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Hydrology and Water Quality of the Carmel and Salinas Lagoons Monterey Bay, California 2001/2002

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Preface

In all but the driest years, the sandbars of the Carmel and Salinas Lagoons in Monterey County, California are breached following winter rains, thus connecting the lagoons to the ocean. Breaching is a natural process, but in most years the time of breaching is brought forward through mechanical intervention by local agencies in order to minimize flood risk to adjacent lands.

This report was commissioned by the Monterey County Water Resources Agency (MCWRA), the agency that breaches the Salinas Lagoon. It was also conducted in cooperation with Monterey County Public Works (MCPW) the agency that breaches the Carmel Lagoon. Information was also provided by Monterey Peninsula Water Management District (MPWMD), National Marine Fisheries Service (NMFS), Carmel RIver Steelhead Association (CRSA).

The work was done in collaboration with a companion study by Hagar and Associates on the impact of lagoon breaching on steelhead trout in the Carmel Lagoon, also commissioned by MCWRA.

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1 Introduction

1.1 Background

Central Coast Steelhead Trout are listed by the National Marine Fisheries Service as a threatened Evolutionary Significant Unit (ESU). The species is anadromous, spawning in the headwaters of both the Carmel and Salinas watersheds. The lower rivers are non-perennial, so when fall and winter come, and the rivers flow, juvenile Steelhead migrate down to their respective lagoons. Between late spring and winter, the lagoons are often blocked from the ocean by sandbars. Their waters provide habitat where the juveniles complete smoltification, the process of physiological adaptation to live in the oceans. In the absence of (further[1]) human intervention, the lagoons eventually fill with river water and breach the sandbars.

The Carmel River supports a large restored run of many thousands of up-migrating adult Steelhead each year[2]. The Salinas River once supported such a run[3], but now is now limited to perhaps 100[4].

Residential (Carmel) and agricultural (Salinas) development have occurred adjacent to the lagoons such that, when filled to their maximum unabated level, the lagoon waters can inundate developed land. This condition is exacerbated during high surf conditions, when the sandbars are higher and the lagoon waters are augmented by waves flowing in from the sea.

Monterey County Public Works (in the Carmel Lagoon) and the Monterey County Water Resources Agency (in the Salinas Lagoon) intervene each year by either causing or assisting the breach using heavy earth-moving equipment. This activity is subject to permitting requirements, which in turn require water quality monitoring. The impact of the breaching process on Steelhead populations is unknown. The juveniles require a substantial amount of time for smoltification. A precise means of determining when they are ready, or the conditions under which they would be most likely to survive the migration, is not known for these runs. It is possible that early breaching might degrade lagoon conditions and lead to premature out-migration. Because of this possibility, decision-makers currently delay breaching as long as possible. However, this entails risk, because if a river flood peak and a spring tide arrive at the same time, it can be difficult to access the sandbar using heavy equipment (Fig. 1.1).

There is a need for better understanding of lagoon hydrology and steelhead response, as well as the ability to predict the best time for breaching given the multiple constraints just outlined.

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[1] The flow of both rivers is heavily modified by human activity.

[2] See MPWMD web page.

[3] Anecdotal evidence has been documented (http://science.csumb.edu/~ccows).

[4] This figure is highly uncertain, and is the number given by a NMFS status report published on their web page (http://www.nwfsc.noaa.gov/pubs/tm/tm27/tm27.htm).

Figure 1.1. Monterey County Public Works fighting against large waves while breaching the Carmel Lagoon - December 3, 2001.

1.2 Aims

The aims of this study were to evaluate, through monitoring, the water quality of the lagoons in relation to Steelhead survival just before and after lagoon breaching, and to provide contextual monitoring during spring, fall and winter. The objectives were not to study or analyze fish behavior and response to changing conditions – this being the topic of a separate study (Hagar, 2002, in prep.), or make judgements as to optimal lagoon management.

We used a limited array of parameters to assess water quality, including chiefly:

- Temperature
- Salinity
- Dissolved oxygen
- Depth
- Bed sediment size

There are many other parameters that were not measured, and that may determine the water and habitat quality for juvenile Steelhead in a lagoon, including:

- Toxic elements and compounds (e.g. pesticides, herbicides, heavy metals)
- Nitrate & phosphate
- Pathogens
- Cover from predators
- Food
- Turbidity
- Hydraulic diversity
- Invasive species
- Fish population estimates
- Fish age-distribution estimates

1.3 Report structure

The remainder of this report is organized into sections describing the study area, monitoring methods, and monitoring results for first the Carmel Lagoon, and then the Salinas Lagoon.

2 Study Area

2.1 Carmel Lagoon

The Carmel Lagoon (Fig. 2.1) lies at the end of the Carmel River between two residential areas Carmel By The Sea to the north (Fig. 2.2) and Carmel Meadows to the south. The lagoon is much smaller than the Salinas Lagoon (Fig. 2.6). However, the surface area of the lagoon expands and contracts with seasonal changes. In winter, the lagoon expands with the addition of increased stream flow, inundating terrestrial vegetation until the lagoon is breached. In summer, the lagoon shrinks, becoming more shallow and exposing small channels and islands in the lagoon bed (Figs 2.3 & 2.4).

The northern backwater (North Arm) section of the lagoon is circular (*c.* 300m diameter) and comprises a system of channels and islands filled with aquatic vascular vegetation.

The smaller Southern Arm of the lagoon is much more linear and confined (*c.* 200m long) (Fig. 2.5). The formation of the South Arm is still unkown. However, it is hypothesized that it was once occupied by the river's main channel which has since migrated to the north (PWA, 1999). Currently, a small hill with underlying granitic bedrock confines the South Arm into a narrow channel that swells at high water into a wetland once used for agriculture. The granite is the outcrop of a larger upthrown block beneath the lagoon. This block protects the Carmel Valley aquifer from seawater intrusion (Johnson, 2000) and would most likely have been the control feature for a cascade or waterfall in the Carmel River at times of lower sea level. Deep-water habitat, currently found in the South Arm, is a result of dredging that occurred in 1996 and 1998 (Entrix, 2001). This dredging was conducted to increase the amount of deep-water habitat for steelhead.

Inland and to the east, the Carmel River enters the lagoon. The river has a USGS gauging station just upstream from the Highway 1 Bridge. In the lagoon, water levels are gauged using two NGVD[5] staff plates located in the northern and southern arms respectively.

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[5] NGVD refers to National Geodetic Vertical Datum 1929; the standard vertical datum for topographic survey.

Figure 2.1. Carmel Lagoon and surrounding area. This image was taken on March 27, 1996.

Figure 2.2 The northern portion (North Arm) of the Carmel Lagoon. Mission Ranch and Carmel By The Sea in the far background.

Figure 2.3 Carmel River Lagoon, January 2001, at close to maximum water level – looking inland toward the river from the sand bar.

Figure 2.4 Seaward view of the Carmel River Lagoon (open) with very low water levels. Here the lagoon is more or less a flowing river, with small pockets of pooled water in the confined South Arm.

Figure 2.5 Looking into the South Arm (center) of the Carmel Lagoon. Note granitic bluffs on the right.

2.2 Salinas Lagoon

The Salinas Lagoon (Fig 2.6) differs from the Carmel Lagoon in size, shape, adjacent landuses, and vegetation. The lagoon is approximately 3 km long and is located in a broad, low-lying, open agricultural setting. Its banks are better defined, so the surface area does not shrink appreciably during the summer. It has a tapered linear outline, sinuously narrowing inland form its widest point of roughly 300 m until it becomes the river itself. The northern bank is well vegetated with semi-aquatic and water-tolerant vascular vegetation. Large woody debris is found scattered throughout the lagoon; but mainly along the northern and western shores. The giant grass, Arundo, is invading the northern banks. The southern banks are actively eroding and have a nearly vertical slope. Currently, riparian restoration efforts are under way along a large portion of the southern bank located in the Salinas River Mouth National Wildlife Refuge as well as agricultural lands neighboring to the east.

Four closely spaced bridges cross the lagoon at a confining point near the river/lagoon interface (the site known as the Twin Bridges). The nearest active and official streamflow gauge is a USGS station located approximately 15km (9.1 miles) upstream from the lagoon at Highway 68 at Spreckels.

Water levels in the lagoon are gauged by a county-maintained staff plate located in the north-western corner of the lagoon. In addition, the county regulates the flow of water down the Old Salinas River Channel, using a manually operated slide gate, which is also located in the northwest corner of the lagoon (Fig. 2.9). However, the outlet gate remains closed during high water events in order to raise the lagoon level prior to breaching. During periods when the sandbar is open, the outlet gate to the Old Salinas River Channel remains closed (Gilchrist et al. 1997).

The majority of fresh water flow entering the Salinas Lagoon during non-event periods comes from the Blanco Drain, an agricultural runoff canal located 8 km (5 miles) upstream from the Salinas River Lagoon, and a wastewater treatment facility near Spreckels. Although this flow is a function of the amount of irrigation and urban use, it does maintain small amounts of perennial fresh water flow into the lagoon. The amount of water and its effect on water quality in the lagoon are not discussed here.

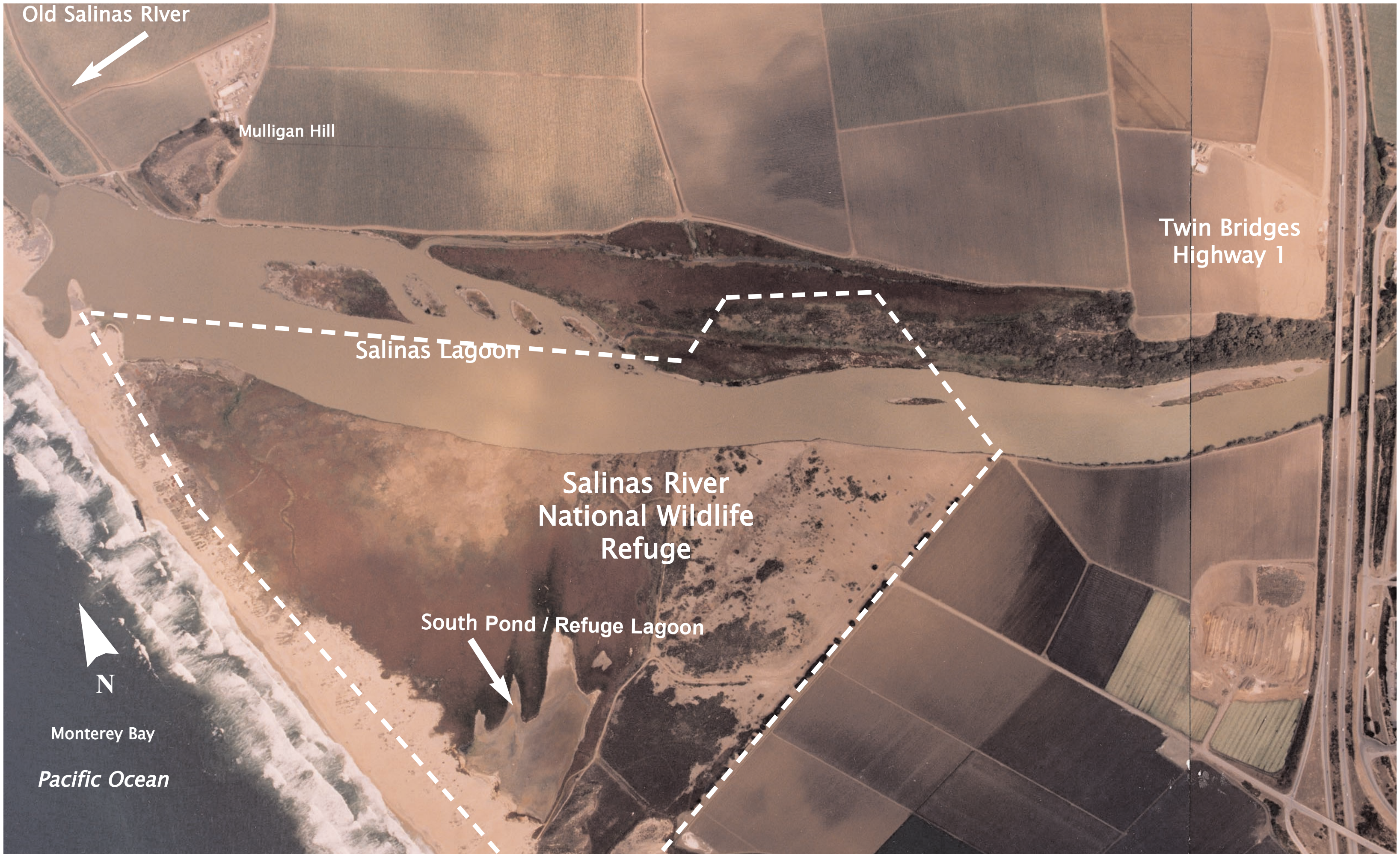

Figure 2.6 The Salinas Lagoon and its surrounding area. This image was taken during an early flood on October 24, 1996. White dashed line represents the approximate boundary for the Salinas River National Wildlife Refuge

Figure 2.7 The shallow waters of the Salinas Lagoon at its north western corner--post breach 2000/01 winter.

Figure 2.8 The Salinas River Lagoon, December 2001, with higher water levels just prior to breaching--looking west at the ocean.

Figure 2.9 The Old Salinas River Channel and flow gates. This channel still occupies the historical route of the Salinas River from the lagoon northward to Moss Landing Harbor via the Potrero Road Tide gates.

3 Methods

3.1 Monitoring

Several sites (7 on the Carmel; 9 on the Salinas) were chosen in the field for detailed water quality monitoring. These were chosen to evenly sample the lagoons with respect to following likely correlates of variation in water quality:

- distance from ocean
- depth to bottom
- proximity to aquatic vegetation
- proximity to river
- windward/leeward side of lagoon

At each site, the following parameters were measured:

- Location
- Depth to bottom
- Water temperature (every 50 cm depth to bottom)
- Salinity (every 50 cm depth to bottom)
- Dissolved oxygen (every 50 cm depth to bottom)

Sampling location was determined by using a *Garmin eTrex Summit* global positioning system (GPS) unit. Using GPS coordinates we were able to return to the same locations in the lagoon with approximately 10 meter accuracy.

Physical water quality data were collected using the *YSI Environmental 556 MPS Multiple Probe System.* Accuracy, range and resolution for temperature, dissolved oxygen and salinity is listed in Table 3.1.

Table 3.1 Accuracy, range and resolution specifications for the YSI 556 Multiprobe System[6]

Sensor	Accuracy	Range	Resolution
Temperature (*YSI Percision^{TM} thermistor*)	± 0.15 ^oC	-5 to 45 ^oC	0.1 ^oC
Dissolved Oxygen (mg/L) (*Steady state polarographic*)	0 to 20 mg/L, ±2% of the reading or 0.2 mg/L, which ever is greater; 20 to 50 mg/L, ± 6% of the reading.	0 to 50 mg/L	0.01 mg/L
Conductivity (*4-electrode cell w/ autoranging*)	±0.5% of reading + 0.001 mS/cm	0 to 100mS/cm	0.001mS/cm to 0.1mS/cm (range-dependent)
Salinity (*Calculated from conductivity and temperature*)	± 1.0% of reading or 0.1ppt, whichever is greater	0 to 70 ppt	0.01 ppt

[6] http://www.ysi.com/environmental.htm

Each of these parameters were measured at the surface and at every 50 cm down until the bottom was reached. The final overall depth was measured based on the length of cable lowered into the water.

Due to the constraints of working on a kayak in inclement weather on short notice, equipment failure occurred on the following occasion:

- Salinity: only one measurement per profile was recorded during the August 28 sampling event on Carmel Lagoon.

In addition to the equipment directly required for measurement of water quality parameters, other equipment on board included:

- mounted storage bins
- duct tape
- staff for measuring depth
- rite-in-the-rain notepad
- camera

A small number of samples were collected during various storms during the early months of 2001. These samples were analyzed for the following parameters:

- NO_3-N (Data not presented in this report)
- NH_4-N (Data not presented in this report)
- PO_4-P (Data not presented in this report)

3.2 Access

The shallow waters of the lagoons are easily accessible by kayak. The use of a tandem kayak allows for easy launching, ability to maneuver between sites with ease and efficiency and it also allows for the transportation and of monitoring instruments (Figure 3.1).

3.3 Mapping

A Global Positioning System (GPS) logging unit was used to locate sampling sites and assist in the collection of bathymetrical data. The *Garmin eTrex Summit* handheld data logger normally results in horizontal positioning errors around ± 5-6 m with no differential correction needed.

Figure 3.1 One of two tandem kayaks used for water quality monitoring showing the variety of equipment used for collecting water quality information, depth, and bathymetrical data.

3.4 Bathymetery

Seven bathymetric transects were measured and mapped in the Carmel Lagoon by Hagar Environmental Science (Hagar, 2002 in prep.) on November 20th 2001. Eight bathymetric transect were measured and mapped in the Salinas Lagoon by CCoWS on March 28th 2002. In both lagoons, the locations of the transects were pre-selected to cover all major geomorphical provinces.

