in or develop unsuitable water quality conditions that preclude occupancy by gobies. The restoration alternatives were not designed with a specific intent to enhance goby habitat in the main lagoon, but rather to ensure that no significant impact would occur to main lagoon goby habitat due to project implementation. Alternatives were designed to benefit gobies within the more protected refugia habitats away from the main lagoon. Improved water circulation predicted for Alternatives 1.5, 1.75 and 2 is expected to improve goby refuge habitat during catastrophic breach events by minimizing anoxic conditions in deeper pools and isolated channels. All of the alternatives provide adequate protected habitat that would meet the requirements for gobies and none of the alternatives stand out as being significantly superior to others from a habitat perspective.

Maintain Steelhead Migration Habitat

Converse to the need to protect gobies from being fully exported from the lagoon during storm events, it is essential that seasonal lagoon openings be maintained to allow interchange of steelhead with coastal waters. Because none of the alternatives would substantively alter the timing of normal seasonal lagoon breaches, none of the alternatives would effect a detectible change on the suitability of the lagoon to support steelhead migration. Improvements to lagoon water quality, particularly improved dissolved oxygen levels may provide some increased availability of habitat for steelhead juveniles, however, it is not anticipated that lower portions of the lagoon will be used differently by steelhead following enhancement.

Enhance Avian Habitat

Avian habitat improvements are addressed by the provision of habitat that is attractive for bird use and limited within the lagoon proper. As a result, provision of islands and bar habitat, or seasonal salt pannes and expanded lower intertidal areas (including mudflats, brackish marsh and freshwater marsh) are considered to be beneficial.

Prolonged presence of these resources through a variety of water levels is considered to be beneficial. For this reason, an elevated resource such as a gravel bar that extends above the surface of the lagoon under all water levels would be considered to be more advantageous than would a bar that is fully inundated for over half of the year.

Under the differing alternatives, enhancement of habitat conditions during open lagoon conditions were optimized as a secondary focus to improvements of aquatic habitat conditions. For Alternative 1, this meant a greater affinity to existing lagoon configurations than for other alternatives. Alternatives 1.5, 1.75, and 2 were more freely configured for enhancement purposes, however circulation objectives limited opportunities for island habitat. Under these alternatives it has been possible to employ more gradual intertidal slopes and provide greater shorebird foraging habitat than would occur under Alternative 1. However, Alternative 1 provides greater opportunity for the development of avian loafing and roosting islands. The incorporation of smaller islands nearer to shorelines within Alternatives 1.5 and 1.75 provide a somewhat reduced island habitat than under Alternative 1. Within Alternatives 1, 1.5, and 1.75 an island has been incorporated within the A4 area of the main lagoon to provide for avian nesting opportunities. This island is protected from the human impacts that threaten the barrier beach avian area during the summer season and the island would not be subject to losses in the event of unseasonal summer breaching and barrier beach erosion. As such, this island is ideally suited to be configured to optimize suitability for nesting by such species as snowy plovers. However, the island does benefit from a greater degree of isolation during open conditions under Alternatives 1 and 2.

Because the presence of elevated habitat features such as islands and peninsulas would adversely effect circulation and thus water quality, the design conditions for Alternatives 1.5, 1.75, and 2 would allow a predominant submersion of habitats during closed lagoon conditions. As a result, loafing and roosting benefits are more limited under these alternatives during closed conditions. Island-type exposed areas above the +5 foot msl high water elevation are greatest for existing conditions and Alternative 1, with lesser island habitat being incorporated into Alternatives 1.5 and 1.75. While the islands under Alternative 1 are reduced in size from those present under existing conditions, the island elevations are lowered, vegetation area has been reduced, and configurations of island surfaces are modified to provide superior loafing and roosting habitat conditions.

When water levels are below the +5 foot msl elevation, the more gradual shorelines of Alternatives 1.5, 1.75 and 2 provide greater intertidal and shallow water foraging habitat than would be provided under either the existing conditions or Alternative 1. Alternatives 1.5 and 1.75 provide a mix of shallower slopes and island habitats that would tend to enhance both foraging and roosting/loafing habitat values within the lagoon.

Management recommendations will be provided for the preferred alternative to provide a protected avian loafing and foraging habitat along the lagoon barrier beach. These recommendations will include retaining kelp wrack along the barrier beach, erection of temporary signage and marker fencing to protect the upper barrier beach from nest trampling during the summer breeding season (March 15 through September 1), and omitting beach maintenance at the barrier beach crest during the summer nesting season. Further optimization of island and shoreline design would also be addressed as a final alternative is advanced forward in design.

Reduce Terrestrial Predator Encroachment

The reduction of adverse effects of terrestrial predators is addressed best by isolation of sensitive areas on islands or protected peninsulas. All alternatives would result in improvements over the existing conditions due to the relatively significant siltation that has occurred to link islands to shorelines under existing conditions and the dense occurrence of cover vegetation that dominates upland habitats on the islands and benefits avian predators. Under Alternative 1, restored island conditions will improve protection of loafing and roosting birds against terrestrial predators. Similar but reduced island areas under Alternatives 1.5 and 1.75 would further provide protection against terrestrial predators during closed conditions. Because of greater exposed marsh linkages at intermediate water levels, these alternatives would not provide the same degree of isolation from terrestrial predators under open conditions as would Alternative 1. This has been the case due to the need for maintaining wide open water bodies under closed conditions to enhance wind circulation while optimizing marsh habitats during open conditions. While the alternatives all provide benefits, Alternative 1 performs best with Alternatives 1.5 and 1.75 being the next best, and Alternative 2 being the least effective for this objective due to a lack of islands as an alternative to long peninsulas.

Reduction of Mosquito Vectors

Mosquito vector control effectiveness is driven by the reduction of dense vegetation and the allowance for predatory fish to better access mosquito larvae. Improvements are also gained by improved circulation and increased lagoon salinities. This metric is not deemed to be as important to open lagoon conditions. For this metric, the more significant lagoon modification alternatives (Alternative 1.5, 1.75 and Alternative 2) would perform similarly with the lesser modifications of Alternative 1 performing least effectively. The lack of capacity to provide consistent tidal conditions within the lagoon limits the effectiveness of all alternatives.

The following summarizes the restoration approach to optimize habitat:

Alternative 1

- **Components:**
    1. Changes in elevation for much of the vegetated islands and shoreline of the lagoon.
    2. Provision of islands and bar habitat, or seasonal salt pannes and expanded mudflats and marsh are considered to be beneficial. Prolonged presence of these resources through a variety of water levels

3. An island within the A4 area of the main lagoon to provide for avian nesting opportunities.
4. The islands are reduced in size from existing conditions, the island elevations are lowered, vegetation area has been reduced, and configurations of island surfaces are modified

- **Theorized results:**

1. Enhanced habitat conditions.
2. Enhancement would be expected to have a relatively minor impact to the lagoon wetland area.
3. Improved habitat connectivity.
4. Reduced eutrophication and anoxia for improved aquatic habitat.
5. Greater opportunity for the development of avian loafing and roosting islands
6. Provides superior loafing and roosting habitat conditions

- **Expected results:**

1. Habitat is enhanced.
2. The extent of wetland impact is intermediate between Alternatives 1.5 and 2.
3. Less improvement for habitat connectivity than other alternatives.
4. No detectible change to support steelhead migration.
5. Superior loafing and roosting habitat conditions
6. Improved protection of loafing and roosting birds against terrestrial predators.

Alternative 1.5

- **Components:**

1. Altered lagoon topography.
2. Development of the low alkali marsh/meadow and seasonally inundated habitat restoration in areas that have been historically displaced by upland fills.
3. Improved water circulation.
4. Islands and bar habitat, and expanded lower intertidal habitat (mudflats and marsh) present through a variety of water levels.
5. An avian island, illustrated as alkali meadow in the figures, occurs within the A4 area. The extent of vegetation on this island would be dependent upon the extent of avian use the island receives.

- **Theorized results:**

1. Enhanced drainage and slopes under open conditions and to optimize substrate elevations under closed conditions.
2. Enhanced habitat.
3. Improved goby refuge habitat during catastrophic breach events and steelhead habitat.
4. Greater shorebird foraging habitat than would occur under Alternative 1.

- **Expected results:**

1. Improved physical conditions for development of improved habitat and habitat quality will be enhanced.
2. Habitat connectivity is not improved for the closed lagoon condition where a narrow channel dead ends without linkage to the main lagoon.
3. Adequate protected habitat for gobies.