For each transect, a minimum of thirteen bottom to surface measurements were taken. Measurements were taken with a two-meter staff in shallow water and a measuring tape weighted with a lead sinker was used in deeper water.

Access for the shallow transects was done on foot and a tandem kayak and anchor were used in the deeper areas. The anchor was used to minimize drift caused by wind. Due to the wide nature of the Salinas Lagoon, use of a transect tape for measuring distace from the bank was not practicle. Instread, a GPS unit was used to estimate the distance from the bank and orange markers, placed on both banks, were used for navigation.

3.5 Benthic Sediment

Benthic sediments were collected in both the Carmel and Salinas Lagoons in late June of 2002. Samples were randomly collected in all areas of the lagoon to ensure that all likely correlates of variation were covered. Sediments were collected from a kayak using a lightweight bottom-sediment sampling dredge with a $36in^2$ capacity. The location of each collected sample was mapped with a GPS unit. Each collected sample was poured directly into a cloth oven-drying bag.

In the lab all samples had to be dried at 70^o C for at least 48 hours before a total weight could be measured. After drying, each sample is weighed to the nearest milligram. Next, each sample is dry sieved through a 25 mm sieve. All particles >25 mm were weighed and recorded. All samples were then wet sieved through 0.063 mm sieve to remove particles smaller than 0.063 mm. The remainder of the sample, or the median particle sizes, was then placed into a numbered tin and dried again as before.

After the second drying, all samples were re-weighed to find the weight percentage of particles smaller than 0.063 mm. The median classes of each sample, if one existed, were then ran through a Micromeritics (R) OptiSizer Particle Size Distribution Analysis (PSDA). The different particle class sizes used are listed in Appendices C & D. The d_{50} for each sample was calculated and overlaid onto a map of each respective lagoon-Figs. 4.10 & 5.7.

4 Results - Carmel Lagoon

4.1 Summary and Timeline of the 2001/02 Season

Monitoring of the 2001/02 season in the Carmel Lagoon began during the end of August 2001 (Table 4.1). By then, the water level in the lagoon had reached its summer lowpoint of 1.21 m NGVD (3.96 ft). As of October 22nd, the water level rose 0.29 m (0.95 ft), most likely due to ocean wave inputs. Late fall monitoring in November showed a further increase in lagoon water level. Although there were several storms in early November that produced increases in stream flow in the upper Carmel River, the lower reaches of the river remained dry. Thus, the increase in lagoon water level is again attributed to ocean wave in-wash. Streamflow did not enter the lagoon until December 2nd, and reached a pre-breach peak of ~ 6.4 m^3/s (225 cfs), at the USGS gauging station near Highway 1.

Early winter monitoring began on December 3rd. The Monterey County Public Works Department informed CCoWS that the lagoon would be breached later that

Table 4.1. Event timeline and weather summary for the Carmel Lagoon.

Lagoon Condition/Season	*Events*		*Weather Condition*
Closed (summer)	**Aug 28, 2001**	morning	CL,S,B
		evening	O,B
Closed (fall)	**Oct 22, 2001**	morning	O,C
		evening	CL,S,C
Pre-Breach (late fall)	**Nov 20, 2001**	afternoon	O,B
Pre-Breach (winter)	**Dec 3, 2001**	morning	R,B
During Breach (winter)	**Dec 3, 2001 Breach Began ~ 14:00**		
		afternoon	S,P,B
Post-Breach/Open (winter)	**Dec 3, 2001**	evening	P,B
	Dec 6, 2001	morning	CL,S,C
Closed (summer)	**Jul 5, 2002**	morning	P,C
		evening	O,C

General Weather Condition

R = raining | W = windy
S = sunny | B = breezy
O = overcast | C = calm
CL = clear | P = partly cloudy

Figure 4.1 Monterey County Public Works bulldozer in the process of breaching the Carmel Lagoon during the afternoon of December 3, 2001.

Figure 4.2 Standing waves formed during maximum breach flow. Within two hours the lagoon surface level dropped approximately 2.3 meters.

day. Water quality monitoring began at 09:30 hours and continued throughout the afternoon. Manual breaching was successful at approximately 14:00 hours with a peak stage of 3.25 m NGVD (10.66 ft) (Figs. 4.1 & 4.2). After breaching, the lagoon levels dropped 2.5 m (8.20 ft) in less than three hours.

A few days later, on December 6th, the lagoon mouth remained open and the water elevation decreased to 0.77 m NGVD (2.48 ft). Mean daily stream flow into the lagoon had declined to 1.27 m^3/s (45 cfs).

No further monitoring was conducted until early July. On July 5th, the Carmel Lagoon was monitored at 8:00 hours and at 17:00 hours. Streamflow entering the lagoon had ceased. Morning water elevation was 1.34 m NGVD (4.39 ft) and the evening water elevation was 1.32 m NGVD (4.34 ft). The slight variation in lagoon water elevations through the day indicated tidal influence.

Detailed results of water quality and hydrologic monitoring are given in Sections 4.2 to 4.7. Section 4.2 presents daily mean streamflow, lagoon stage, tide levels and significant wave height. These parameters were analyzed in order to detect both the frequency of ocean wave inputs into the lagoon as well actual conditions present when the lagoon was manually breached by MCPW. Section 4.3 contains bathymetric transect data collected at seven different locations in the Carmel Lagoon by Hagar Environmental Science (Hagar, in prep, 2002). Finally, Sections 4.5 (pre-breach), 4.6 (during and after breach) & 4.7 (reclosure) contain a summary of the results for the six monitoring events on the Carmel Lagoon. Figures 4.11-4.13 illustrate seasonal water level change, as well as, temperature, dissolved oxygen, and salinity profiles throughout the lagoon. Further, Figures 4.15-4.17 provide a closer look at how the water elevation and the three water quality analytes changed immediately after the induced breach.

4.2 Carmel River Streamflow and Monterey Bay Oceanographic Data

Following the 2000-1 winter, streamflow into the Carmel Lagoon ceased by June 30, 2001 and remained at zero flow until December 2nd (Fig 4.3). Increases in lagoon water level during fall are therefore ascribed to ocean wave inputs. Based on an analysis of lagoon water levels between 1991 and 1994, James (1994) suggested that the maximum lagoon water level attainable due to ocean wave inputs alone is approximately 2.43 m NGVD (8 ft).

Tidal and ocean wave height data for Monterey Bay (Figs 4.5 & 4.6) are being analyzed to confirm a relationship with increases in lagoon water level. Qualitatively, it is clear from Figure 4.6 that high ocean waves occurred during periods of non-streamflow resulting in a more rapid increase in lagoon water level. Waves were observed to wash into the lagoon on August 28 and October 9th, when the Monterey Bay wave height was recorded as 3.1m (10.17ft) and 3.3m (10.82ft) respectively. In-wash is presumed to have also occurred on many other dates during this period.

Analysis was conducted to detect the occurrence of ocean in-wash using lagoon water level data along with tide and wave height data from NOAA Buoy 46042 Monterey Bay-Figure 4.7. The results suggest that low to medium tide heights (-1 to 1 meter above mean sea level) along with medium sized waves (1.5-3 m) produced the greatest occurrence of wave in-wash. We hypothesize that this is caused by the physical nature of the near-shore bathymetry at the river mouth.

The Carmel lagoon was mechanically breached on December 3rd, 2001 after the river had been flowing for approximately 36 hours. The lagoon stage at the time of breaching was estimated at 3.25 m NGVD (10.66 ft) from staff plate observations. During most years, natural breaching would occur when lagoon water elevation reaches 4-5 m NGVD (12-14 ft) (ENTRIX, 2001). Dettman (1984) states that a flow of 5.66 m^3/s (200 cfs) is needed to naturally breach the lagoon and that a minimum of 2.12 m^3/s (75 cfs) is required to keep it open. On December 3rd, the daily mean streamflow (275 cfs) was enough to breach the lagoon naturally had water levels been able to reach the 4-5 m elevation, which presumably could have occurred later that evening.

High frequency changes in water elevation after the initial breach of December 3rd is indicative of tidal effects while the sandbar was open (Fig. 4.4). In addition, the bar was mechanically breached on other occasions through the end of May. On May 26th, the water elevation in the lagoon changed significantly from 2.48 m NGVD (8.13 ft) at 9:00 hours to 0.82 m NGVD (2.69 ft) at 11:00 hours, suggesting that a breaching of the sandbar had occurred.

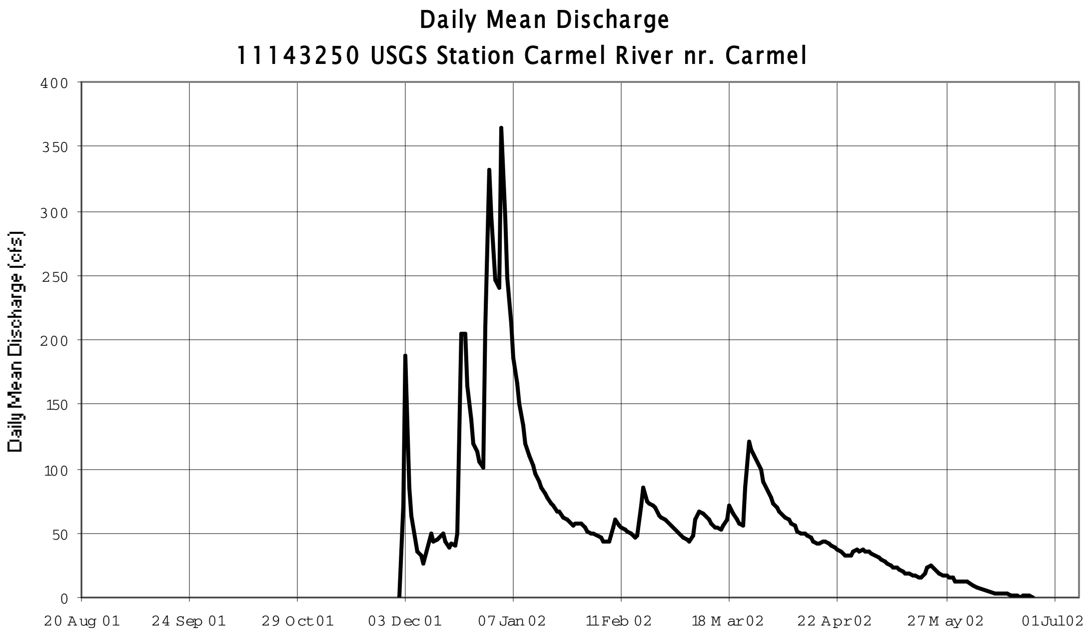

Figure 4.3 Daily mean discharge for the Carmel River USGS station 11143250 nr Carmel Highway 1and seasonal water levels for the Carmel Lagoon. Data range is from August 20, 2001 to July 8, 2002.

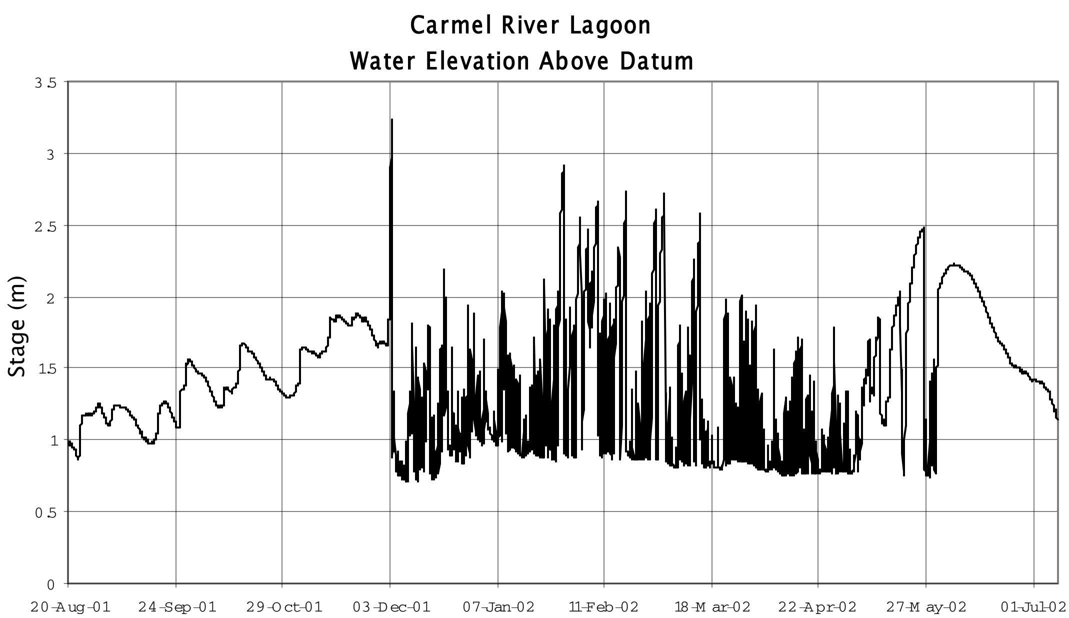

Figure 4.4 Hourly stage data for the Carmel Lagoon. Data range is from August 20, 2001 to January 20, 2002.

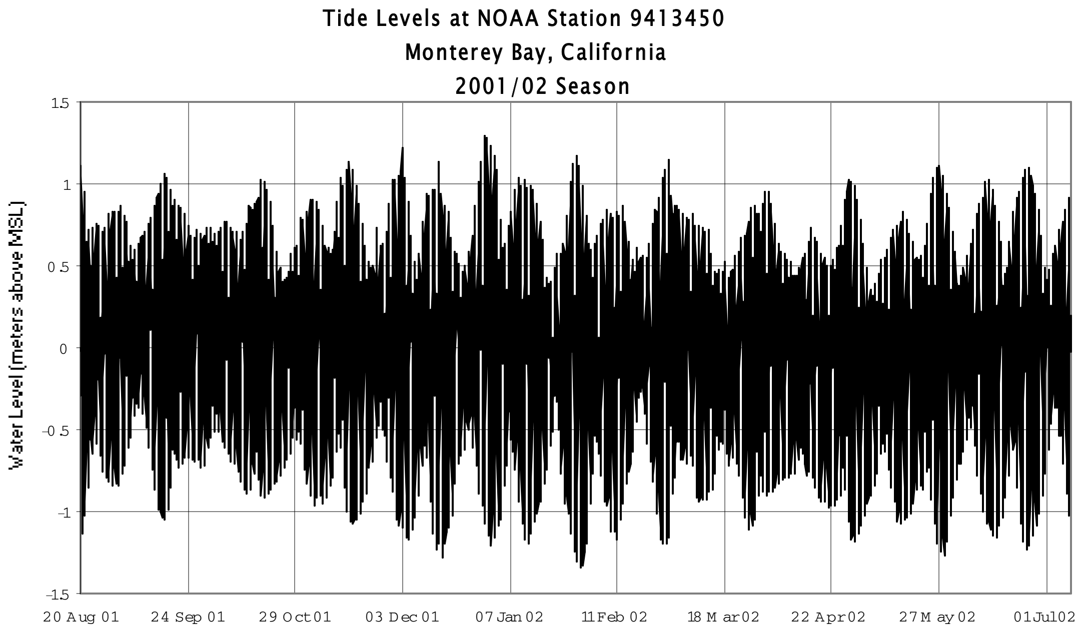

Figure 4.5 Hourly tide levels for Monterey Bay. Data range is from August 20, 2001 to January 20, 2002.

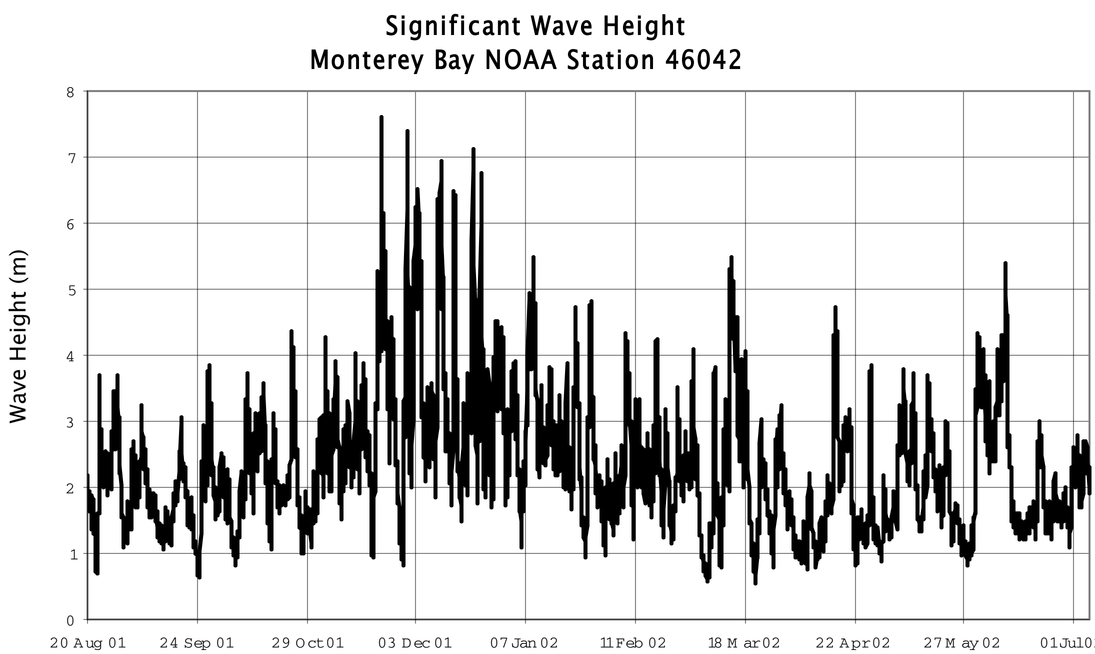

Figure 4.6 Hourly significant wave height[6] for Monterey Bay. Data range is from August 20, 2001 to July 8, 2002.

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[6] The significant wave height data is based on the average height of the highest 1/3 of all waves that occurred during a 20 minute sampling period. Data Source: http://www.ndbc.noaa.gov/measdes.shtml#std-met

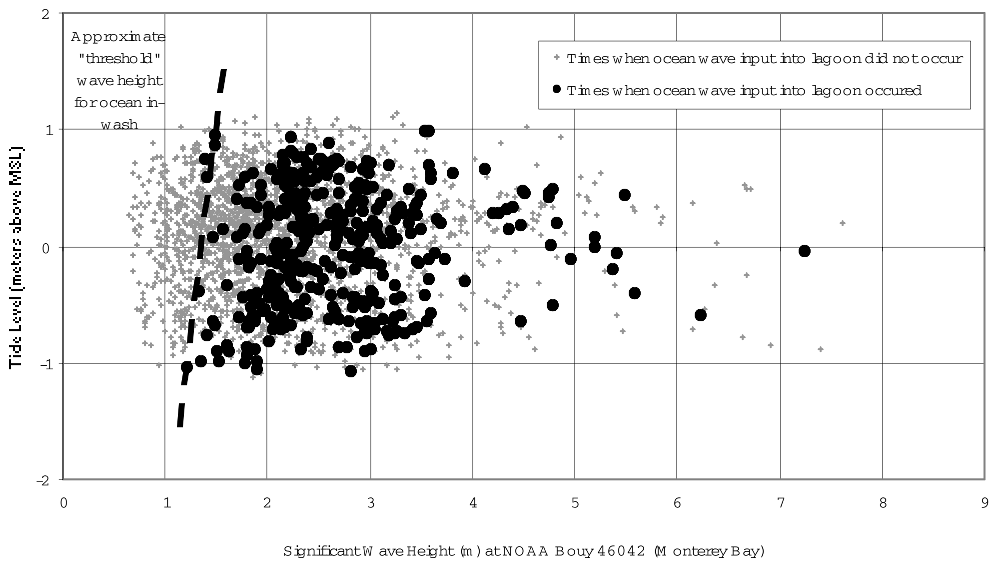


Figure 4.7 Occurrence of ocean in-wash to the lagoon as detected by a water level recorder, plotted against tide level and significant wave height data.

Streamflow at the USGS gauge near Highway 1 continued through June 20th. At this time the lagoon water elevation had already started to decline. As of early July 2002, all surface flow from the Carmel River had ceased, yet it is presumed that limited sub-surface inputs were still occurring.

4.3 Bathymetric Data

Seven bathymetric transects were located and measured throughout the Carmel Lagoon by Hagar Environmental Science (Hagar et. al., in prep, 2002). Measurements were taken on November 20th 2001, at a stage of 1.82m NGVD (5.96 ft.). Figure 4.8 shows the location of the transects and Figure 4.9 shows each of the transects depth to surface plots with maximum and minimum water levels recorded this year.

Transect C is located in the north arm of the lagoon. This area of the lagoon is characterized by a series of narrow/shallow well-vegetated channels that have water present during periods of high water elevation. Transect E, located in the center of the lagoon, is broad and shallow.

Transects J,K, and L are all located in the South Arm of the lagoon. Transect J is closest to the beginning of the South Arm and is the deepest section of the lagoon. The back portion of the South Arm, Transect L, is broad and shallow. This area generally remains dry after the lagoon is breached.

Transects M and Q are found in the eastern mainstem, or transition zone, of the lagoon. Here, the lagoon is still heavily influenced by river channel processes and dense stands of riparian vegetation on both banks of the channel. Moving downstream from Transect Q to M the channel does widen and increase its depth.

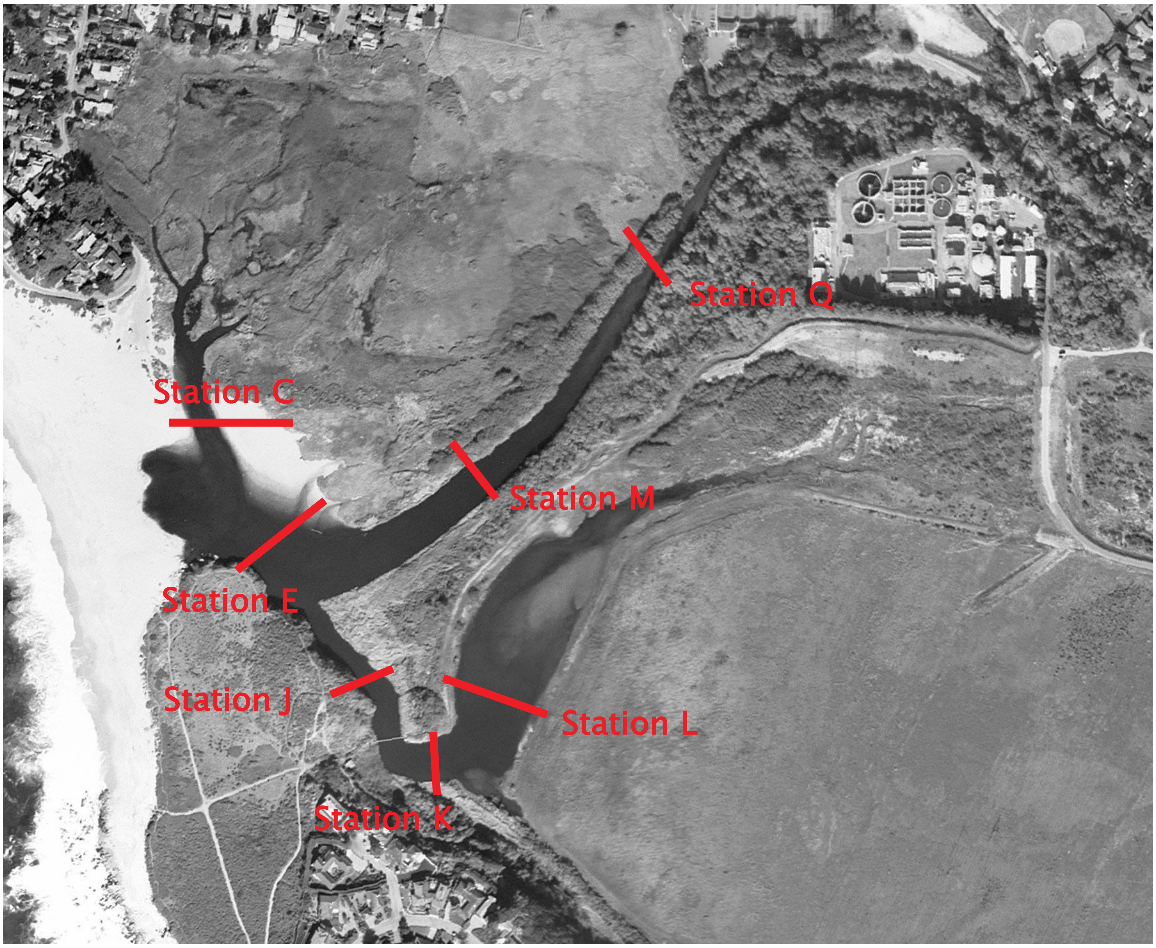
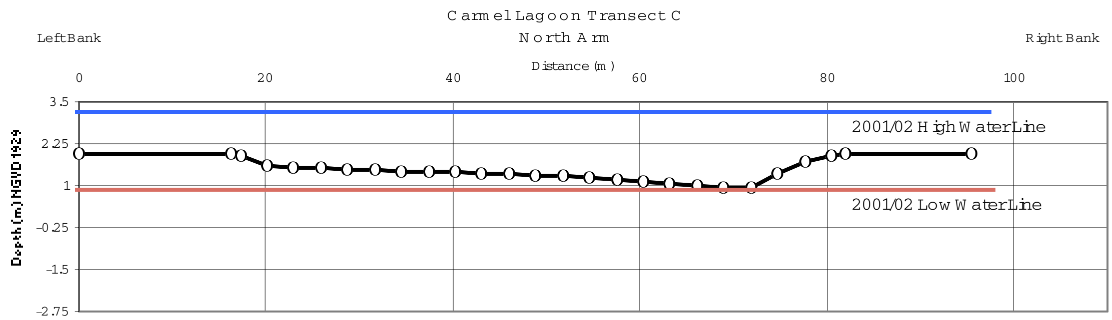


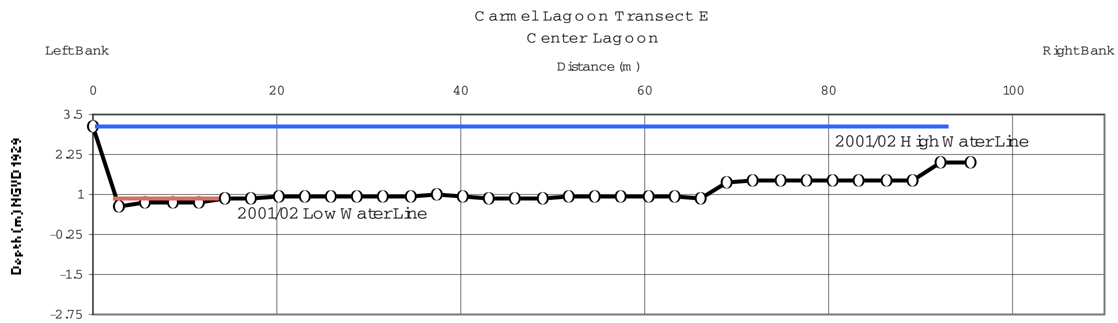
Figure 4.8 Location of bathymetric transects across the Carmel Lagoon surveyed by Hagar Environmental Science in late 2001(data courtesy of Hagar Environmental Science). This image is a Digital Ortho Quad (DOQ) (*c. 1998*).

Figure 4.9 Bathymetric cross-sections of the Carmel Lagoon displayed in order from closest to the ocean (C) to farthest upstream (Q) (data courtesy of Hagar Environmental Science, late 2001).

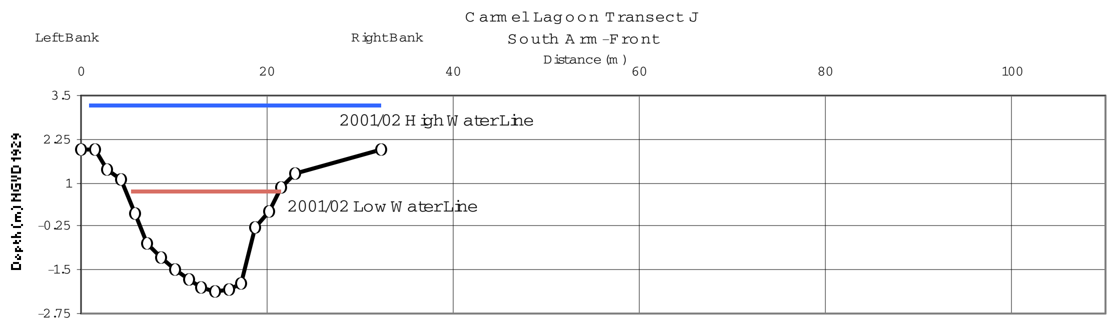
C



E



J



K

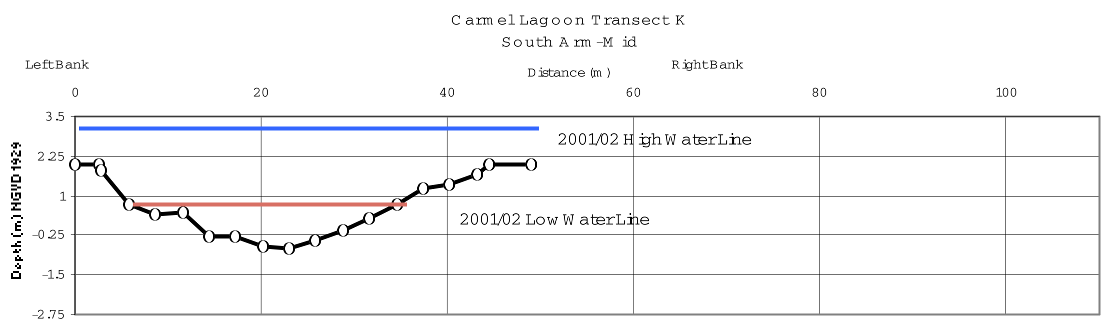


Figure 4.9 Cont.

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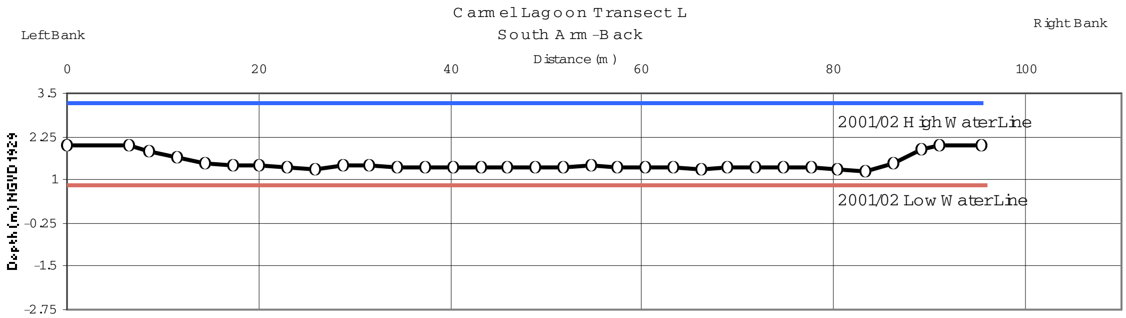

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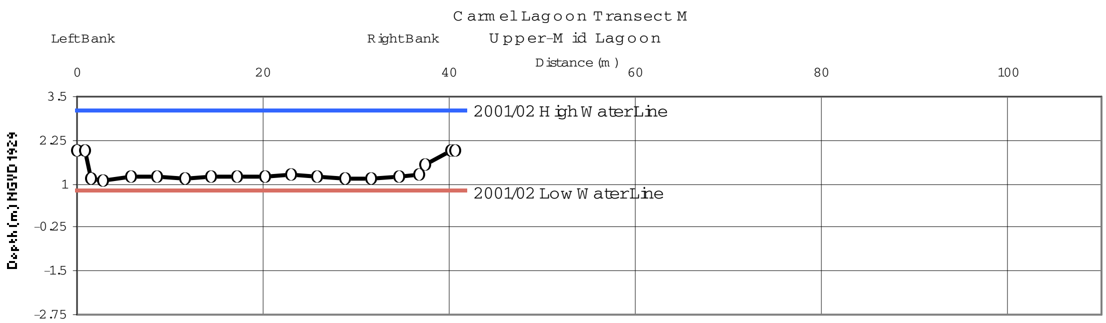

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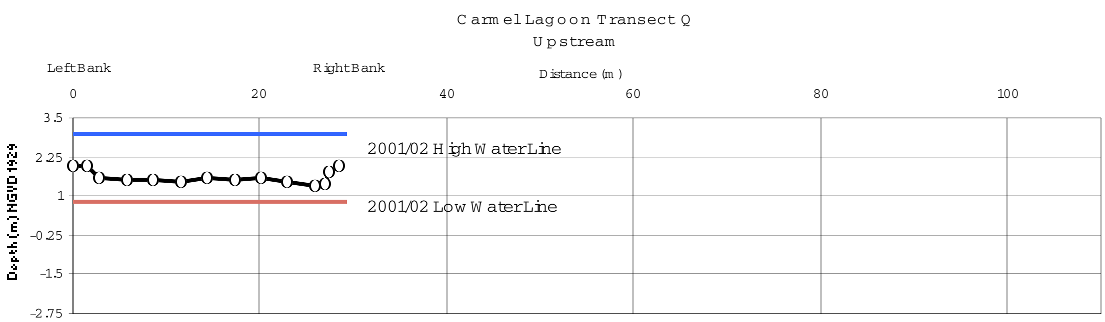


4.4 Benthic Sediment

Benthic sediments are an important indicator of certain longer term aspects of lagoon water quality. The sediment size classes partially determine the habitat for benthic invertebrates and in turn, the food supply for higher organisms such as steelhead trout. The size classes also give an indication of the hydraulic conditions experienced at the lagoon bottom. This affects habitat controls such as mixing of surface oxygen down to deeper waters, and the velocities experienced by migrating organisms.