4. No change in supporting the steelhead migration.
5. When water levels are below the +5 foot msl elevation, greater intertidal and shallow water foraging habitat will exist compared to Alternative 1.
6. Enhanced foraging and roosting/loafing habitat values.
7. Improved protection against terrestrial predators during closed conditions, but not as protected as Alternative 1 under open conditions.

Alternative 1.75

- **Components:**
  1. Altered lagoon topography.
  2. Development of the low alkali marsh/meadow and seasonally inundated habitat restoration in areas that have been historically displaced by upland fills
  3. Improved water circulation
  4. Islands and bar habitat, a seasonal salt panne and expanded lower intertidal habitat (mudflats and marsh) present through a variety of water levels
  5. An avian island within the A4 area.
  6. The North Channel corridor.
- **Theorized results:**
  1. Enhanced drainage and slopes under open conditions and to optimize substrate elevations under closed conditions.
  2. Enhanced habitat.
  3. Improved goby refuge habitat during catastrophic breach events and steelhead habitat.
  4. Greater shorebird foraging habitat than would occur under Alternative 1.
  5. Increased bird breeding and loafing area.
  6. Improved habitat connectivity.
- **Expected results:**
  1. Same as Alternative 1.5, but with improved habitat connectivity for the closed lagoon condition as the channel system has been linked back to the main lagoon by the North Channel.

Alternative 2

- **Components:**
  1. Altered lagoon topography.
  2. Install low alkali marsh/meadow and seasonally inundated habitat restoration in areas that have been historically displaced by upland fills.
  3. Provide islands and bar habitat, or seasonal salt pannes and expanded lower intertidal habitats (mudflats and marsh) present through a variety of water levels.
  4. Provide more gradual intertidal slopes.
  5. The North Channel is included.
- **Theorized results:**
  1. Enhanced drainage and slopes under open conditions and to optimize substrate elevations under closed conditions.
  2. Enhanced marsh habitat.
  3. Improved bird loafing and breeding areas.

4. Greater shorebird foraging habitat than would occur under Alternative 1.
5. Improved habitat connectivity.

- **Expected results:**
  1. Improved physical conditions for development of improved habitat and habitat quality will be enhanced.
  2. Adequate protected habitat for gobies.
  3. No change in supporting the steelhead migration.
  4. When water levels are below the +5 foot msl elevation, greater intertidal and shallow water foraging habitat will exist compared to Alternative 1.
  5. Enhanced foraging and roosting/loafing habitat values.
  6. Habitat connectivity is improved for the closed lagoon condition as the channel system has been linked back to the main lagoon by the North Channel.
  7. Improved protection against terrestrial predators during closed conditions, but not as protected as Alternative 1 under open conditions.
  8. The least effective for predator protection due to a lack of islands as an alternative to long peninsulas.

Conclusion: Each alternative significantly improves habitat value at the site. All decrease the extent of areas labeled as parking/disturbed, ornamental landscaping, and exotic vegetation to reclaim native habitat. Wetland habitat acreages increase significantly under open conditions for Alternatives 1.5 and 1.75 with slightly lesser increases being observed under Alternative 2 and Alternative 1 (Table 11). Alternative 1.75 possesses the advantage of a North Channel corridor to connect to northern habitat areas with upstream waters of the lagoon. Inundated areas increase for all alternatives from that observed during current closed conditions (Table 12). These increases in inundation levels have been made to promote open water for wind-driven circulation.

Alternatives 1.5 and 1.75 will have greater intertidal and shallow water foraging habitat for average water levels (below +5 feet msl) than other alternatives, enhanced foraging and roosting/loafing habitat values, and improved predator encroachment protection. Even at a +5 foot msl elevation, shallow waters over the inundated terrain are expected to allow greater access to wading marsh and shorebirds under Alternatives 1.5 and 1.75 than for the other alternatives or the existing conditions.

Alternative 1.5 is considered superior to other alternatives due to overall habitat improvements and greater capacity for adaptive management of the system.

5.6. PUBLIC ACCESS AND INTERPRETATION

Public access is required for any project at Malibu Lagoon. The project team met with stakeholders and devised approaches to access for each scenario. Plans for access have been developed and are described below and shown in Figures 39, 40 and 41.

All four alternatives present possible access components that can, to some extent, be mixed and matched. Of the four, only Alternative 1 leaves the current parking lot in place. All of the other alternatives propose moving the parking lot to the extreme northwest corner of the site, where it would be surfaced with permeable paving with a filtering substrate, decreasing the amount of storm water runoff from the lot into the lagoon. In addition to increased space efficiency and reduction of ornamental, non-native landscape resulting in increased habitat acreage, moving the parking would eliminate isolated habitat currently located between the parking lot and Pacific Coast Highway and allow for more contiguous and functional landscape.

In all four alternatives the dirt access road along the western edge of the site (currently used for lifeguard and emergency vehicular access) could be improved with native vegetation, interpretive overlooks, and aesthetic re-alignment. One such overlook appears on the figures (labeled "Duck Blind") that indicates the position of a possible bird-viewing screen.

All alternatives include a plan to reconnect the eastern and western portions of the lagoon together for easier interpretive loops, and to allow access between the Adamson house and the lagoon proper. There is currently a gap in continuous access between the house and the lagoon. The access plans for all alternatives envision reconnecting the two sites, and allowing for greater integration between the site history and the lagoon environment. The connection would be across PCH bridge and could be accomplished by attaching a separate footbridge adjacent and attached to the existing structure that would separate pedestrian traffic. Another possibility is to encourage pedestrian traffic to use the existing southern sidewalk of the bridge by creating sidewalk access to the lagoon and Adamson house at both ends of the bridge.

The alternatives also show access to the Adamson house dock that can become an exceptional interpretive node with restoration of the avian island at site A-4. It will provide an excellent vantage point for both the nearby avian island, the open water habitat of the lagoon proper, and of the plover nesting sites to be seasonally protected on the lagoon side of the beach.

The alternatives all include creation of a trail underneath the eastern side of the lagoon under PCH bridge to allow access and connection to wilderness trails and riparian habitat north of the bridge.

There are essentially two options for access through the middle of the lagoon. One is to maintain access approximately along the existing pathway alignment and the other is to shift the path farther to the east and more through the center of the lagoon. Regardless of the precise alignment, the path would need to be rebuilt to accommodate new grading in the western arms for any alternative. Also, there would need to be portions of bridge/causeway to span over areas of the lagoon that would be subject to being submerged.

Alternative 1.5 (Figure 40) shows an "Interpretive Bridgeway" with the path more through the center of the lagoon ecosystem along the shallow bar marking the separation of the main lagoon and western marsh channels. This would be a longer, continuous elevated causeway that allows for interpretive opportunities for habitat along the bridge alignment. Also, the bridge could be designed and constructed in such a way as to enhance the effects of wind on circulation on the lagoon (e.g., as a wind foil) and demonstrate its significance. Both the Bridgeway and access along the existing circular path would allow for a number of "Interpretive nodes." These would be areas where the path is widened to accommodate seating, signage, outdoor classroom areas, places to set up easels for painting, or any of a number of other possible activities. Possible locations are noted on the access figures, but they are not to be taken as an exhaustive list.