When the lagoons are closed, benthic velocities are generally very low, being influenced only by wind, limited inflows, and perhaps mild convective circulation. Lagoon breaching creates a radically different hydraulic environment in certain parts of the lagoon. The mouth itself experiences supercritical flow, and similarly high velocities are observed along the main line of flow from the lagoon inlets to the mouth. At these sites, we expect to find only coarse benthic sediments - the fines being easily washed out to the ocean. Backwater and or deep-water areas may then be identified by the presence of residual fine sediments after breaching. Such areas may be beneficial to fauna seeking refuge from the breach, or conversely, they may in-fact be sub-optimal due to poorer mixing and lower dissolved oxygen concentrations. This would depend upon other factors.

The median diameter (d_{50}) in the Carmel Lagoon follows a predictable spatial pattern (Appendix C). The main stem of the Carmel River, as well as the central lagoon, contain coarse sands (1.0-6.29 mm) (Fig. 4.10.) These values indicate areas of higher flow velocities and sediment transport. Fine particles are carried through these areas and out to the ocean. However, near the sand bar the d_{50} decreases suggesting localized post-closure deposition.

The South Arm sites contained d_{50} values < 0.063 mm. This indicates that no significant fresh water or tidal scouring is occurring there. It is hypothesized that overbank flows and possibly past agricultural activity surrounding the South Arm have accumulated fine sediments in this isolated portion of the lagoon. The bottom of the South Arm is well vegetated which may attribute to the accumulation and retention of fine sediments during breaching events.

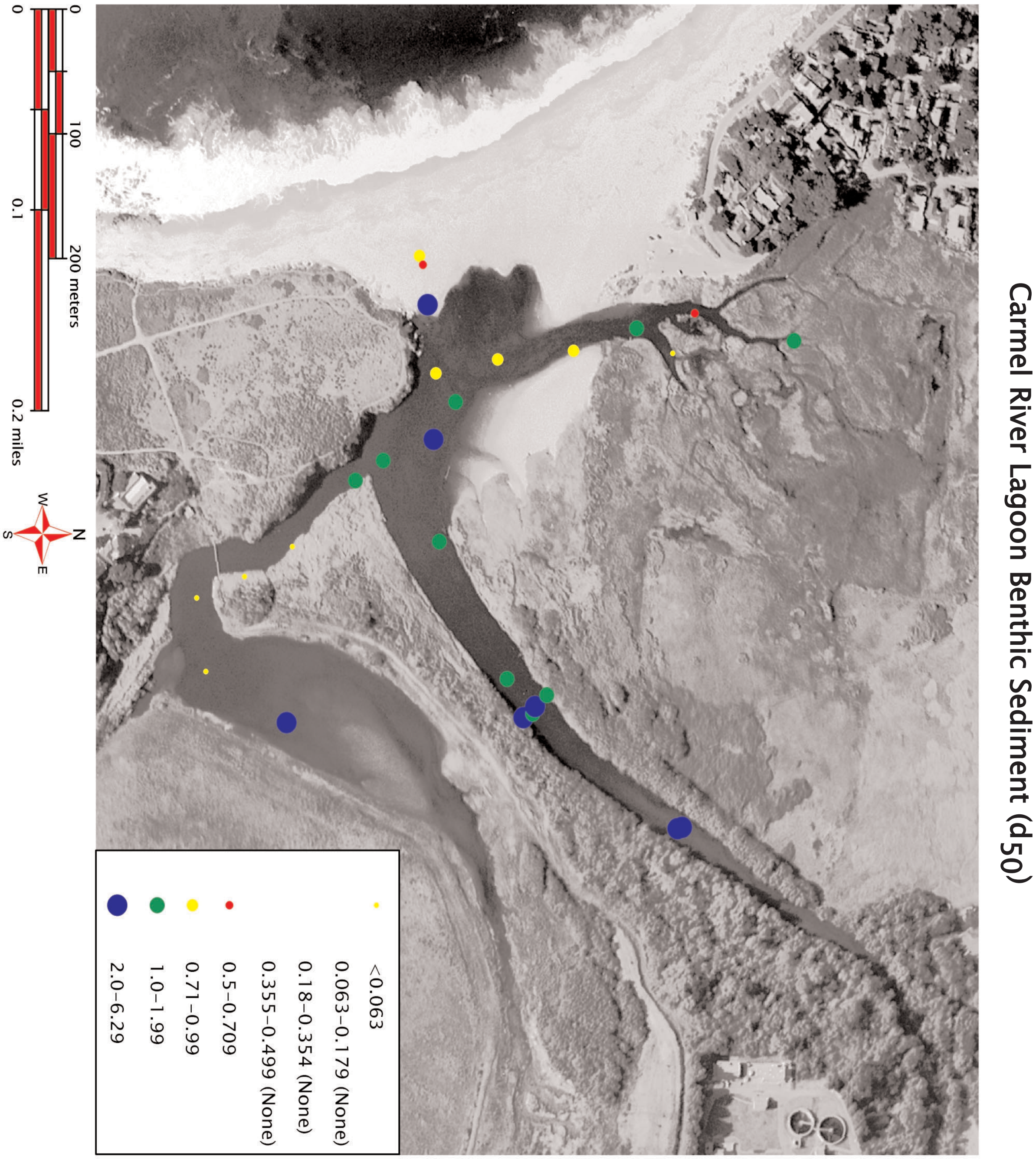


Figure 4.10. Map illustrating the d50 of the Carmel Lagoon. Particle size classes (d50) are in millimeters.

4.5 Water Quality Pre-Breaching

For this section, refer to Figures 4.11 through 4.17 and Appendix A.

August 28, 2001

In late August, lagoon waters are expected to begin a cooling phase due to a reduction in average daily air temperatures from those experienced during July and early August. At this time stream flow was not entering the Carmel Lagoon. Water at all levels was relatively warm, and in agreement with the expectation of an early cooling phase at this time of year, afternoon surface waters slightly cooler than at depth, and significantly cooler at night. Diurnal fluctuation was large at the surface, and minimal at depth. Isothermal conditions persisted to about one meter depth, a result of moderate wind-forced mixing.

Dissolved oxygen concentrations were moderate at the surface, very high (super-saturated) in mid-level waters, and anoxic at depth. This is termed a positive heterograde oxygen distribution (Cole, 1994). Diurnal fluctuation was pronounced at the surface, and slightly lower at mid-level. A number of hypotheses can be invoked to explain the positive heterograde oxygen distribution observed in late summer and early fall for this lagoon. The first is that higher air temperatures may have occurred just prior to sampling, so that surface layers were cooled relative to layers deeper than the typical mixing depth (~1m). This hypothesis is confounded by the fact that the warm mid-level waters are observed in almost every summer and fall sampling event. The second hypothesis is that a positive feedback is occurring between algal production and light absorption at all depths-higher production leads to greater opacity, greater absorption of solar radiation, warmer temperatures, which completes the cycle by fueling higher production. The surface layers may experience this phenomenon equally as much as the deeper layers, but their exposure to the colder atmosphere at night means that they would equilibrate at a lower temperature than the deeper layers. A third hypothesis involves photo-inhibition - lower production due to super-saturated light (particularly ultra-violet) levels in the uppermost layers. This is unlikely to explain all observations, as photo-inhibition is generally limited to depths less than one meter (Cole, 1994). A fourth hypothesis is that both surface and mid-level waters display algal production capable of super-saturating the water with oxygen, but that only the surface waters may degas this excess oxygen to the atmosphere. Surface DO is slightly higher above the deeper, more-productive mid-level waters, which suggests diffusion of oxygen upward from the mid-level hyper-oxic layers. Yet another hypothesis is that the algal or bacterial species responsible for the production of oxygen are sensitive to turbulence near the surface, or display optimal photosynthesis in lower light conditions.

Brackish water was observed through the lagoon, as would be expected after several months without freshwater input. The surface meter was well-mixed by wind, with salinity thereafter increasing through density stratification to near-seawater levels at the bottom of the sump in the South Arm.

October 22, 2001

By late October, air temperature was considerably cooler than in late August. Significant ocean wave in-wash was observed entering the lagoon, and kelp was littered throughout the lagoon. Water temperatures were 4-8 degrees cooler than in August, probably through a combination of influences from cooler air and cooler ocean water. Surface temperatures were cooler than mid-levels depth, suggesting an air-cooling influence. But also, deep waters were cooler than mid-level waters, suggesting either an ocean influence as wave in-wash flows down the lagoon-bottom slopes to the South Arm sump, or a net upward convective heat flow toward the cooler air, mitigated by the heat of mid-level production zone. Diurnal fluctuation was high at the surface, and negligible below about 1.5 meters depth. The wind-mixed isothermal layer was slightly shallower than in August, at about 75 cm. Note that lagoon turnover due to colder surface temperatures, as observed in freshwater lakes, does not occur here because of the over-riding influence on the density of the more saline water at depth.

The dominant feature of the DO profile remained the mid-level super-saturation, accompanied by high diurnal fluctuation at both surface and mid-levels. This implies that a pronounced production/respiration cycle had continued through mid-Fall, and that the mechanism causing the positive heterograde oxygen distribution was still in operation. Surface DO was lower near the lagoon mouth, either because of the lower DO of ocean water washing in, or because of the absence of upward oxygen diffusion from a super-saturated layer beneath, or perhaps because of respiration associated with kelp decomposition in this area.

Overall salinity had increased since August and is quantified in Figure 4.11. A density stratification persisted, with near-seawater at depth. Mid-level waters above this deep water were saltier than elsewhere, implying that turbulent diffusion at around 1.5 meters was significant.

November 20, 2001

By November 20th, the weather was characterized by cool temperatures, overcast skies, and breezy conditions. Ocean in-wash had raised the lagoon level by about 0.5 meters. Surface and mid-water temperatures had cooled a few degrees in the past month, but the deep water temperature remained the same. Afternoon dissolved oxygen was much lower, falling below saturation levels in the mid-water for the first time since summer, and the profile was clinograde, monotically decreasing with depth. Algal production was probably minimal, being limited most likely by temperature, daylength, or possibly the lack of available nutrients. Salinity profiles were indicative of a basin of salt water almost completely filling up due to wave in-wash, below an evaporating, brackish surface layer. The halocline had risen about 0.5 meters in the previous month.

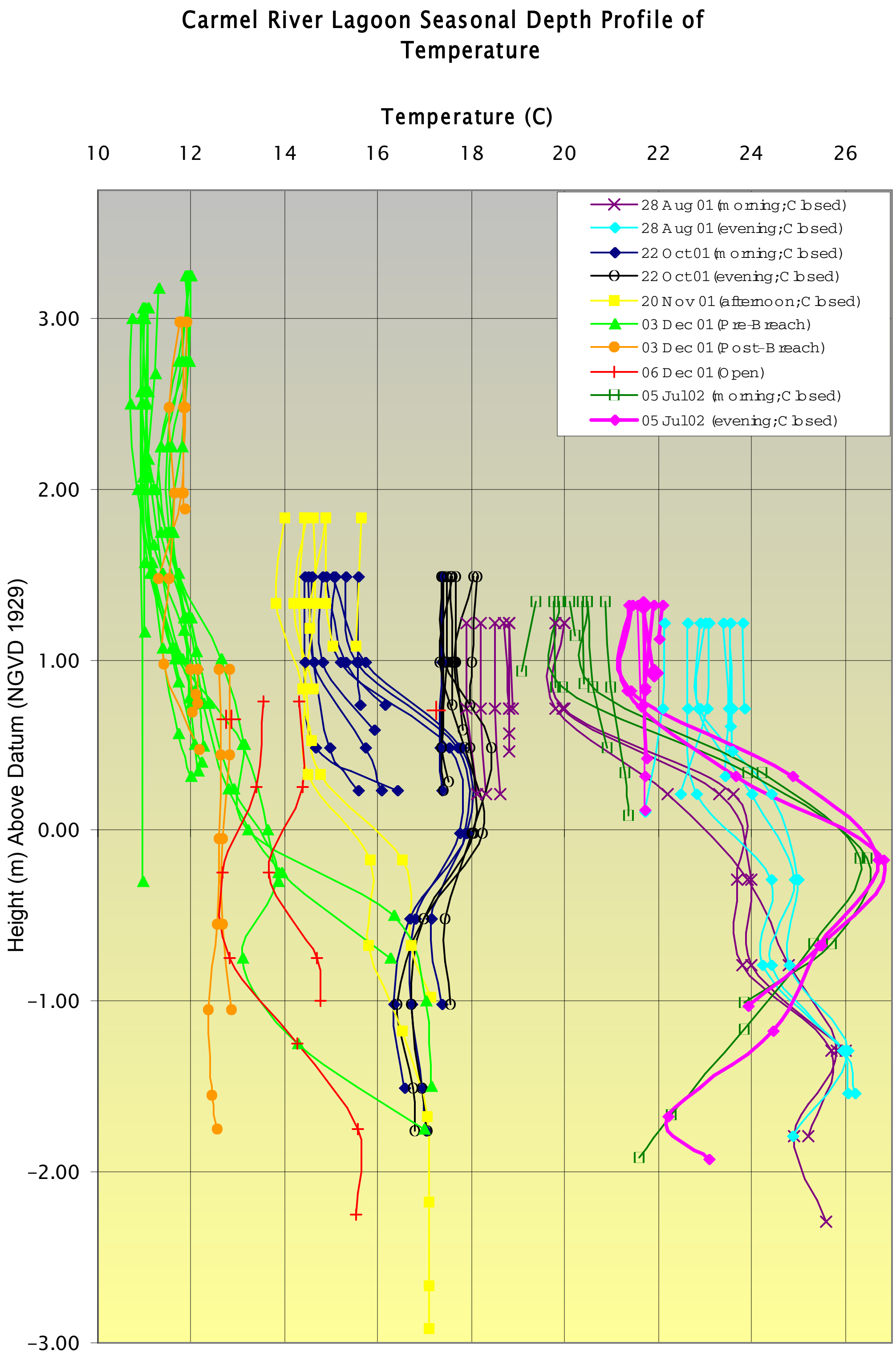


Figure 4.11 Carmel River Lagoon depth profile of temperature for all seasonal and lagoon conditions.

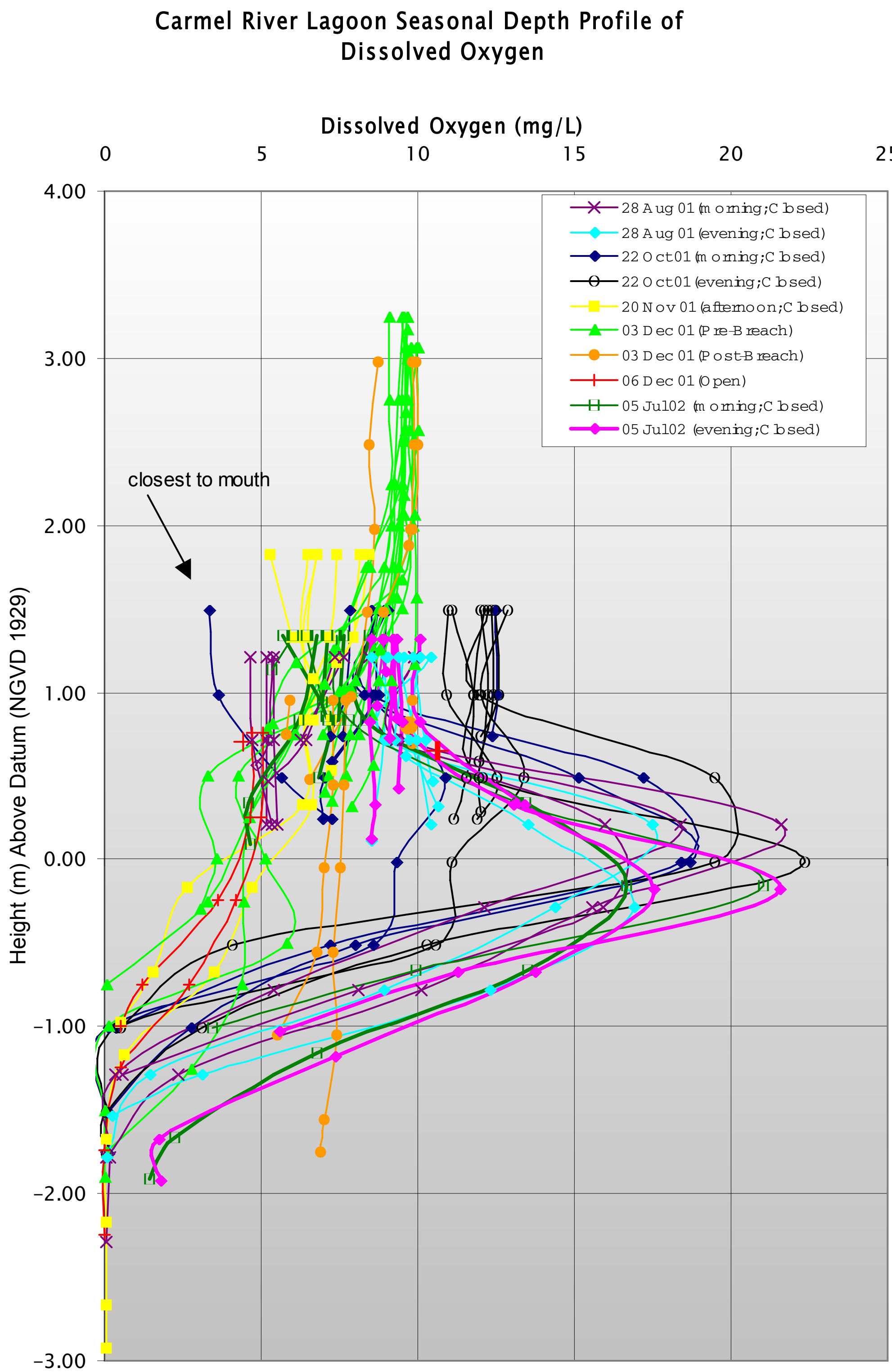


Figure 4.12 Carmel River Lagoon depth profile of dissolved oxygen for all seasonal and lagoon conditions.

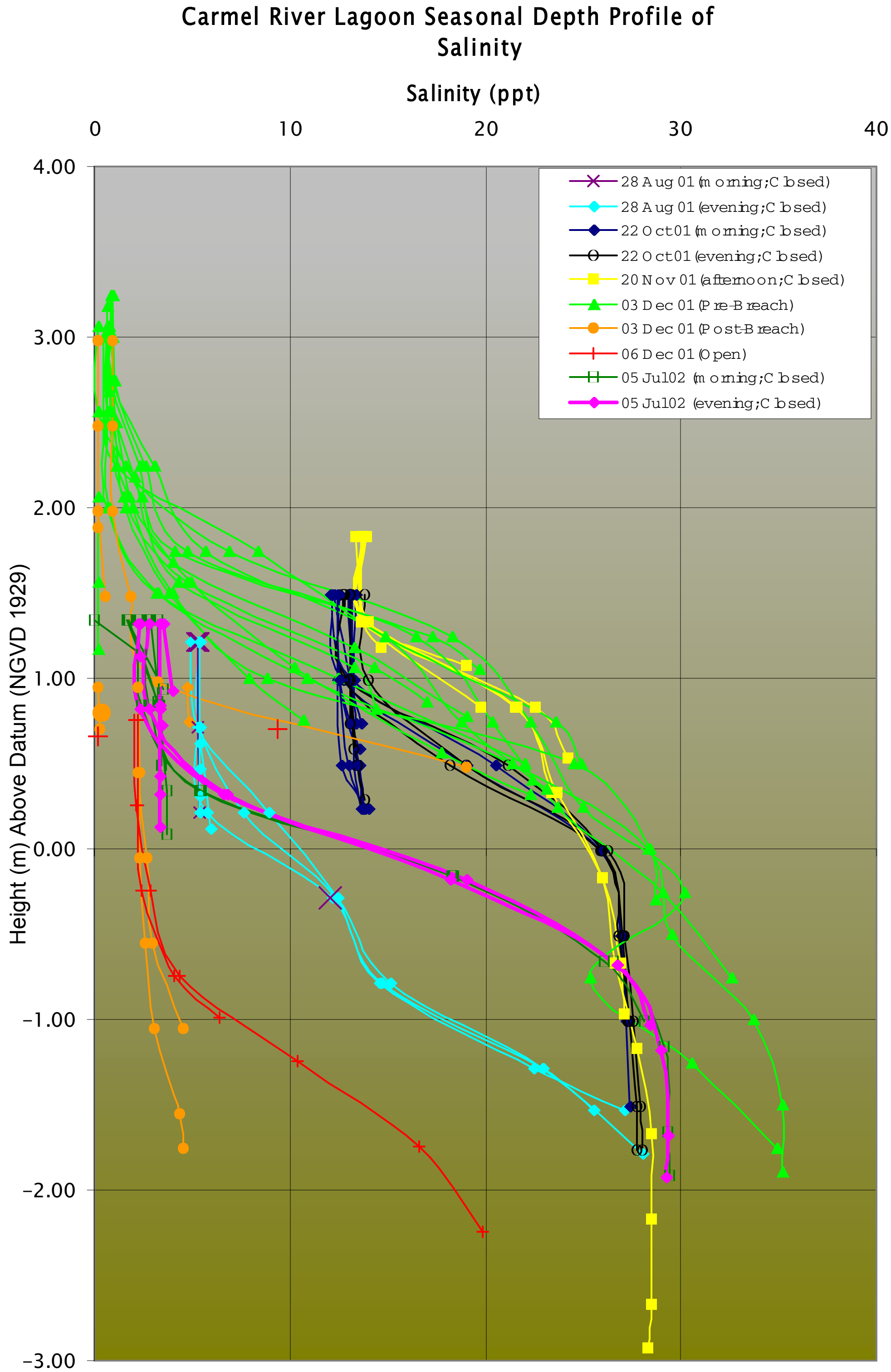


Figure 4.13 Carmel River Lagoon depth profile of salinity for all seasonal and lagoon conditions. Note: Missing much of the morning data for August 28, 2001.

4.6 Water Quality - during and after breaching

For this section, refer to Figures 4.11 through 4.17 and Appendix A.

December 3, 2001

Just prior to breaching, freshwater inflows had built up the surface layers to a uniformly cold, oxygenated, fresh two meter layer. Below this, the water was slight warmer, de-oxygenated, and saline - all residual features from previous months.

The breaching flow was violent, draining the entire lagoon in about two hours with high velocity, high volume flows forming standing waves over two meters high at the mouth (Fig. 4.14). The pre and post-breach depth profiles indicate that most of the drained water was taken from the upper 2.5 meters of the lagoon, but that the deeper water in the South Arm sump was by no means hydraulically isolated. The deep-water thermocline became isothermal over the bottom 2.5 meters; the near-benthic anoxic zone was enriched to moderate oxygen levels, and the slightly hypersaline sump became almost fresh in places. The South Arm sump is not in the direct path of the River as it flows to the ocean,

Figure 4.14 The mixing of fresh and salt water shortly after the Carmel Lagoon breached at approximately 14:00 of December 3, 2001.

and yet its waters became well mixed to depths well below sea-level. This indicates that the shear forces imparted by the River and breaching flows adjacent to the South Arm, and by the surface waters of the South Arm as they passed over the sump were sufficient to induce turbulence down to a depth of 2.5 meters below the eventual post-breach water level.

The mixing down to deep levels may not have been turbulent enough to displace and entrain the fine sediments that rest there. The benthic particle size data collected in the following June indicate fine sediments in the sump, at least in the uppermost 10 cm. Our observations do not suggest a significant winter input of fine sediments to the sump during the winter of 2001-2002 after the December 3rd breach. During the few storms that did occur, the river was relatively clear, and there was a sharp lateral boundary layer between stream flow and placid lagoon waters above the sump across which there did not appear to be significant fine sediment flux.

Data from the previous season's breach are not as detailed (Watson et al., 2001). The breach itself was not as violent, and the first post-breach monitoring was done some days afterwards, and did not sample the very bottom of the lagoon. However, isothermal conditions below sea level indicate that there is some evidence for deep mixing associated with the breaching process.

December 6, 2001

Almost immediately after the breaching day on December 3rd, the well-mixed, and now much shallower lagoon waters began to re-stratify. During this week, both ocean and air temperatures were around 13 degrees, but the deep lagoon water heated to over 15 degrees. This is most likely due to groundwater heat flux upward from the saturated lagoon sediments overlying the lower Carmel aquifer. Given that the sump water temperature had been around 17 degrees for the past few months, it would be expected that the sub-lagoon groundwater would have locally equilibrated to this temperature and could retain this heat for later dissipation back into the newly mixed lagoon water after breaching. A small amount of surface warming was evident at the backwater sites in the South Arm, perhaps due to sensible or radiative heat fluxes, and mixed down to about 0.5 m.

Deep-water dissolved oxygen remained low during this period, removing the possibility that the deep-water warming might have been due to inflow from warmer, oxygenated surface sources, or some phenomenon related to algal-production. The lagoon sediments would be expected to be low in oxygen due to respiratory processes. Surface oxygen was moderate in the lagoon proper, and saturated upstream in the River itself. The moderation of oxygen rich river water in the lagoon may have been due to mixing with tidal ocean water.

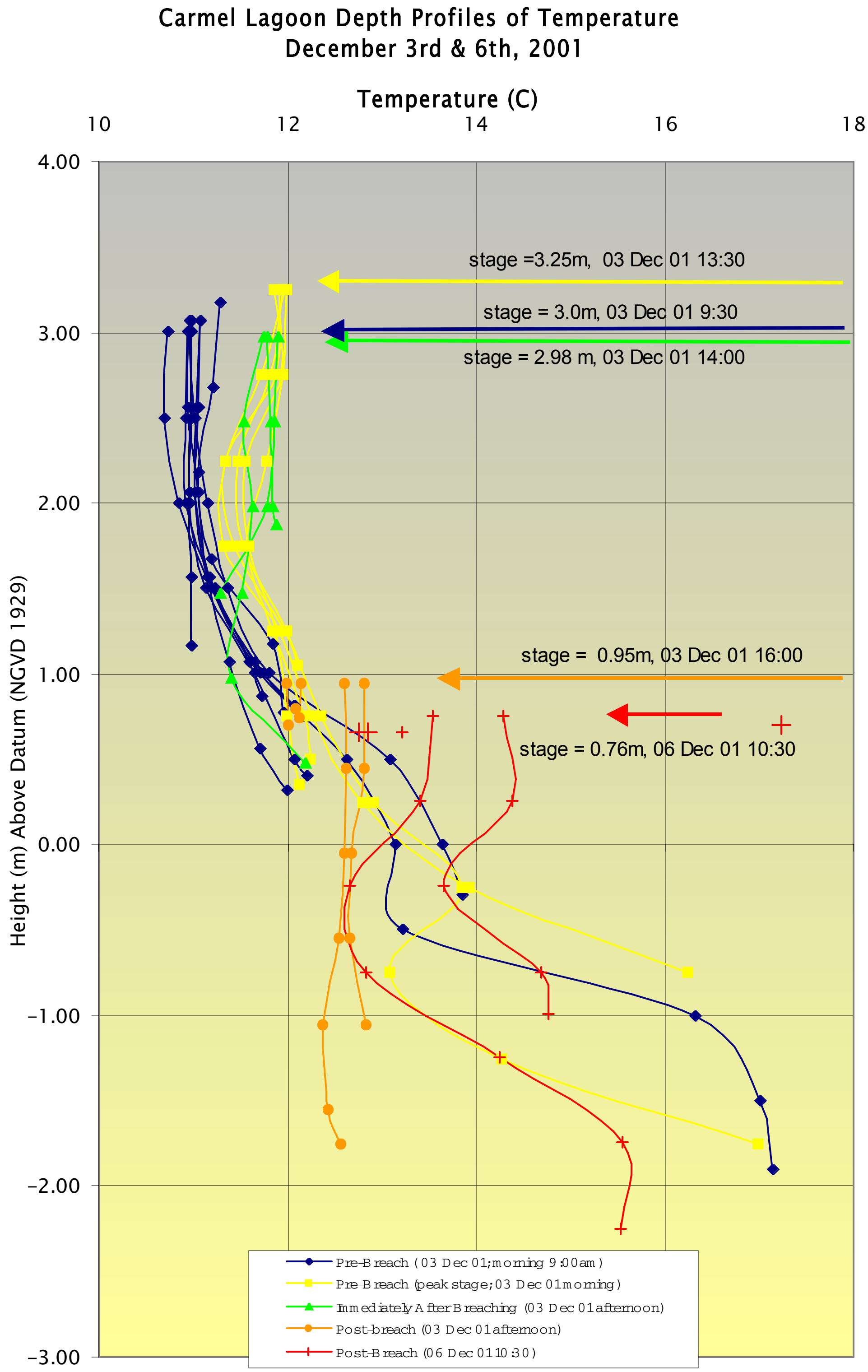


Figure 4.15 Stage/timeline of depth profile measurements for temperature during December 3&6th monitoring events. Note the change in surface level in the lagoon between 13:30 and 16:00 of December 3, 2001.

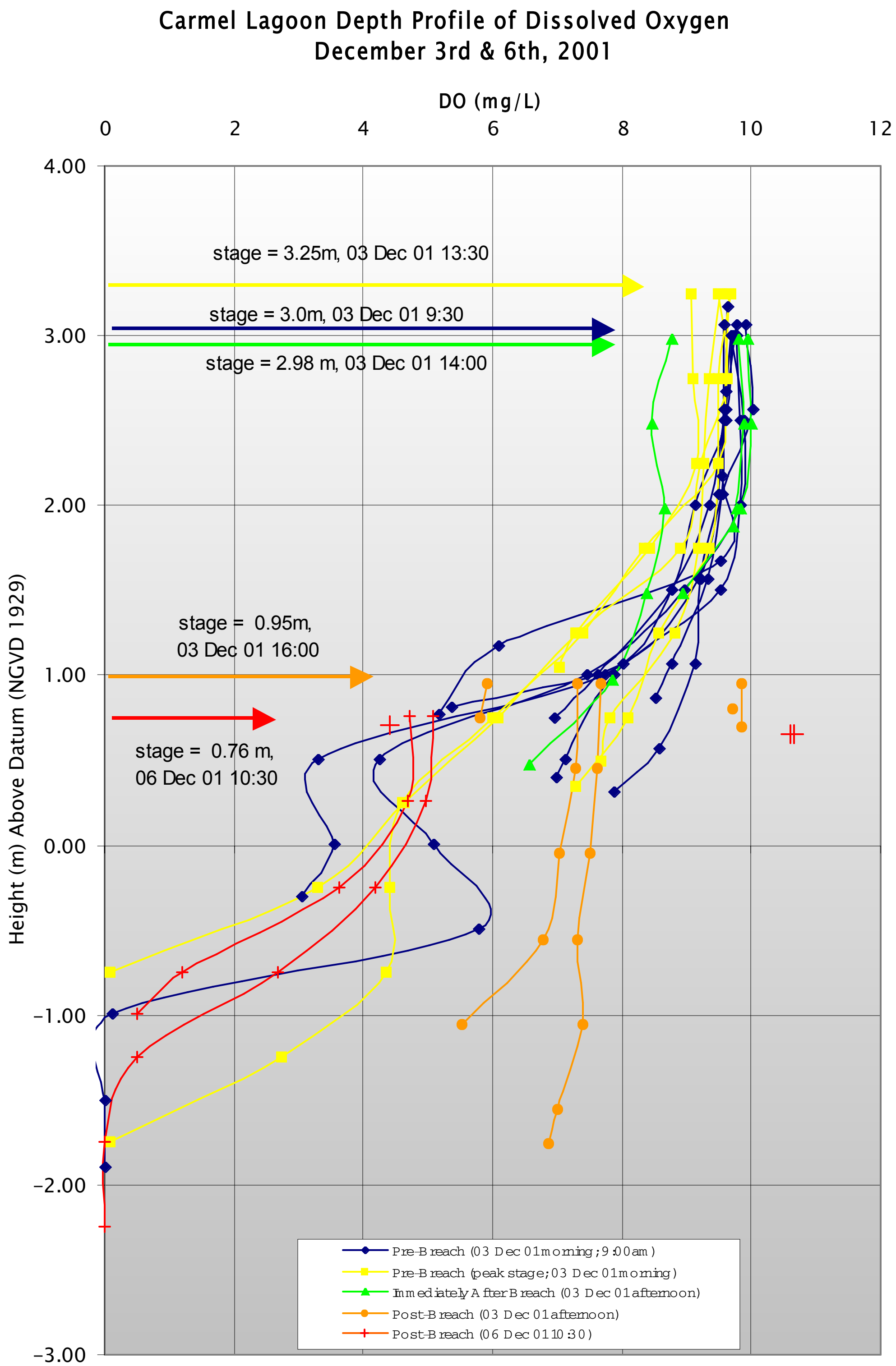


Figure 4.16 Stage/timeline of depth profile measurements for dissolved oxygen during December 3&6th monitoring events. Note the change in surface level in the lagoon between 13:30 and 16:00 of December 3, 2001.