Figure 39 – Access for Alternative 1

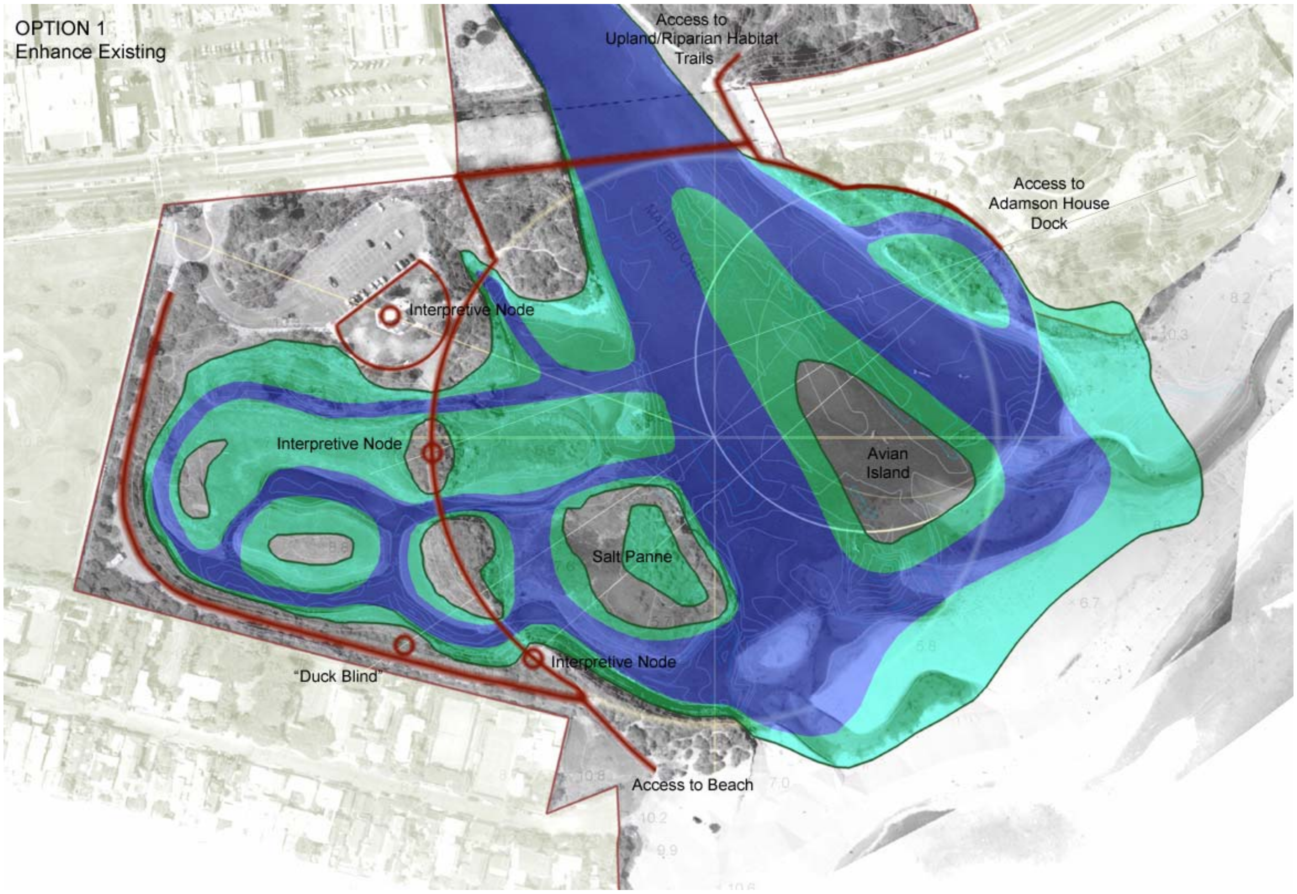


Figure 40 – Access for Alternatives 1.5 & 1.75

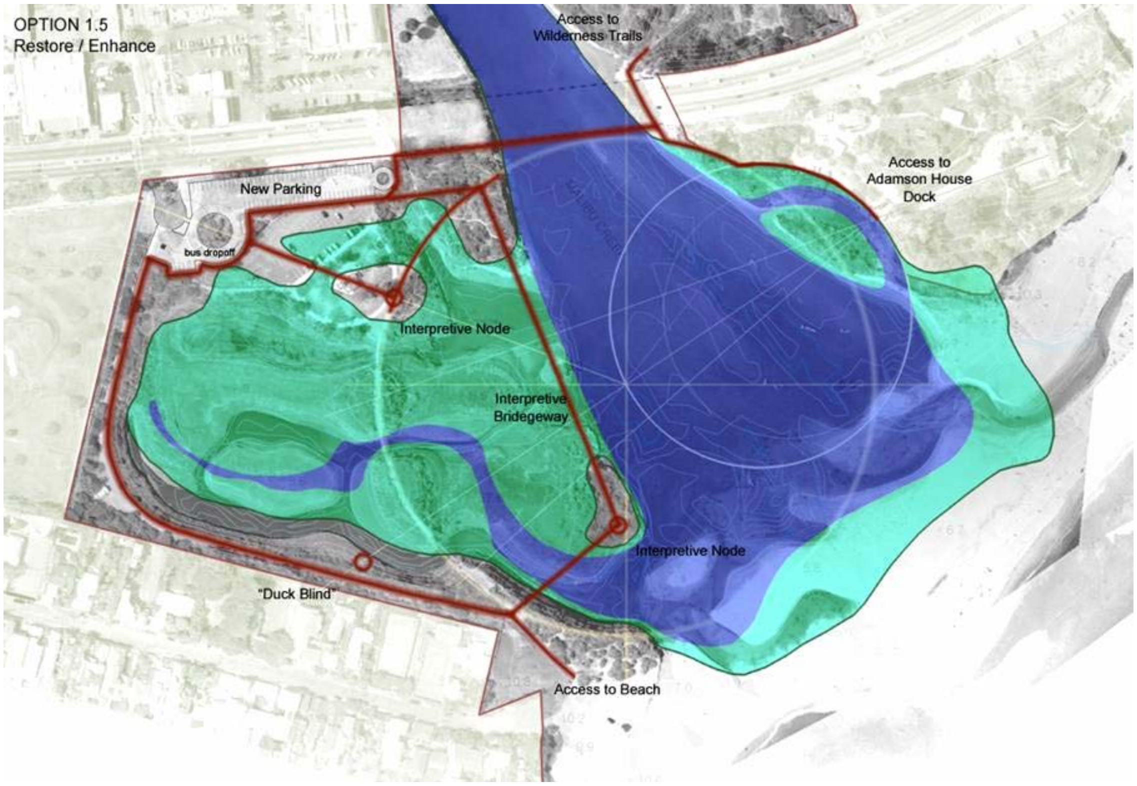
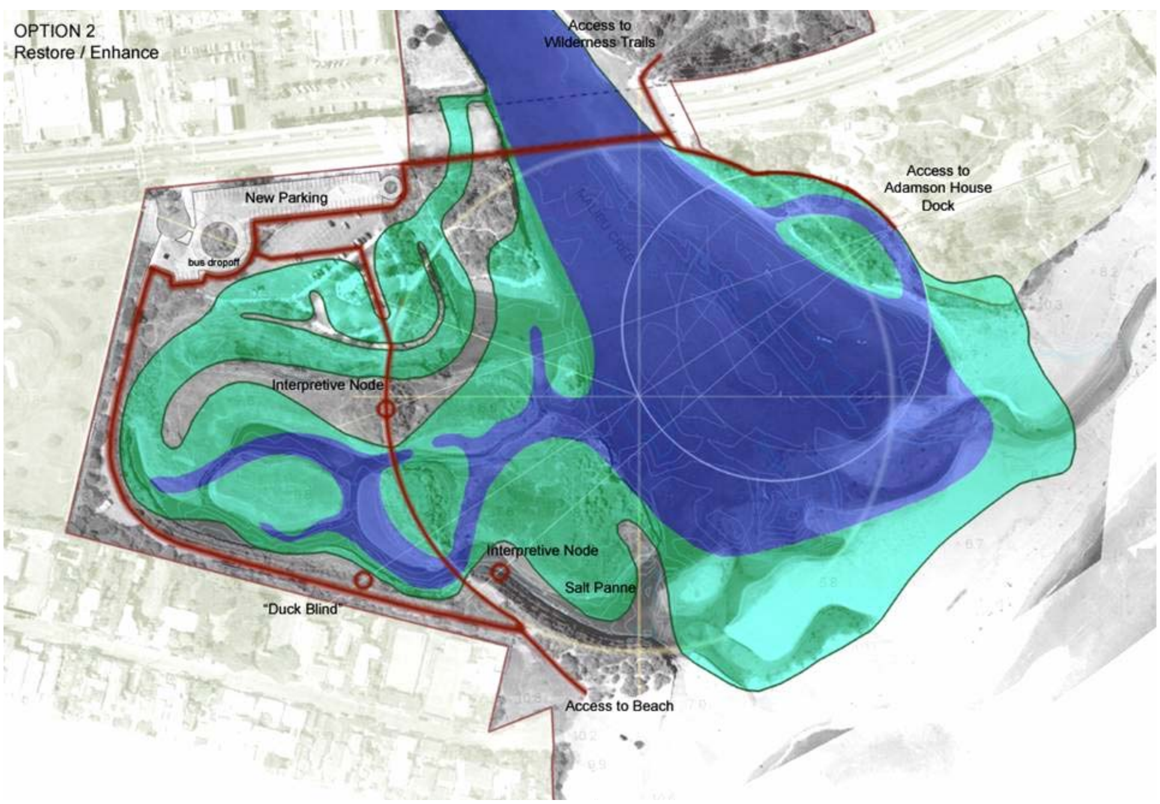


Figure 41 – Access for Alternative 2



5.7. CONSTRUCTION PHASING

Construction of any wetland project should be phased to be as sensitive to the existing environment as possible during disruption. All alternatives, except no project, will result in disturbance to existing habitat. That fact is unavoidable and previously determined to be acceptable by resource agencies in light of the overall long-term benefits the project will have on the entire ecosystem. Other restoration sites experience the same type of shorter-term disruption in exchange for significant long-term improvement. Some local examples include:

- Bolsa Chica wetland in Orange County where 360 acres of existing degraded wetland are being entirely transformed by grading/dredging into a higher quality, functioning salt marsh (construction in 2004-2006).
- Carpinteria Marsh in Santa Barbara County where 39 acres of existing wetlands of both moderate and degraded quality are being modified through grading to create higher quality salt marsh (construction in 2004-2005).
- Batiquitos Lagoon in San Diego County where 350 acres of degraded wetland were transformed by dredging to become functioning salt marsh in 1994 and 1995.
- Anaheim Bay in Orange County where 150 acres of degraded salt marsh were transformed into high quality habitat by grading and filling in 1989-1990.