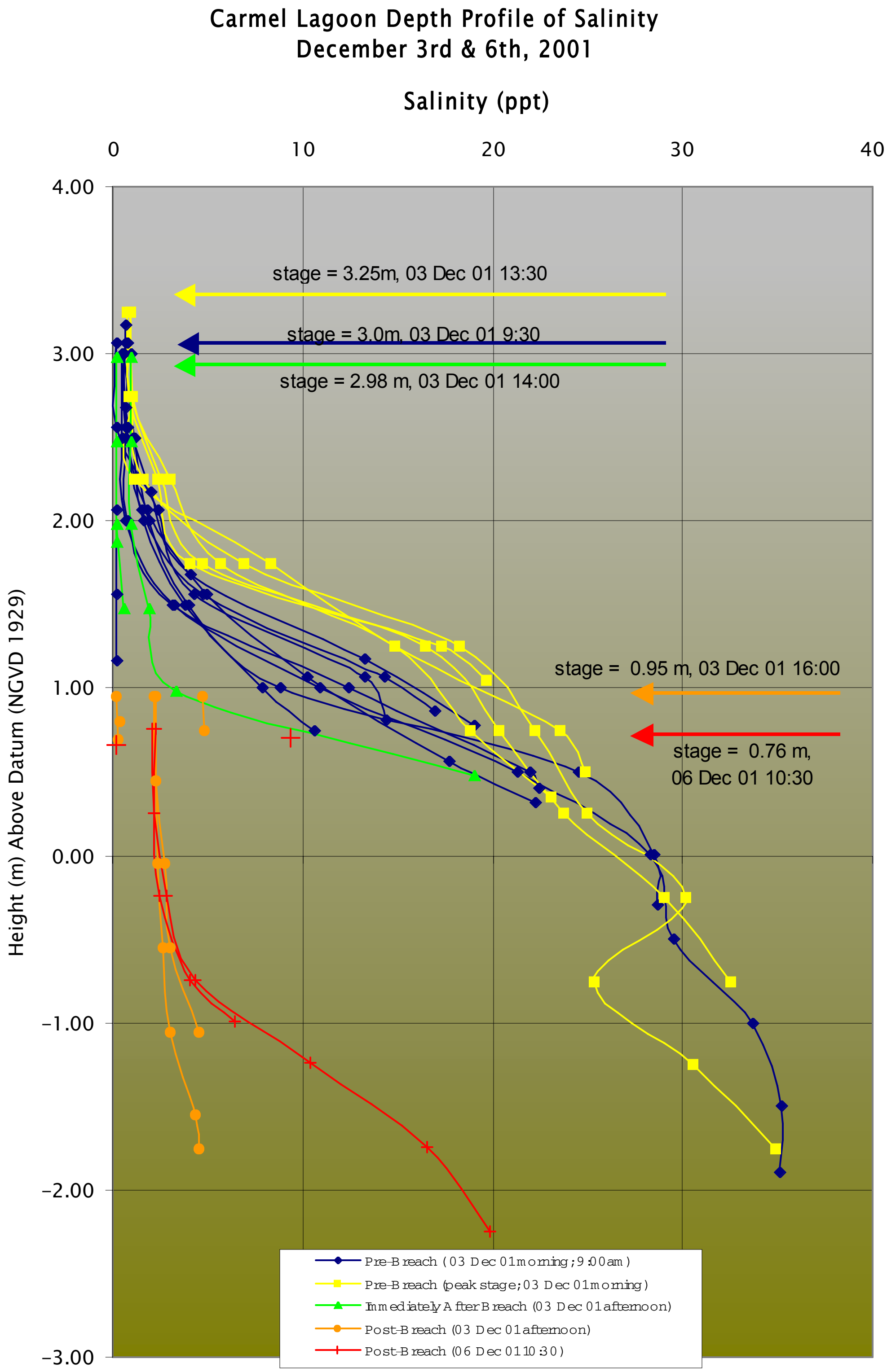


Figure 4.17 Stage/timeline of depth profile measurements for salinity during December 3&6th monitoring events. Note the change in surface level in the lagoon between 13:30 and 16:00 of December 3, 2001.

4.7 Water Quality Post Reclosure

July 5, 2002

By the following July, the lagoon waters appeared much as they had in the previous August. A spate of above average air temperatures was in progress. The mid-level water was significantly warmer than the layers above and below. Diurnal fluctuations were highest in the well-mixed surface meter. Dissolved oxygen also peaked in the mid-level waters at super-saturated concentrations typical of algal production, heralding a return to positive heterograde oxygen distribution. The surface was brackish, and the deep water was saline.

The lagoon is thus characterized at this time as having a cool to warm, oxygenated, wind-mixed surface layer that interacts daily with the atmosphere; underlain by a non-mixed zone of warmer super-saturated water hypothesized to be some form of solar radiation sink; below which is a darker, cooler, inactive saline zone above the benthos. This condition is typical of the summer months when the lagoon is closed to the ocean, with no surface water inputs, and is experiencing evaporative loss.

5 Results - Salinas Lagoon

5.1 Summary and Timeline of the 2001/02 Season

Physical water quality monitoring of the Salinas Lagoon began on August 30th 2001 –Table 5.1. At this time the lagoon water level was 0.76m NGVD (2.50ft.).

Fall monitoring of the Salinas Lagoon was done on October 24th at a water elevation of 0.30m (0.98 ft). The lower water levels in the lagoon are presumed to be the result of maintaining fresh water flow down the Old Salinas River Channel and evaporation.

Pre-breach conditions were monitored on December 4th. By then, surface level in the lagoon had increased to 1.89m NGVD (6.20ft.). Recent storms had produced light to moderate inflow from the Salinas River. Just prior to breaching, daily mean stream flow at the USGS gauge near Spreckels was 13.5 m^3/s (478 cfs).

The Salinas Lagoon breached itself sometime in the late evening of December 4th 2001. County employees estimated that the lagoon breached at approxi-

Table 5.1 Event timeline and weather summary for the Salinas Lagoon.

Lagoon Condition/Season	*Monitoring Timeline and Weather Conditions*		
Closed (summer)	**Aug 30, 2001**	morning evening	O,B O,B
Closed (fall)	**Oct 24, 2001**	morning evening	CL,C CL,C
Pre-Breach (winter)	**Dec 4, 2001**	morning	CL,C
Lagoon Breached (winter)	**Dec 4, 2001 (~23:00)**		
Post-Breach (winter)	**Dec 5, 2001**	morning	O,W
Closed (summer)	**Jul 3, 2002**	morning evening	P,C CL,B

General Weather Condition

R = raining	W = windy
S = sunny	B = breezy
O = overcast	C = calm
CL= clear	P = partly cloudy

mately 23:00 hours due to a combination of large surf and high water levels in the lagoon . However, they estimated that the lagoon was only open for a brief period and by the next morning the sandbar had reformed.

On the 5th of December, low to moderate stream flow 5.7 m^3/s (200 cfs) was still coming into the lagoon. However, due to the small breach, levels in the lagoon decreased to 1.40m (4.60ft.) as of 10:30 hours.

The final monitoring event was conducted on July 3rd 2002. Measurements were taken during both the morning and early evening hours of the day. There was no streamflow at the Spreckels USGS gauge. Any fresh water coming into the lagoon at this time would have been tail water from the Blanco Drain.

Detailed results of hydrologic monitoring and water quality are given in Sections 5.2 to 5.7. Section 5.2 presents daily mean streamflow, lagoon stage, tide levels and significant wave height. Section 5.3 contains bathymetric transect data collected at eight different locations in the lagoon by CCoWS. Section 5.4 contains the results for the benthic sediment samples collected throughout the lagoon.

Finally, Sections 5.5, 5.6 & 5.7 are a summary of the results for the five monitoring events on the Salinas Lagoon. Figures 5.9-5.11 illustrate seasonal water level change, as well as, temperature, dissolved oxygen, and salinity profiles throughout the lagoon.

5.2 Salinas River Streamflow and Oceanic Data (Monterey Bay)

Salinas River streamflow at the USGS Spreckels Gauge ceased as of July 15th 2001. Water released from the San Antonio and Nacimiento Dams did not reach Spreckels except for a brief period in mid September-Figure 5.1.

An increase in lagoon water elevation during mid November is presumed to be the result of ocean wave in-wash and/or water pumped into the lagoon from the Blanco Drain-Figure 5.2. Detailed records of water pumping into the lagoon from the Blanco Drain and water releases from the lagoon into the Old Salinas River do not exist. Thus, the absence of these records prevent any further quantitative water balance analysis (i.e. the detection of ocean wave in-wash coming into the lagoon).

On December 3rd, 2001, the Salinas River re-connected due to a series of storms in late November and early December. As a result of this streamflow, water elevation in the lagoon began to rise significantly reaching 1.93 m NGVD (6.32 ft) -Figs 5.1 & 5.2. On December 4th, high lagoon water levels along with significant incoming streamflow [13.53 m^3/s(478 cfs)] and high surf, naturally breached the lagoon at approximately 23:00 hours. However, the duration of this breaching was brief and only lowered lagoon levels to 1.43 m NGVD (4.70 ft) as of 8:00 hours on December 5th. Later that evening the sandbar had reformed.

On December 24th at approximately 14:00 hours, the Salinas Lagoon was mechanically breached by MCWRA after lagoon levels rose to 2.07 m NGVD (6.82 ft.). The lagoon remained open through early January. Intense fluctuations (Fig 5.2) in the lagoon water elevation data after the December 24th confirm this. These intense fluctuations show the rise and fall of the tide within the Salinas Lagoon while the mouth was open.

The 2001/02 winter peak daily mean discharge at the USGS Spreckels Gauge on the Salinas River was13.90 m^3/s (491 cfs) on December 31st, 2001.

During late spring and summer, water elevations in the lagoon fluctuate due to water releases down the Old Salinas Channel as well as the addition of pumped tail water from the Blanco Drain. Water released from the Nacimiento and San Antonio Dams rarely reaches the lagoon.

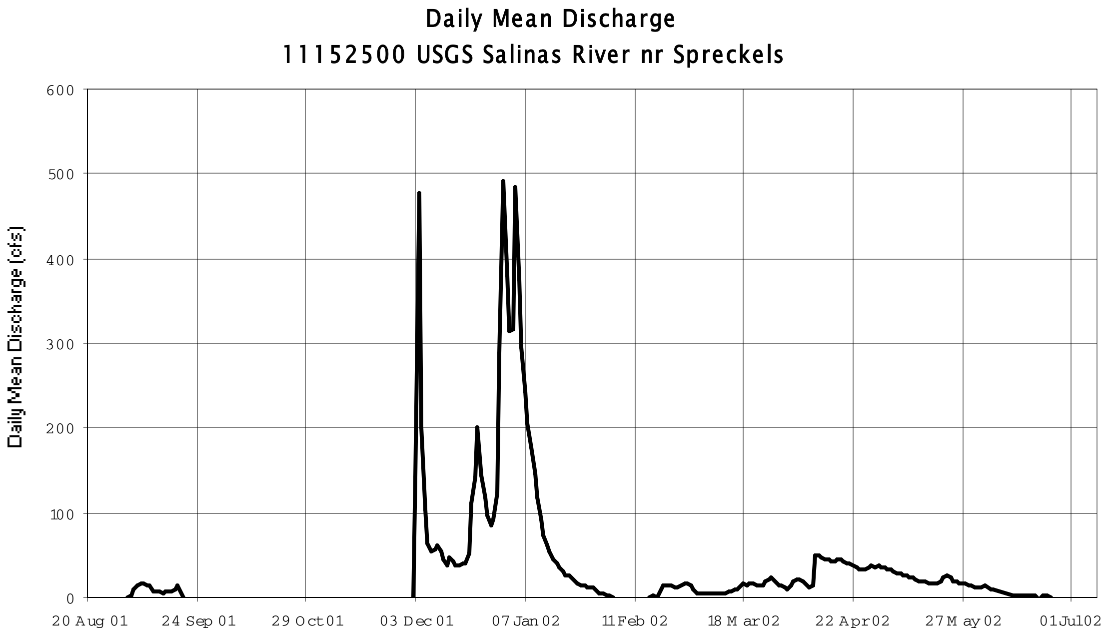


Figure 5.1 Daily mean discharge for the Salinas River USGS station 11152500 nr Spreckels and seasonal water levels for the Salinas Lagoon. Data range is from August 20, 2001 to July 8, 2002.

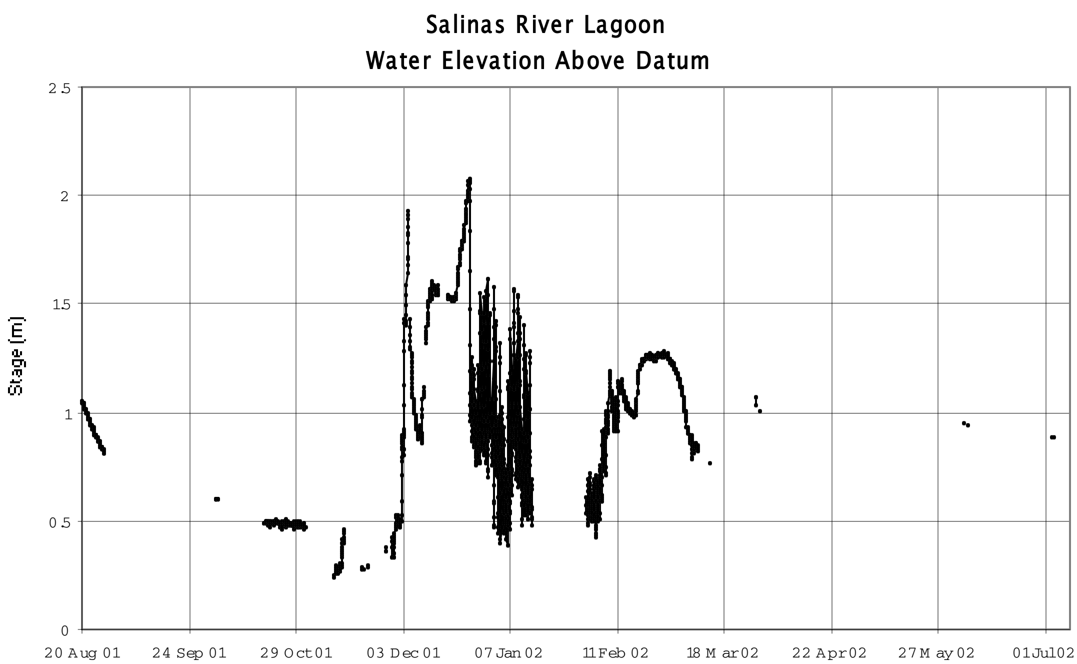


Figure 5.2 Salinas Lagoon water levels. Data range is from August 20, 2001 to July 8, 2002. <u>Note</u> some data not available.

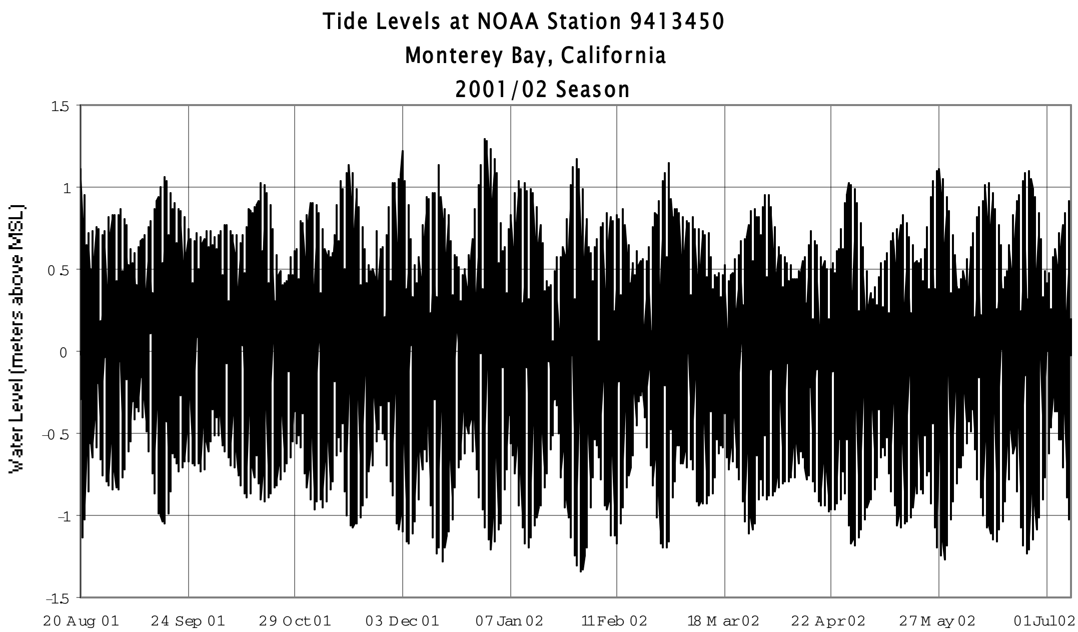


Figure 5.3 Hourly tide levels for Monterey Bay. Data range is from August 20, 2001 to July 8, 2002.