Construction is typically less expensive if projects are built as quickly as possible, suggesting that the contractor often has permission to fence off the entire site and rework it in one larger-scale effort. Temporal impacts to a site are also minimized if a project is constructed relatively quickly. On the other hand, phasing the construction from one end of a site to another can be one way to allow fauna to move out and away from the construction zone and into a refuge area temporarily. This approach may be more costly, but may be more sensitive in the short-term. The future project proponent and resource agencies will have to decide on the best approach to construction of the restored lagoon.

Malibu Lagoon can be modified in phases to protect certain areas and allow for them to be available as refuge to existing fauna during construction. This report outlines one possible approach to demonstrate the feasibility of relatively sensitive construction. Other approaches may also exist and could be considered as this project moves forward.

The general approach is to separate the work into two phases with site A-1 (western lagoon) moving ahead as Phase 1. During Phase 1 construction, Areas A-4, B-1, B-2 and B-3 are protected as refuge areas. Refuge areas could be cordoned off and access limited or prohibited to allow for greater seclusion of habitat to encourage fauna to temporarily relocate. After the construction of the A-1 area is complete, Phase 2 construction would occur at the main lagoon and at Area A-4. During Phase 2 construction, Areas A-1, B-1, B-2 and B-3 are protected as refuge areas that could be protected in a fashion similar to that of Phase 1.

In more detail, lagoon construction could be performed in the following sequence to minimize disturbance and maximize sensitivity:

Phase 1 – Site A-1 in Late Summer (Start in August and Complete by November 1)

1. Close off the entire site A-1 to humans, except for the contractor and monitors. Leave the connection under PCH bridge to site B-1 as an available land corridor to refuge areas for mammals, assuming site B-1 remains vacant during construction.
2. Initiate site modification in site A-1 (the western lagoon) in late summer.
   a. Install a temporary cofferdam wall between A-1 and the main lagoon;
   b. Pump water from A-1 into the main lagoon to dewater the western arms;
   c. Round up fish from A-1 and convey them manually to the main lagoon;
   d. Perform construction.
      i. Clearing and grubbing of the surface could occur from southernmost edge along the Malibu Colony toward the north and east to allow mammals to escape toward refuge areas.
   e. Reflood the completed western arms while leaving the temporary dam in place;
3. Sweep the main lagoon for fish and relocate them to the newly-restored western arms with seines as a seed population of native species. Exotics can be relocated to the ocean.

Phase 2 – Main Lagoon and Site A-4 (Complete in Fall/Winter)

1. Breach the mouth or wait until the first natural breach occurs;
2. Perform work at the main lagoon and site A-4 as appropriate;
3. Rebuild the beach barrier berm or wait until the first natural closure and let the lagoon fill;
4. Remove the temporary cofferdam.

This approach, or another effective one, can be specified in the construction contract to maximize sensitivity and accomplish the project. Construction can be monitored for effects on biota and other resources to further protect the environment.

5.8. CONSTRUCTION AND MAINTENANCE COSTS

Implementing and maintaining any alternative project will cost money. The probable construction cost estimates of alternatives are shown in Table 15 below as a range for each scenario. Costs were estimated as shown in Appendix 4. Alternatives 1.5 and 1.75 will cost slightly less than Alternatives 1 and 2 owing to the moderately reduced material disposal quantities, shown as net export of earth in Table 16 below. For purposes of this study, it is assumed that excess earth material is disposed of offsite at an approved upland landfill resulting in the higher construction cost of the cost range. The lower construction cost of the range is based on assuming that the excess earth material is barged to the Port of Long Beach and used for fill at future landfill sites. Alternative 2 will cost the most of any alternative due to its larger earth disposal quantity. Predicted maintenance costs are similar for Alternatives 1 and 1.5, and they are lower than for Alternatives 1.75 and 2 that include the weirs in the North Channel (Table 17).

Table 15. Construction Costs for Each Alternative

Alternative	Construction Cost Estimate
Alternative 1	$3.4 to 5.5 Million
Alternative 2	$5.1 to 8.2 Million
Alternative 1.5	$3.5 to 5.2 Million
Alternative 1.75	$3.5 to 5.2 Million

Table 16. Earthwork Quantities for Each Alternative (Western Arms Only)

Alternative	Cut (Cubic Yards)	Fill (Cubic Yards)	Surplus for Disposal (Cubic Yards)
Alternative 1	**33,215**	**3,553**	**29,663**
Alternative 2	**54,139**	**15,772**	**38,368**
Alternative 1.5	**34,793**	**16,329**	**18,454**
Alternative 1.75	**37,571**	**16,329**	**21,241**

Annual maintenance costs are also estimated for the alternatives and Alternative 1 will cost the least and Alternative 1.75 will cost the most. Maintenance costs relate to the need to maintain infrastructure or modifications into perpetuity. Maintenance costs will range from roughly $29,000 to $41,000 per year if maintained properly. Annual maintenance costs are shown in Table 17 below.

Table 17. Range of Annual Maintenance Cost Estimates for Each Alternative

Alternative	High Estimate	Low Estimate
Alternative 1	$33,430	$28,970
Alternative 2	$40,630	$35,210
Alternative 1.5	$35,460	$30,730
Alternative 1.75	$41,460	$35,930

5.9. CONSTRAINTS AND DATA LIMITATIONS

The purpose of this project is to design a restoration plan for the Malibu Lagoon ecosystem that provides the greatest benefit for enhanced ecosystem structure and function while accommodating the various stakeholders in the region to preserve existing recreational use activities as defined by the Malibu Lagoon Task Force.

As previously stated, numerous regulatory and socio-political constraints have limited the extent of ecological improvements presently possible at the site. Based on the evaluation, the team concludes that this restoration project may not be able to meet some goals or significantly address certain problems. Challenges arising from conflicting goals, and regulatory and socio-political constraints limit the extent of ecological improvement presently possible at the site.

Incremental improvement of all problematic conditions should be possible with the optimum actions presented herein.

An example of basic constraints include:

- All restoration alternatives must be natural, non-mechanical, and require little to no maintenance, and rely on natural hydrological and biological processes to persist.
- Restoration actions shall not decrease water quality at Surfrider beach.
- Minimal structural components are to be included in restoration.

Data limitations on this study also exist that need to be recognized. Sufficient data are available to perform restoration planning and concept design. However, certain data are not presently available for further design and analyses that would be required to complete the project. Additional data that may be needed to complete project designs and analyses include:

- Soils data for grain size;
- Phase I site assessment for the existence of potential contaminants or debris;
- Water quality data with depth throughout the lower lagoon (south of PCH) including:
  - A time series of water quality transition from open to closed, and closed to open conditions;
  - Rate of bottom water dissolved oxygen depletion in west arm areas as the lagoon transitions from open to closed conditions;
  - Impacts of breach events on water quality and ecology;
  - The degree and distribution of stratification during closed conditions; and
  - The representativeness of the Tapia gage at PCH relative to the water quality in the remainder of the lagoon.
- More complete hydrology data of lagoon water levels over time to supplement the Tapia gage by filling temporal data gaps;
- A comprehensive tidewater goby survey of the lagoon;
- The effects of potential bacteria and nutrient loads to the west arms as an effect of the North Channel;
- Hydraulic analyses of the North Channel to determine of the magnitude of its effects with greater certainty; and
- Further study of the appropriate design of the naturalized berm to determine the appropriate crest elevation.

6. CONCLUSIONS

The Malibu Lagoon Restoration Feasibility Study addresses existing problems identified at the lagoon and offers solutions. The study assesses the existing ecosystem for problems, presents alternatives to solve problems, and presents analyses of the performance of alternatives to identify the preferred option. The work consisted initially of acquiring and reviewing all available existing data, interviewing local experts, visiting and examining the site, and recording and measuring new data to quantify existing baseline conditions. Existing processes of circulation, sedimentation, nutrient cycling, eutrophication, and habitat evolution are identified as being problematic. These processes are integrated and comprise components of the existing ecosystem, and disturbances in any problem area have ramifications throughout the entire ecosystem.

Initial alternatives were conceived with the assistance of the Lagoon Technical Advisory Committee (LTAC) and the Lagoon Restoration Working Group (LRWG) and developed to address problem areas. The alternatives were further developed and tested for their performance relative to one another and to existing conditions to quantify potential improvements. Alternatives include:

1. Alternative 1 – Enhance Existing – The west lagoon remains in its existing basic configuration with widening and deepening of existing channels to improve circulation;
2. Alternative 2 - Restore/Enhance – The west lagoon is modified to possess a more natural meandering planform, with a North Channel to flush the upper west lagoon end.
3. Alternative 1.5 - Restore/Enhance Modified –Alternative 2 was modified to be more naturalized, but provides maximum open water surface area during closed conditions for wind circulation;
4. Alternative 1.75 - Restore/Enhance Modified With The North Channel – Alternative 1.5 was further modified to include the benefits of flushing from the North Channel resulting in creation of Alternative 1.75.

The alternatives were analyzed for their improvement to the processes of circulation, sedimentation, nutrient cycling, eutrophication, and habitat. Conclusions of these analyses are summarized below.

6.1. CIRCULATION

Alternatives were analyzed using a one-dimensional numerical model of hydraulics to quantify water flow velocities and elevations during open conditions, and using appropriate equations to quantify wind effects during closed conditions.

Circulation under open conditions does not improve from existing conditions for Alternative 1, as water follows the same pathways into and out of the western arms. Expanding the channels in Alternative 1 causes tidal flow velocities to drop, causing circulation to become either equivalent or poorer than existing conditions. Alternatives 1.5 and 1.75 significantly improves tidal circulation into and out of the western arms as the feeder channel is sized appropriately to convey the tidal discharge constantly throughout its reach. Alternative 2 also improves circulation over existing conditions and from that of Alternative 1, but not to the degree of Alternatives 1.5 and 1.75. Its main channel is broader and causes lower tidal flow velocities to occur and circulation if therefore not maximized.

Alternatives 1.5 and 1.75 provide the best circulation of lagoon waters under open conditions. Due to uncertainties of the magnitude of benefit posed by the North Channel, Alternative 1.5 is determined the superior alternative for promoting circulation under open lagoon conditions.

Storm flow circulation is also improved for Alternatives 1.5, 1.75 and 2. Each allows storm flows into and out of the western arms as needed, without severely high flow velocities to cause damage. The North Channel is intended to provide a significant benefit in that it could flush the most distant reach of the western arm during storms, but its effect is uncertain. Alternative 1 performs essentially the same as existing conditions with storm flows allowed to very slowly penetrate the marsh.

Under closed conditions, Alternative 1 performs poorly at creating wind-induced circulation. An extremely short wind fetch is provided across the lagoon so wind-generated waves will be smaller and currents lower than for other alternatives. Alternatives 1.5 and 1.75 perform the best, with highest wind wave generation and probable wind-generated return currents.

Accurately quantifying wind-generated currents is extremely difficult at this scale and is therefore prone to error, so alternatives are analyzed relative to one another. Alternatives 1.5 and 1.75 possess a southern lagoon shore that is free of impediments to a western return current, while Alternative 2 possesses a salt panne protruding from the southern shore than will partially block and reduce the return current. Alternatives 1.75 and 2 include the North Channel to convey possible return currents into the western arms.

Alternatives 1.5 and 1.75 will perform superior to other alternatives to provide circulation under closed conditions due to higher wind waves and more pathways for return currents, with Alternative 1.75 possessing the added potential advantage of return current conveyance through the North Channel, although the extent of this effect is uncertain. While the North Channel may theoretically provide additional circulation during closed conditions, it is not possible at this time to accurately quantify the circulation benefit gained from his additional feature, and therefore the magnitude of this effect is uncertain and requires further study. Due to this uncertainty, it is concluded at this time that Alternative 1.5 performs superior to all other alternatives at improving circulation in the western lagoon.

6.2. SEDIMENTATION

The alternatives were analyzed for their exposure to receive sediment from the main creek during floods, and their ability to expel sediment during subsequent ebbing tides.

Alternative 1 performs poorest because it is exposed to freely receive sediments during floods, and it cannot effectively expel them. Three large slough arms are oriented at 90 degrees into the creek flow allowing storms to more freely deliver sediment to the western arms. Post-storm tidal currents are insufficient in velocity to remobilize the sediments and expel them from the system. These processes evidently occurred during a severe stormflow that occurred in January of 2005 that closed the western arms from the main lagoon as observed in the field after the storm by both Heal the Bay and Moffatt & Nichol staff.

Alternatives 1.5 and 1.75 perform similarly in terms of receiving sediment. Both alternatives include a channel mouth that is located as far downstream as possible and is oriented at an angle away from the flow of the main creek. This configuration should provide some measure of shelter from sediment delivery by floods. Both alternatives will experience subsequent tidal flow velocities that are higher than other alternatives, but not sufficiently high to re-suspend and mobilize fine-grain particles such as silts and clays. Alternative 1.75, however, includes the North Channel that was designed to augment flushing of the western arm during storms. Subsequent analyses, however, revealed that as currently designed, the North Channel may not convey sufficient storm flows to remove fine-grain sediments.

Alternative 2 will experience more direct exposure to receiving sediments during stormflows than Alternatives 1.5 and 1.75, but less than Alternative 1. Its mouth is located farther upstream than Alternatives 1.5 and 1.75, and it is oriented nearly 90 degrees into the main creek flow and will likely be subject to greater sediment delivery. Subsequent tidal currents are insufficient to flush sediments from the west arms for Alternative 2.

Alternatives 1.75 and 2 theoretically provide the greatest potential for storm flow flushing of sediment from the western lagoon, but the magnitude of this effect is uncertain and requires further study. Due to this uncertainty, it is concluded at this time that Alternative 1.5 performs superior to all other alternatives at reducing sedimentation fine-grained particles in the western lagoon.

6.3. NUTRIENT CYCLING

None of the alternatives can address nutrient cycling by major source reduction. Major source reduction must occur throughout the watershed. However, minor source reduction can occur by inducing flushing of fine sediments and organic matter deposited in the west lagoon that harbor nutrients.

Alternative 1 performs poorly to enhance nutrient cycling. Its configuration creates deeper and steep-sided channels, and it will not experience improved circulation compared to existing conditions. These conditions will result in no improvement in oxygenation of water and sediments that would stimulate denitrification. Also, the relatively poor circulation will not induce horizontal and vertical water exchange, nor reduce stratification of the water column and thus low dissolved oxygen levels will persist.

Alternatives 1.5 and 1.75 have the potential to improve nutrient cycling by increasing circulation, and provide for improved circulation under both open and closed conditions. Improved circulation will increase horizontal and vertical exchange, reduce stratification, increase dissolved oxygen levels, and increase the time for oxygen-rich waters to interface with bed sediments. These alternatives also possess flatter slopes that can be exposed to the atmosphere at low tide for further oxygenation. Increased oxygen levels in the water and sediment increases denitrification and completes the nitrogen cycle, thus reducing nutrient levels in the lagoon.

Alternative 2 performs poorer than Alternatives 1.5 and 1.75 due to slightly poorer circulation and lower horizontal and vertical water exchange, and less reduction of stratification, less increase in dissolved oxygen levels, and less increase in oxygen conveyance to bed sediments.

Alternative 2 may possess a shallower channel and an incrementally increased area of coarse bed sediments compared to Alternatives 1.5 and 1.75, but benefits are only incremental and do not outweigh the remaining benefits of Alternatives 1.5 and 1.75.

Alternatives 1.5 and 1.75 will receive less direct sediment and nutrients delivery to the western arms, will experience greater vertical and horizontal water exchange, and will increase the time of oxygen rich water contact with the bed sediment from improved circulation under all conditions. Alternatives 1.75 and 2 theoretically provide the greatest potential for storm flow flushing of sediment from the western lagoon, but the magnitude of this effect is uncertain and requires further study. Due to this uncertainty, it is concluded at this time that Alternative 1.5 performs superior to all other alternatives at improving nutrient cycling.