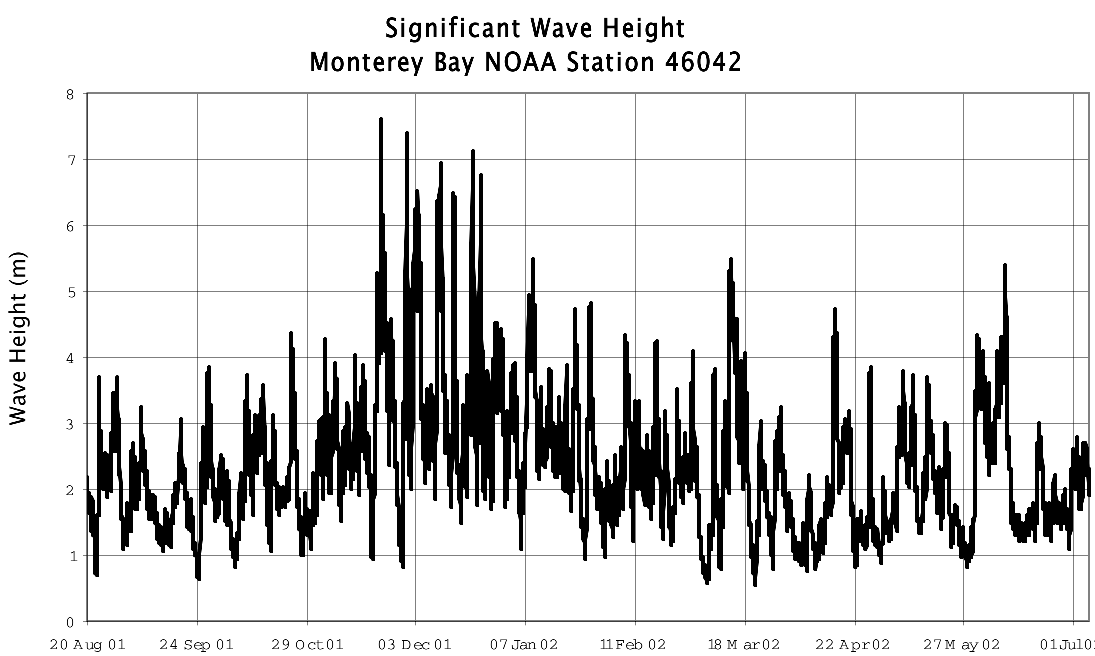


Figure 5.4 Hourly significant wave height for Monterey Bay. Data range is from August 20, 2001 to July 8, 2002.

5.3 Bathymetric Data

On March 28 & 29, 2002, CCoWS mapped eight bathymetric transects (A-H) in the Salinas Lagoon (Fig. 5.5). Figure 5.6 shows each of the transects depth to surface plots with respect to datum (NGVD, 1929) along with maximum and minimum water levels recorded for this year.

Starting closest to the ocean, Transects A & B cross the lagoon in its northwest corner. In each of these transects there were two well defined channels on the right and left bank. Further upstream, Transects C & D are located in the long, broad, and more shallow section of the lagoon. Transect E, still shallow and broad, dissects a large semi-permanent island in the channel.

Upstream at Station F a deeper thalweg is located along the left bank with a maximum depth of 2.7m (8.85 ft.). Transect G, located between the Highway 1 and the Del Monte Blvd bridges, contained the deepest location in the lagoon at approximately 5.83m (19.1 ft). The deep trench is most likely a result of scouring processes formed around the bridge supports. Transect H, furthest upstream from the Twin Bridges, is more shallow with a well defined thalweg along the right bank.

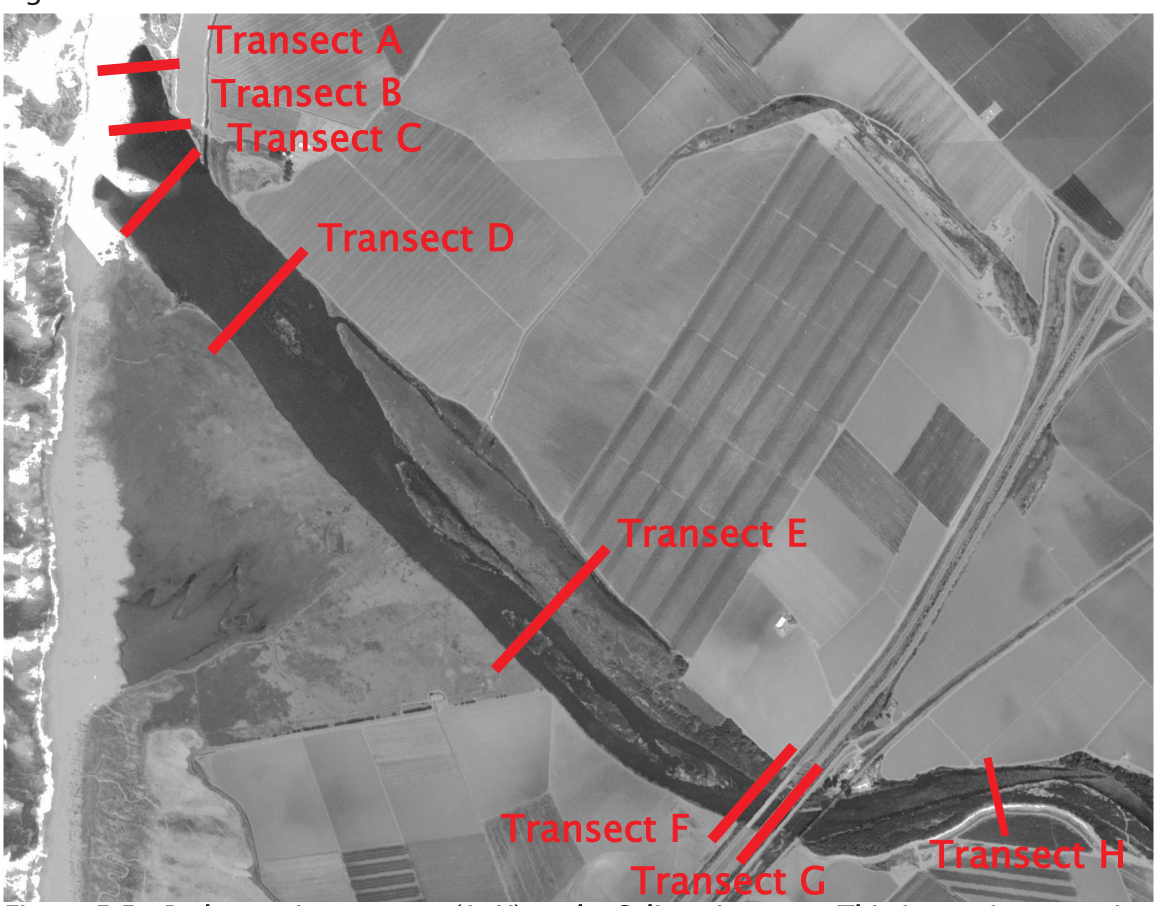
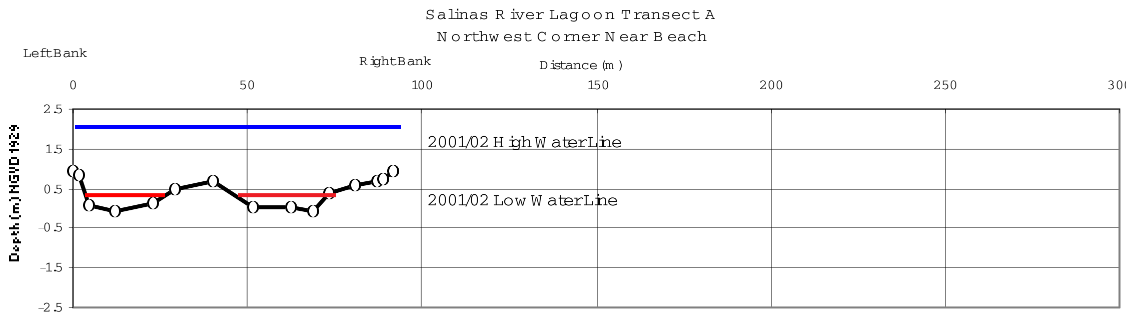


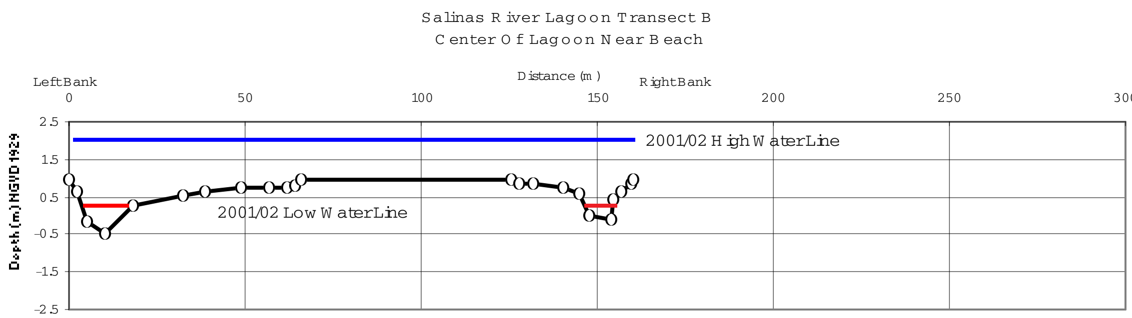
Figure 5.5. Bathymetric transects (A-H) at the Salinas Lagoon. This image is a mosaic Digital Ortho Quad (DOQ) (*c.* 1998).

Figure 5.6. The eight transects of the Salinas Lagoon displayed in order from closest to the ocean (A) to east of the twin bridges (H). Note that vertical scale for Transect G is much larger than others.

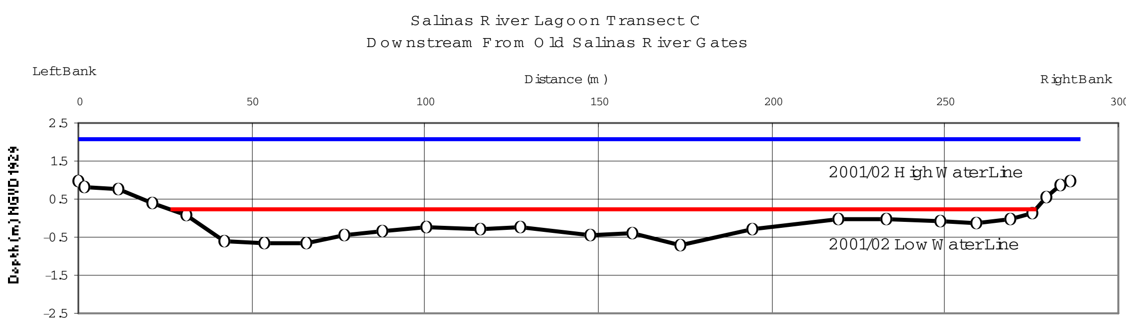
A



B



C



D

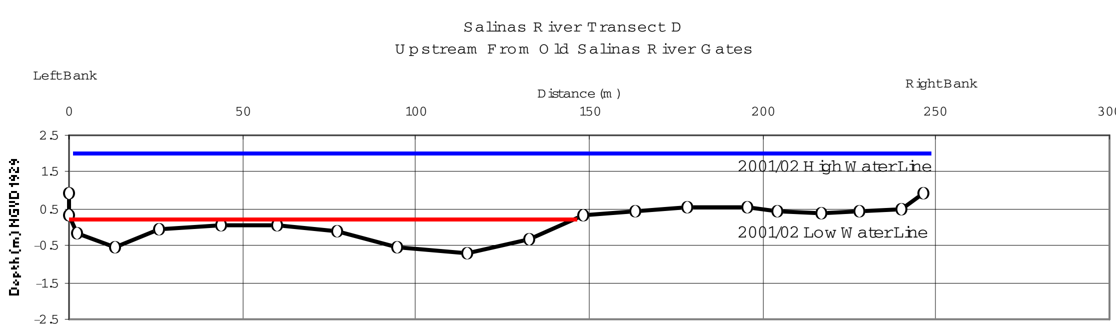
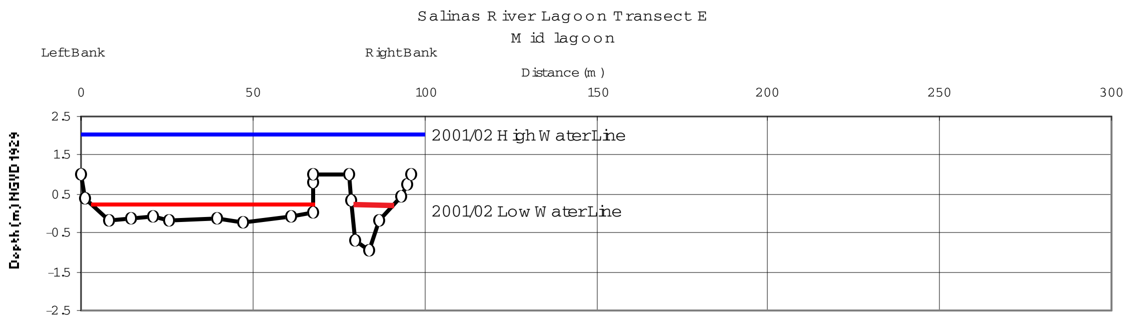
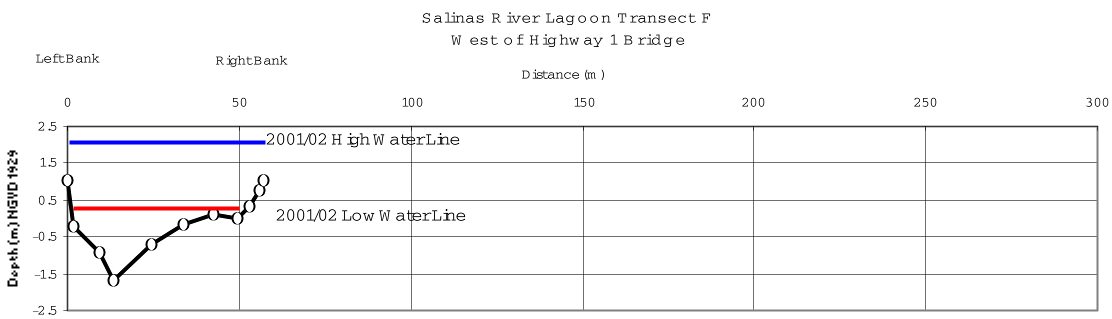


Figure 5.6 Cont.

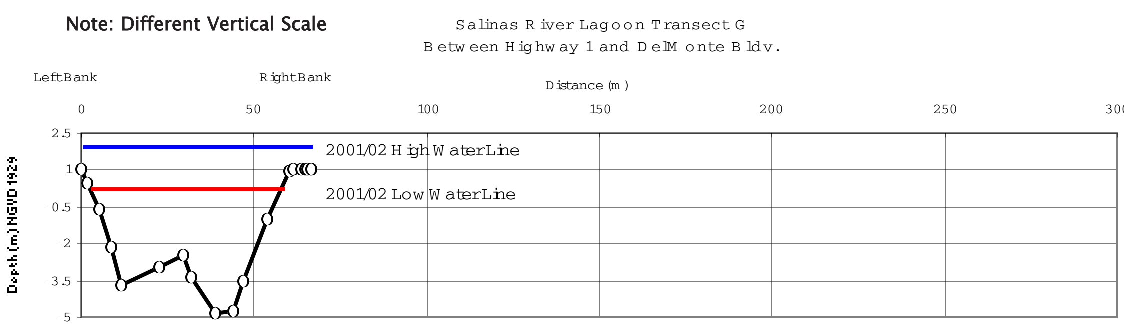
E



F



G



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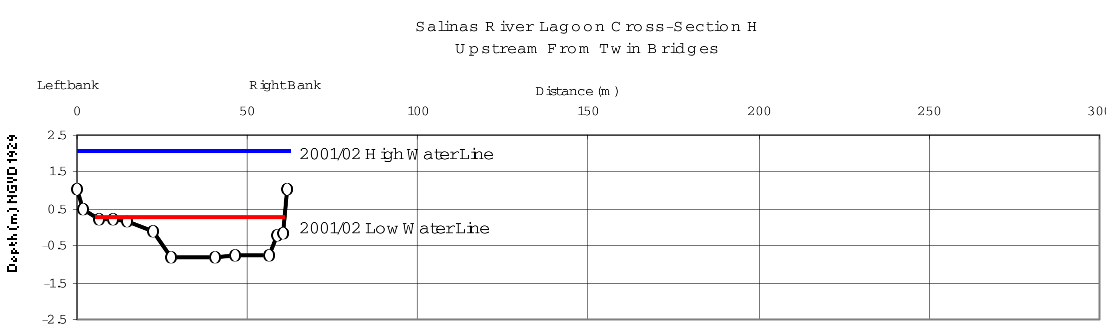

5.4 Benthic Sediment

In the Salinas Lagoon, coarse sediments were found in the more shallow waters of the main channel and breach corridor indicating areas of higher velocities-Figure 5.7. These areas include the majority of the left bank (downstream of the Twin Bridges) and the right bank (upstream of the Twin Bridges). The d_{50} values for these sample were in the 1-1.99 and 2-6.99 mm range (coarse sand).