6.4. EUTROPHICATION

Eutrophication and nutrient cycling are linked, in that improved nutrient cycling reduces eutrophication. Thus, similar to their performance for nutrient cycling described above, Alternatives 1.5 and 1.75 perform superior to other alternatives due to increased oxygenation of waters and sediments during open and closed conditions, better mixing, less stratification and overall increased denitrification. Primary production will be reduced during closed conditions. However, the magnitude of water quality benefits by implementation of these physical components is limited by excessive non-point source loading of nutrients from the watershed.

While Alternative 1.75 with the North Channel may theoretically provide additional circulation during closed conditions, it is not possible at this time to accurately quantify the circulation benefit gained from this additional feature, and therefore the magnitude of this effect is uncertain and requires further study. Due to this uncertainty, it is concluded at this time that Alternative 1.5 performs superior to all other alternatives at reducing eutrophication in the western lagoon. Alternative 1.5 will set the stage to the best performing lagoon with respect to water quality if future pollutant reductions were implemented.

6.5. HABITAT

Alternatives significantly improve habitat values at the lagoon. Wetland habitat acreages increase significantly under open conditions for Alternatives 1.5 and 1.75. Alternative 1.75 possesses the added advantage of the North Channel to provide a habitat connection corridor to northern habitat areas. Open water areas from existing closed (highest water) conditions as the alternatives are configured to provide more open water for wind-driven circulation. Alternatives 1.5 and 1.75 will have greater intertidal and shallow water foraging habitat for average water levels (below +5 feet msl) than other alternatives, enhanced foraging and roosting/loafing habitat values, and improved predator encroachment protection. All alternatives possess bird islands for use during closed conditions, with the fewest islands available in Alternative 2 and most available with Alternative 1.

Alternative 1.75 is considered superior to other alternatives due to overall habitat improvements and flexibility for adaptive management provided by the North Channel component.

6.6. PREFERRED ALTERNATIVE AND NEXT STEPS

Alternative 1.5 is recommended to be carried forward for planning, approvals, design engineering, and phased implementation. Although Alternative 1.75 with the North Channel is theorized to provide greater restoration benefits, uncertainty exists about the magnitude of the beneficial effects. Therefore, it is recommended to implement the preferred alternative in stages, with the basic lagoon restoration footprint of Alternative 1.5 being installed first, followed by close monitoring to track changes at the lagoon while holding the North Channel component aside as an adaptive management tool. If monitoring suggests the need for the North Channel and subsequent analyses result in greater certainty of the magnitude of its effects, this component could be added into the project at a later date.

Alternative 1.5 will be further developed to enable additional future analyses. Subsequent to these analyses, it will be scrutinized further for restoration design optimization. A primary goal of plan optimization will be to minimize impacts to existing habitat Restoration design optimization can be accomplished using an approach as is shown in Figure 42, the proposed footprint of Alternative 1.5 overlain onto a black and white aerial photograph of the lagoon. This figure shows locations of work relative to existing lagoon features. The figure shows that the future channels in the western arms are not shown to be in the exact same location as existing channels. This alternative could be optimized in a later stage of design to slightly modify the footprint to minimize impacts to existing topography and habitat.

Public access and interpretative facilities will also be further developed during design optimization. An example of a low-impact access plan for Alternative 1.5 is shown in Figure 43 that shows the accessway along the naturalized berm to be cut-off just south of the main entry area. This reduces intrusion into sensitive wetland areas to maintain the integrity of the functioning ecosystem.

Figure 42 – Alternative 1.5 Over Existing Aerial Photography

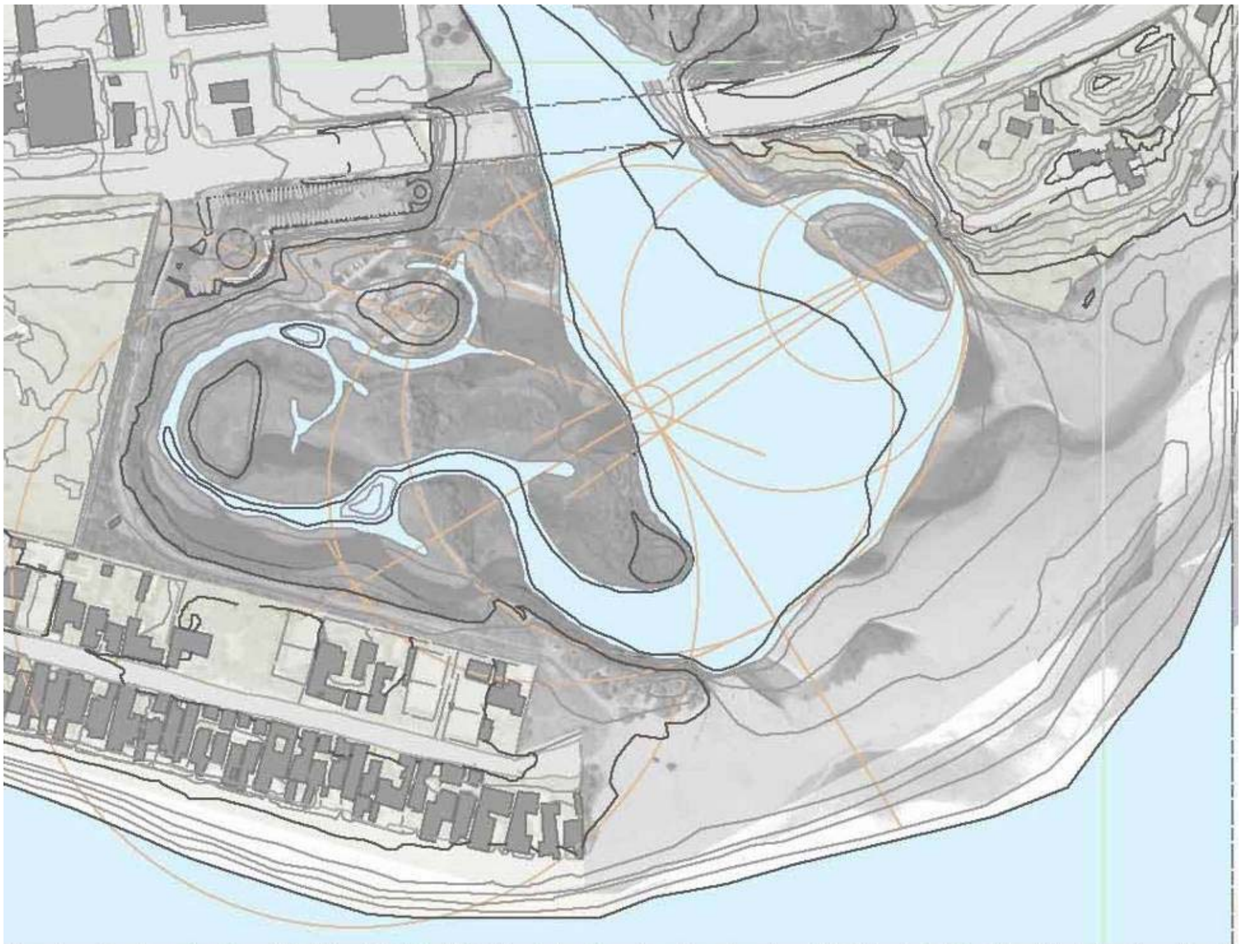


Figure 43 –Alternative 1.5 With Modified Berm Planform

6.6.1. *Malibu Lagoon Restoration Preferred Alternative (1.5) - Description of Elements*

Alternative 1.5 is expected to most readily achieve the goals of the restoration while introducing the least amount of impact to the existing lagoon ecosystem. All work should be performed in succinct stages to minimize impacts to the existing wetland habitat and to provide refuge for species displaced by construction activities. A strong adaptive management approach will be implemented to minimize work required to accomplish restoration success while providing a level of security against the possibility of failing to meet restoration objectives. A primary components of the adaptive management framework is implementation of a detailed monitoring program. Another component will be additional analysis of improvements which may promote wind-driven return currents, increase habitat connectivity, and possibly convey storm or creek flows to increase flushing of fine sediments.

Parking Lot and Staging Lawn

The existing parking lot will be relocated to the north and west to be adjacent to PCH, the current parking lot entrance from PCH and Cross Creek Road, and the current western property line. The new parking lot and staging area will be created with runoff treatment controls, including porous concrete or other similar substances, native and drought tolerant plants, and will include a staging area. The new parking lot will maximize the use of Best Management Practice (BMP) improvements to minimize or eliminate runoff to the lagoon. The current number of parking spaces will remain and new interpretative displays and panels will be installed.

Main Channel

The Main Channel will remain substantially "as is." The western edge of the main lagoon at the interface with the western arms complex will be reconfigured in the form of a naturalized slope to provide a degree of separation between the main lagoon and west channel system.

East (A4)

The existing boat house channel will be deepened and recontoured to create a new avian island along the eastern bank of the Adamson House grounds. This work is expected to have a minimum impact on the existing habitat, will create additional mudflat habitat and promote additional water circulation around the new island. Slightly less than 4,000 cubic yards of cut and fill will be required to complete work at this site.

West Lagoon Complex

A new channel will be created along the southern edge of the west lagoon to create a single main entrance and exit for water conveyed into and out of the west lagoon. This channel will be optimized to possibly overlie the existing "C" channel to minimize the impact to existing habitat and will be designed to enable a future connection to the "golf course" parcel located adjacent and to the west of the lagoon. A naturalized slope separating the main channel from the west channel, with minimum elevation change, will be created using lagoon materials displaced by dredging of the new main west channel and those that currently exist along this edge. The main west channel will possess a natural dendritic planform to maximize tidally influenced water inundation to the west channel and its fingers. Isolated bird islands will be created to provide refuge for foraging and/or loafing birds. These islands will be optimized to maximize the use of the existing wetland habitat to minimize impacts to the existing system.

Future Work

The current project stage is intended to identify the feasibility of alternatives for selection of the preferred alternative. A restoration plan will be developed based on the preferred alternative to facilitate the initiation of environmental review and permitting. Additional work will be required to refine the project design to enable the project to move through subsequent stages. These stages will include:

- Pre-restoration monitoring;
- Environmental review that will include additional data collection (includes public comments and hearings);
- Permitting (includes public comments);
- Final design for the restoration program that will likely include additional data collection and analyses;
- Phased Restoration Implementation; and
- On-going monitoring.

The restoration design will evolve and be optimized further as it proceeds through these varying stages. The public will have opportunities to comment and provide input throughout the permitting and restoration design optimization stages.

MALIBU LAGOON ALTERNATIVE COMPARISON MATRIX

All scores are ranked on a scale of -3 to 3 with zero value serving as the baseline for comparison. Negative values show the factor is rated worse than existing (baseline) conditions. Values are assigned relative to existing conditions and one another.

ISSUE AREA	NO ACTION Existing Conditions		ALTERNATIVE 1 Enhance Existing		ALTERNATIVE 2 Restore/Enhance		ALTERNATIVE 1.5 Restore/Enhance Modified		ALTERNATIVE 1.75 Hybrid With the North Channel	
	Open Lagoon	Closed Lagoon	Open Lagoon	Closed Lagoon	Open Lagoon	Closed Lagoon	Open Lagoon	Closed Lagoon	Open Lagoon	Closed Lagoon
CIRCULATION										
Open Conditions (Tidal Flows and Stormflows)	0 - Baseline conditions	0 - Baseline conditions	-1 - lower flow velocities and poorer circulation due to larger channel cross-sections.	Not Applicable	3 - Single main marsh channel to focus flows; North Channel for flushing, although its effect is uncertain.	Not Applicable	2 - Single main channel to funnel flows that is narrower and deeper throughout its course than that for Alternative 2, but the North Channel is not included.	Not Applicable	3 - Single main channel to funnel flows that is narrower and deeper throughout its course than that for Alternative 2, and the North Channel is included., although its effect is uncertain.	Not Applicable
Closed Conditions (Wind-Induced Currents)	0	0	Not Applicable	0 - No improvements over existing conditions.	Not Applicable	1 - Longer fetch than existing conditions, but return current partially blocked by salt panne.	Not Applicable	2 - Longest fetch for wind currents, and reshaped south shore for return currents, but no North Channel for greater return current movement.	Not Applicable	3 - Longest fetch for wind currents, and reshaped south shore and the North Channel for potentially increased return currents from wind circulation, although its effects are uncertain.
Ability for Future Hydrologic Connection to A2 (Golf Course)	0	0	1 - Marsh channels extend closer to the property line.	1 - Marsh channels extend closer to the property line.	1 - Marsh channels extend closer to the property line.	1 - Marsh channels extend closer to the property line.	1 - Marsh channels extend closer to the property line.	1 - Marsh channels extend closer to the property line.	1 - Marsh channels extend closer to the property line.	1 - Marsh channels extend closer to the property line.
SEDIMENTATION AND SCOUR OF FINES										
Sediment Disposition (Accretion by Stormflows)	0	0	-1 - Retains existing lagoon planform, yet channels are enlarged to accumulate greater sediment volumes from stormflows than existing conditions.	0 - No change from existing, however, sediment delivery to the lagoon occurs mainly during stormflows when the lagoon mouth is open.	1 - The single main connection to the creek is smaller than the three existing channels, and it is shifted slightly downstream to reduce sediment inflows. The opening is still oriented perpendicular to the creek reducing protection from stormflows.	0 - Sediment delivery to the lagoon occurs mainly during stormflows when the lagoon mouth is open.	2 - The single main connection to the main lagoon is smaller than the three existing channels, it is shifted as far downstream as possible, and oriented at an angle away from stormflows to minimize sediment inflows.	0 - Sediment delivery to the lagoon occurs mainly during stormflows when the lagoon mouth is open.	3 - The single connection to the main lagoon is smaller than three existing channels, shifted as far downstream as possible, oriented at an angle away from stormflows to reduce sedimentation from stormflows.	0 - Sediment delivery to the lagoon occurs mainly during stormflows when the lagoon mouth is open.
Sediment Expulsion (Removal by Scour From Stormflows and Tidal Flows)	0	0	-1 - Reduced scour from lower flow velocities from the lagoon by stormflows and tides.	Not Applicable - No scour and flushing occurs during closed conditions.	2 - Flushing is provided by stormflows through the North Channel, although its effects are uncertain; the main channel is broader than Alternative 1.5 so scour flow velocities are lower.	Not Applicable - No scour and flushing occurs during closed conditions.	1 - Sediment removal by tides and receding stormflows is improved by the narrow single channel over existing conditions, but no North Channel is included for flushing.	Not Applicable - No scour and flushing occurs during closed conditions.	3 - Sediment removal by tides and receding stormflows is improved by the narrow single channel over existing conditions, and the North Channel is included for flushing, although its effect is uncertain.	Not Applicable - No scour and flushing occurs during closed conditions.
NUTRIENT CYCLING										
Reduced Sequestering	0	0	-1 - Greatest sediment sequestering occurs from maximum deposition by storm flows, and least expulsion by tidal and/or stormflows.	Not applicable as sediment sequestering does not significantly occur during closed conditions.	2 - Flows from the North Channel may flush fine sediments and summer organics from western arms during stormflows reducing nutrient sequestering, although its effects are uncertain, but flushing is limited by the broad channel cross-section.	Not applicable as sediment sequestering does not significantly occur during closed conditions.	1 - Less sediment is delivered to the western lagoon during stormflows due to it being more protected by its configuration; also, very limited flushing of fines may occur due to better circulation of tides.	Not applicable as sediment sequestering does not significantly occur during closed conditions.	3 - Less sediment is delivered to the western lagoon during stormflows due to it being more protected by its configuration; flushing of fines may occur by the North Channel, although its effects are uncertain.	Not applicable as sediment sequestering does not significantly occur during closed conditions.

MALIBU LAGOON ALTERNATIVE COMPARISON MATRIX

All scores are ranked on a scale of -3 to 3 with zero value serving as the baseline for comparison. Negative values show the factor is rated worse than existing (baseline) conditions. Values are assigned relative to existing conditions and one another.

ISSUE AREA	NO ACTION Existing Conditions		ALTERNATIVE 1 Enhance Existing		ALTERNATIVE 2 Restore/Enhance		ALTERNATIVE 1.5 Restore/Enhance Modified		ALTERNATIVE 1.75 Hybrid With the North Channel	
	Open Lagoon	Closed Lagoon	Open Lagoon	Closed Lagoon	Open Lagoon	Closed Lagoon	Open Lagoon	Closed Lagoon	Open Lagoon	Closed Lagoon
Increased Denitrification Rates	0	0	-1 - Steeper channel banks and deeper centers result in poorer circulation than exists, resulting in greater stratification, less vertical and horizontal water exchange, and less exposure of bed sediments to the atmosphere during low water levels.	-1 - Deeper and steeper channel banks leads to smaller ratios of bed sediment area to water surface area, greater stratification, and poorer oxygenation of water.	2 - Channels are reconfigured to be flatter and broader than existing conditionsand other alternatives to improve vertical and horizontal water exchange. Improvements over Alternatives 1.5 and 1.75 are only incremental.	1 - Wind-driven circulation is improved thus increasing horizonal and vertical water exchange; this effect is not as great as for Alteratives 1.5 and 1.75 due to a more limited fetch and a salt panne along the south shore reducing return currents.	1 - Improved circulation results in better horizontal and vertical water exchange and oxygenation.	2 - Greater wind-generated currents due to longer fetch and less restriction of return current at south shore leads to better horizontal and vertical water exchange and oxygenation of water and sediments.	1 - Improved circulation results in better horizontal and vertical water exchange and oxygenation.	3 - Greatest wind-generated currents due to longer fetch and least restriction of return current at south shore. North Channel is available as additional circulation source, although its effect is uncertain, for possibly better horizontal and vertical water exchange and oxygenation of water and sediments.
EUTROPHICATION										
Primary Production Rates	0	0	Not Applicable because production is significantly limited during open conditions.	Higher production rates over existing conditions and other alternatives.	Not Applicable because production is significantly limited during open conditions.	Reduced production rates over existing conditions and most other alternatives due to flushing benefits of the North Channel, although its effects are uncertain.	Not Applicable because production is significantly limited during open conditions.	Reduced production rates over existing conditions and most Alternative 1, but slightly greater than Alternatives 1.75 and 2 due to lack of stormflow flushing.	Not Applicable because production is significantly limited during open conditions.	Reduced production rates over existing conditions and all other alternatives due to benefits of circulation and flushing by the North Channel, although its effects are uncertain.
HABITAT										
Enhancement of Vegetation Diversity & Persistence	0	0	0.5- Habitat is enhanced slightly by reducing upland areas.	0.5 - Same as for open conditions.	1 - Habitat is enhanced by providing improved slopes and drainage than exist.	1 - Same as for open conditions.	1 - Habitat is enhanced by providing improved slopes and drainage than exist.	1 - Same as for open conditions.	1 - Habitat is enhanced by providing improved slopes and drainage than exist.	1 - Same as for open conditions.
Fisheries Maintenance	0	0	0 - No changes to fisheries; adequate protection during breaches.	0 - Same as for open conditions.	0.5 - Slightly improved water quality conditions to improve goby refugia during breaches; no changes to steelhead access.	0.5 - Same as for open conditions.	0.5 - Slightly improved water quality conditions to improve goby refugia during breaches; no changes to steelhead access.	0.5 - Same as for open conditions.	0.5 - Slightly improved water quality conditions to improve goby refugia during breaches; no changes to steelhead access.	0.5 - Same as for open conditions.
Avian Benefits	0	0	1.5 - Best avian conditions due to four isolated islands and one salt panne area; least intertidal foraging area.	1.5 - Same as for open conditions.	0 - One salt panne and one avian island; loss of main lagoon tree snag perches; more intertidal foraging areas.	0 - No areas available other than at the managed area at the beach.	1 -Two avian islands and main lagoon remains as exists; greater intertidal foraging areas.	1 - Same as for open conditions, but without intertidal foraging area.	1 -Two avian islands and main lagoon remains as exists; greater intertidal foraging areas.	1 - Same as for open conditions, but without intertidal foraging area.
Connectivity	0	0	0.5 - Habitat connectivity is not improved over existing conditions.	0.5 - Same as for open conditions.	1 - Connectivity is improved by the corridor provided by the North Channel.	1 - Same as for open conditions.	0.5 - Connectivity is only moderately improved over existing conditions due to relocation of the parking lot.	0.5 - Same as for open conditions.	1 - Connectivity is improved by the corridor provided by the North Channel.	1 - Same as for open conditions.
Isolation from Predators	0	0	1.5 - Best protection against predators due to isolated islands under open conditions.	1.5 - Best protection during closure with most isolated islands.	0.5 - Least protection from predators, but improved over existing conditions.	0.5 - Least protection from predators under closed conditions.	1 - Improved protection from predators but not as good as Alternative 1.	1 - Improved protection from predators but not as good as Alternative 1.	1 - Improved protection from predators but not as good as Alternative 1.	1 - Improved protection from predators but not as good as Alternative 1.
COST AND MAINTENANCE NEEDS										
Construction Cost	0	0	-2 - $3.4 m to $5.5 m	Same as for open conditions.	-3 - $5.1 m to $8.2 m	Same as for open conditions.	-1 - $3.5 m to $5.2 m	Same for open conditions.	-1 - $3.5 m to $5.2 m	Same for open conditions.
Maintenance Costs (Long-Term)	0	0	-1 - $33,400 to $29,000 per year.	Same as for open conditions.	-3 - $40,600 to $35,200 per year.	Same as for open conditions.	-2 - $35,500 to $30,700 per year.	Same as for open conditions.	-3 - $41,500 to $35,900 per year.	Same as for open conditions.

7.0 REFERENCES

Ambrose, R. F., and A. R. Orme. 2000. Lower Malibu Creek and Lagoon resource enhancement and management. University of California, Los Angeles.

Bascom, Willard. 1980. Waves and Beaches. The dynamics of the ocean surface. Revised and updated. Anchor Press/Doubleday, Garden City, New York, xviii + 166 pp.

Beck, N. G., Bruland, K.W. and Rue, E.L. 2002. Short Term Biogeochemical Influence of a Diatom Bloom on the Nutrient and Trace Metal Concentrations in South San Francisco Bay Microcosm Experiments, Estuaries. V25 (6A) p. 1063-1076.

Caffrey, J.M., Harrington, N., Solem, I. and Ward, B.B. 2003. Biogeochemical processes in a small California estuary. 2. Nitrification activity, community structure and role in nitrogen budgets. Marine Ecological Progress Series v. 248: 27-40.

Carter, R. W. G. and C. D. Woodroffe. 1994. Coastal Evolution. Late Quaternary shoreline morphodynamics. Cambridge University Press, Cambridge, UK, xxi + 517 pp.

CH2M Hill, 2000. Evaluation of nutrient standards for Malibu Creek and Malibu Lagoon. Prepared for Las Virgenes Municipal Water District and Triunfo Sanitation District.
Garrett, Kimball unpub. field notes 1980-1996.

Gold, Mark, Heal the Bay. 2004. Personal Communication with Chris Webb.

Kjerfve, B. (Editor). 1994. Coastal Lagoon Processes. Elsevier, Amsterdam

Lall, Yugall, City of Malibu. 2004. Personal Communication with Chris Webb.

LARWQCB, 2000. Wastewater disposal issues and Malibu technical investigation in the City of Malibu

Manion S. and Dillingham, J., 1989. Malibu Lagoon: A Baseline Ecological Survey.

Monbet, 1992. Monbet, Y. 1992. Control of phytoplankton biomass in estuaries: A comparative analysis of microtidal and macrotidal estuaries. *Estuaries*, v 15(4) p. 563-571.

Orton, Randal. 2004. Los Virgenes Municipal Water District, employee, personal communication and data exchange.

Shuman, Craig, Heal the Bay. 2005. Personal Communication with Chris Webb.

Stone Environmental, Inc, 2004. Risk assessment of decentralized wastewater treatment systems in high priority areas in the City of Malibu, California. Draft Final Report Prepared for Santa Monica Bay Restoration Project.

Stumm, W. and Morgan, J. 1996. Aquatic Chemistry; chemical equilibria and rates in natural waters. John Wiley and Sons, p. 1022.

Sutula M., Kamer K, and Cable, J., 2004. Sediments as a non-point source of nutrients to Malibu Lagoon, California (USA) DRAFT Final Report to Los Angeles Regional Water Quality Control Board.

Swift, Camm, 2004. Entrix staff, Personal communication with Chris Webb.

Tetra Tech, Inc. 2002. Nutrient and coliform modeling for the Malibu Creek Watershed TMDL studies. Prepared for USEPA and LARWQCB.

URS Greiner Woodward Clyde, 2000. Study of the water quality in the Malibu Lagoon area, City of Malibu, CA; Phase II. Prepared for the City of Malibu.

USEPA 2003a. Region 9, Total maximum daily load for nutrients Malibu Creek Watershed, submitted March 2003. (http://www.epa.gov/region9/water/tmdl/final.html)

USEPA 2003b. Region 9, Total maximum daily load for bacteria Malibu Creek Watershed, submitted March 2003. http://www.epa.gov/region9/water/tmdl/final.html)

Wetzel, 1975. Limnology. W.B. Saunders Company, p. 7.

Woodroffe, Colin D. 2002. Coasts: Form, process and evolution. Cambridge Univ. Press, Cambridge, UK, xiv + 623 pp.