Fine sediments (< 0.063mm) were collected in deep-water areas of the lagoon (under Twin Bridges). These sediments were collected in water that was >4 m in depth. Fine sediments were also collected in other areas of the lagoon that were not characterized by deep water, yet characterized by slower hydraulic velocities and active bank erosion.

In the center, the lagoon separates into two channels (transect E; Figure 5.6). These channels are separated by a semi-permanent island during low flow conditions. The left bank channel captures the majority of the flow. Along the far left bank, active erosion is occurring. The Watershed Institute is currently restoring riparian vegetation along this reach to prevent further erosion. A sample collected along this bank yielded a d_{50} of < 0.063 mm. The right bank channel is situated between the island and a well-defined point bar. A sample collected within the right bank channel also yielded a d_{50} of < 0.063 mm. This is also an indication of lower velocities.

Salinas Lagoon Benthic Sediment (d_{50})

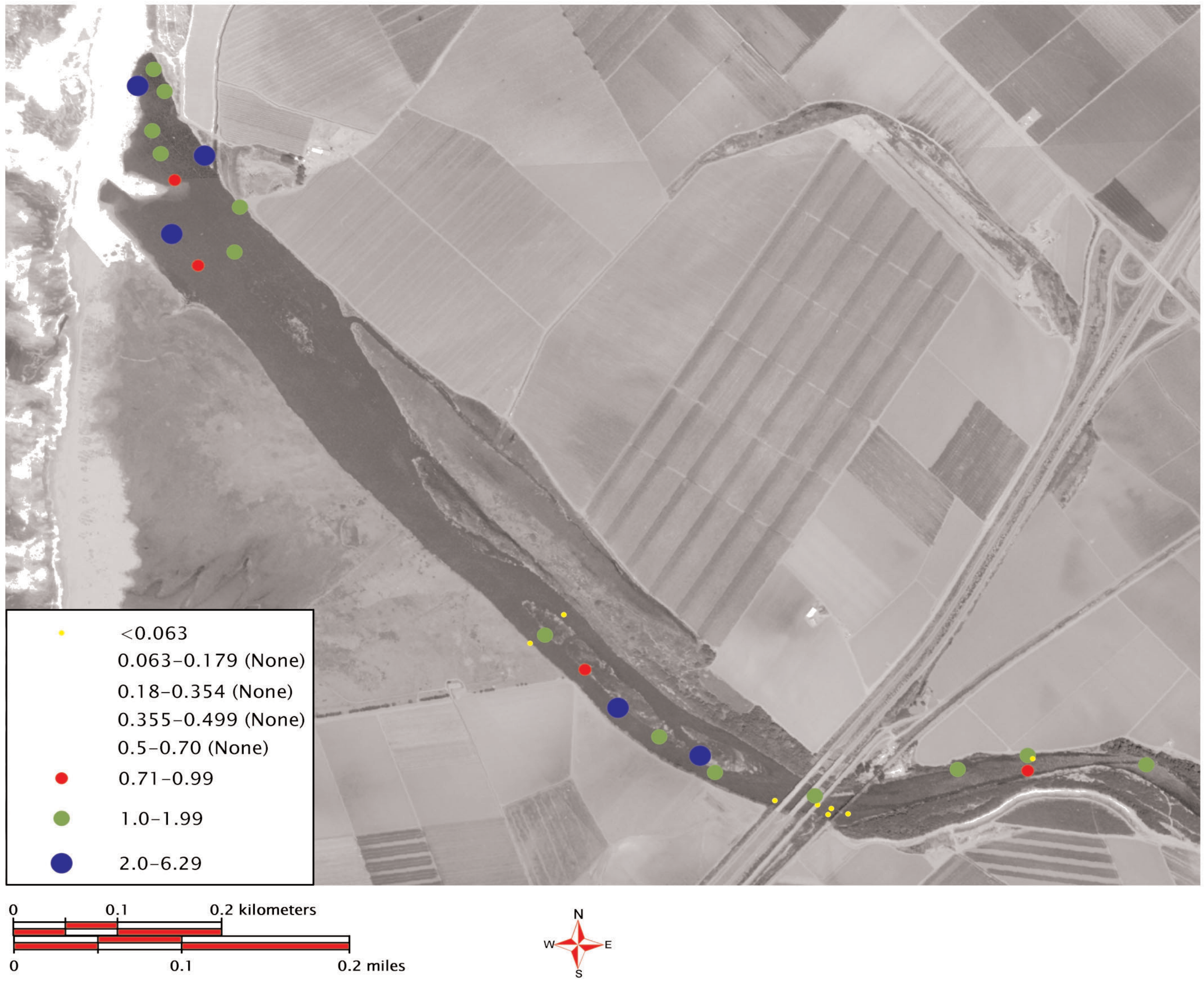

Figure 5.7. Map illustrating the benthic sediment d50 of the Salinas Lagoon. Particle size classes (d50) are in millimeters.

5.5 Water Quality Pre-Breaching

August 30, 2001

At the end of summer, the Salinas Lagoon displayed a temperature and oxygen profile characteristic of freshwater lakes. A well-mixed surface layer of warm water up to 3 m deep occurred above a gradual thermocline to cooler, deeper waters. Dissolved oxygen levels were high, but only slightly super-saturated. At about 3 m depth, a very sharp halocline occurred above the sump below Highway 1 where the water was highly saline and anoxic. In the mixed surface layers, diurnal fluctuations in temperature and oxygen were significant, indicating a strong production/respiration cycle. However, unlike Carmel Lagoon, no peak in temperature and oxygen occurred in the mid-level waters. This difference is hypothesized to be because of higher winds that blow down the length of the Salinas Lagoon, mixing the surfaces down to much deeper levels; as opposed to the sheltered waters behind granite bluffs guarding the mouth of the Carmel Lagoon.

A longitudinal gradient was also present, with surface temperatures increasing and oxygen levels rising as one moved inland.

October 24, 2001

By October 24th, the whole temperature profile had cooled a few degrees, but large diurnal fluctuations and a a strong mixing regime persisted. Surface dissolved oxygen was moderate near the ocean, increasing to super-saturated levels further inland, where diurnal fluctuation in oxygen was the highest yet measured. Salinity was near-fresh, apart from the deep inactive anoxic saline zone beneath Highway 1.

The high DO fluctuations at sites except those immediately adjacent to the ocean are indicative of extremely high algal production and associated respiration, and possible risk of crashes in dissolved oxygen levels.

December 4, 2001

Just prior to breaching, streamflow inputs had risen the lagoon level over 1.5 m from October and, in combination with cool air temperatures, had chilled surface waters to temperatures below the lower layers. The coldest surface water was found at upstream sites more directly influenced by streamflow inputs. Moderate dissolved oxygen levels were measured, but with an unseasonal layer of highly variable oxygen concentration between 0.5 and 1.5 m below the surface, ranging from very low levels to saturated levels. Although the surface remained fresh to brackish, hyper-saline water was observed from about 1 m depth down to over 5 m depth, implying that ocean waves had brought sea water into the lagoon that eventually flowed all the way along the shallow sections of the lagoon to the deep water beneath to Highway 1, some 900 meters inland.

The longitudinal pattern of the variable dissolved oxygen layer at 1 m depth is of saturated oxygen concentration near the mouth, and low levels upstream of Highway 1, with well-mixed, moderate profiles at Highway 1. One explanation for this is that just prior to the influence of streamflow, the surface 1.5 m was saturated or nearly so, as a result of strong wind-forced mixing. Then, water flowed into the lagoon that had a low oxygen content possibly associated with organic sediments. This water remained buoyant over the prior surface waters, thus disconnecting the previous surface waters from further atmospheric exchange. The new low-oxygen surface waters then underwent their own mixing, but only to 0.5 m depth due to lower winds, thus increasing their oxygen levels to about 7 mg/L. In upstream sites most influence by stream flow, this meant higher oxygen leaves overlying lower ones. At the ocean end of the lagoon, the opposite was true. Under the bridges, a uniform profile was observed. This is speculative – a much more detailed study would be required to understand such processes better.

5.6 Water Quality Post-Breaching

December 5, 2002

A natural breach occurred on the night of December 4th, and some of the lagoon water emptied to the ocean before the bar closed up again. The resulting temperature and salinity profiles are similar to those of the previous day, although transposed downward, indicating negligible turbulence and other shear-force effects associated with this breaching. The highly variable oxygen patterns of the previous day had now aligned somewhat, with moderately high levels reported in all surface waters and a monotonic gradient down to moderately low levels at 1.5 m depth. The mean oxygen concentration throughout the profiles did not change significantly, indicating that enough turbulence, diffusion, and other mixing had occurred to smooth out the mid-water patterns of the previous day. At the surface, the inland waters were slightly warmer and more oxygen rich, and much less saline than those near the ocean. The halocline was typically much sharper in the still waters below the bridges, where density stratification can occur with less abatement by the wind. Closer to the ocean, the halocline is slightly less severe – possibly due to higher winds causing more pronounced mixing to offset density-driven flow.

A full, manual breach was induced on Christmas Eve. The monitoring team did not become aware of this until sometime later, so the event was not monitored.

Figure 5.8 The Salinas Lagoon flowing out to sea (foreground); ocean background.

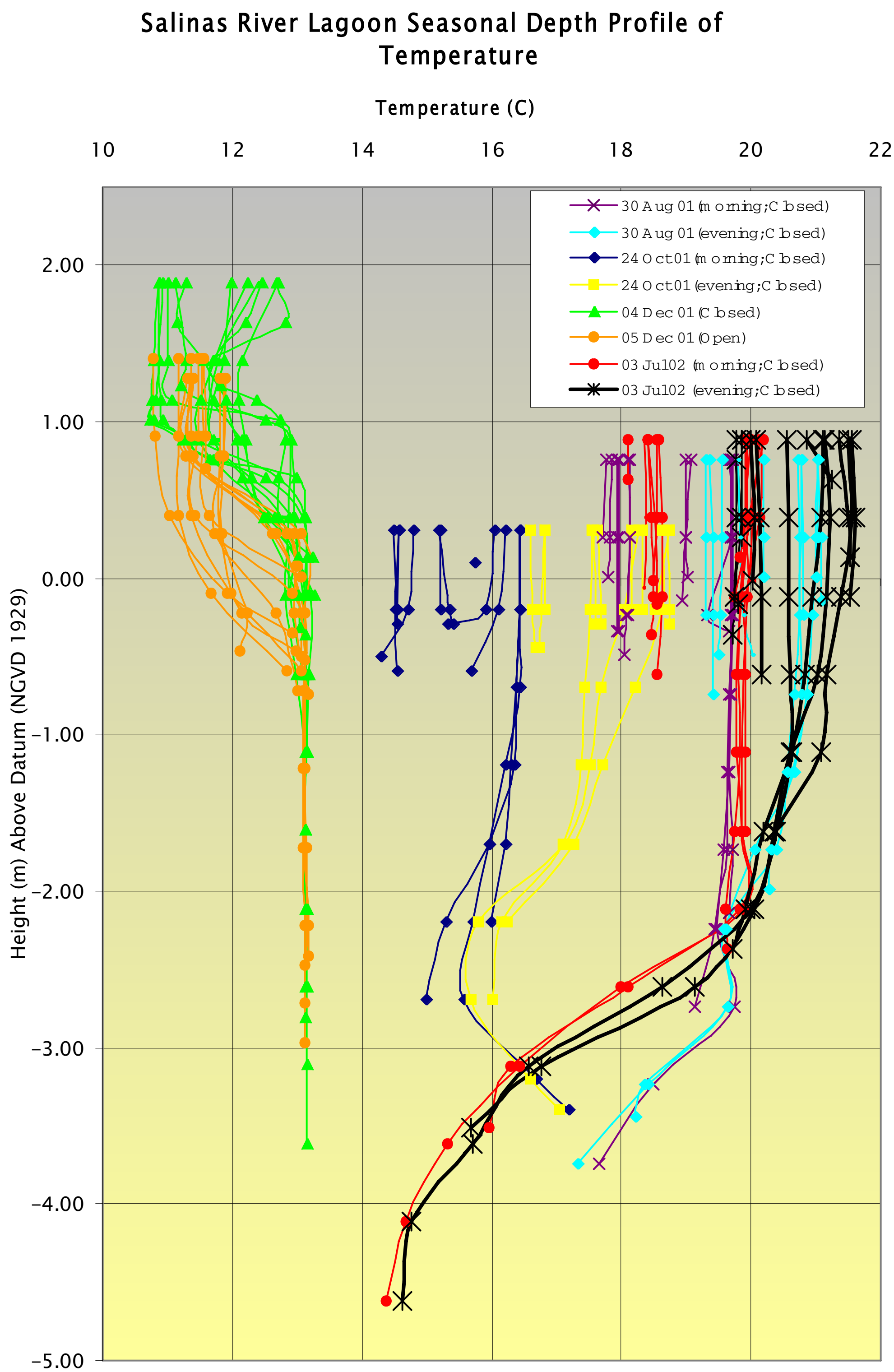

Figure 5.9 Salinas River Lagoon depth profile of temperature for all seasonal and lagoon conditions.

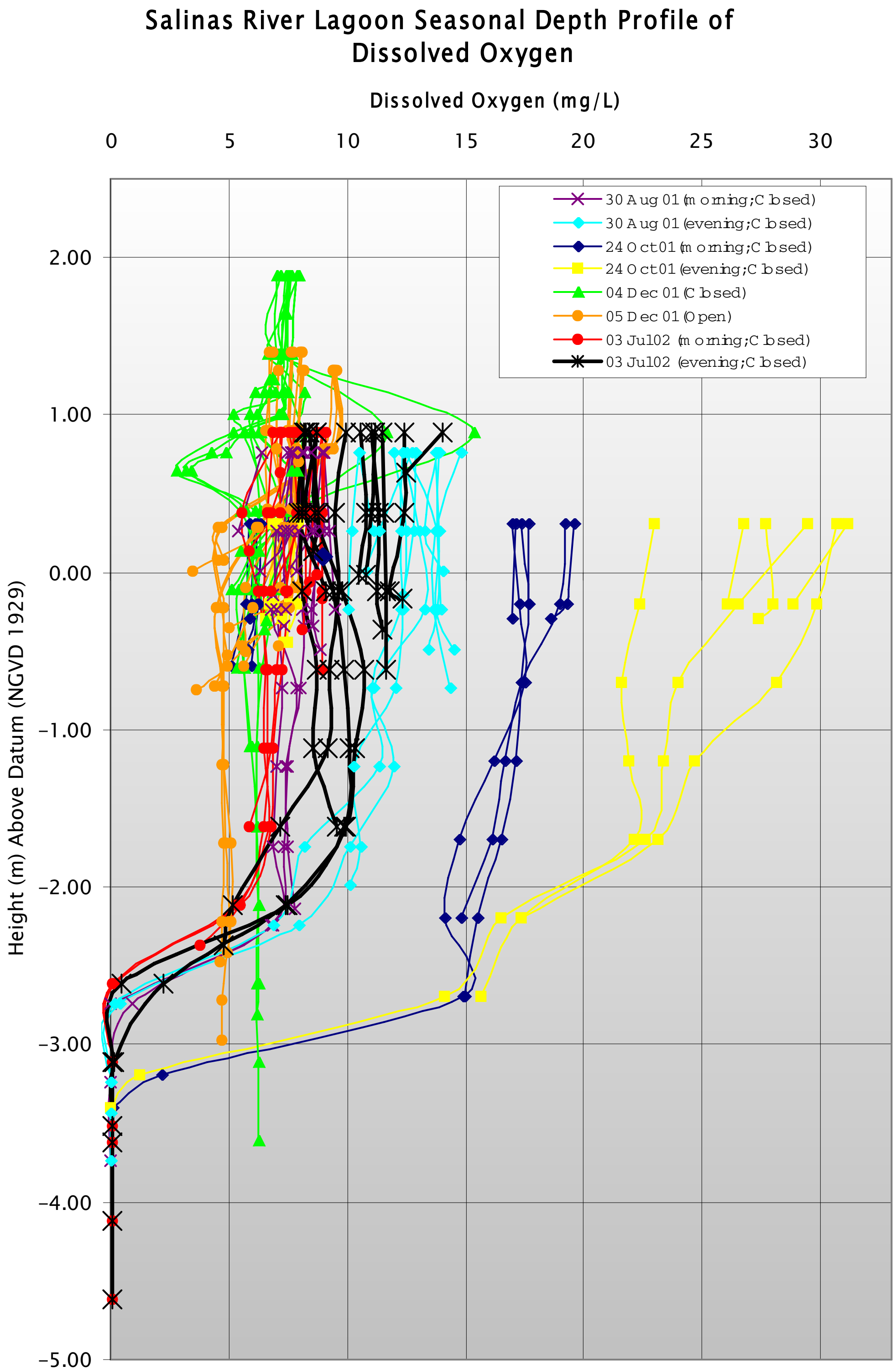

Figure 5.10 Salinas River Lagoon depth profiles of dissolved oxygen for all seasonal and lagoon conditions.

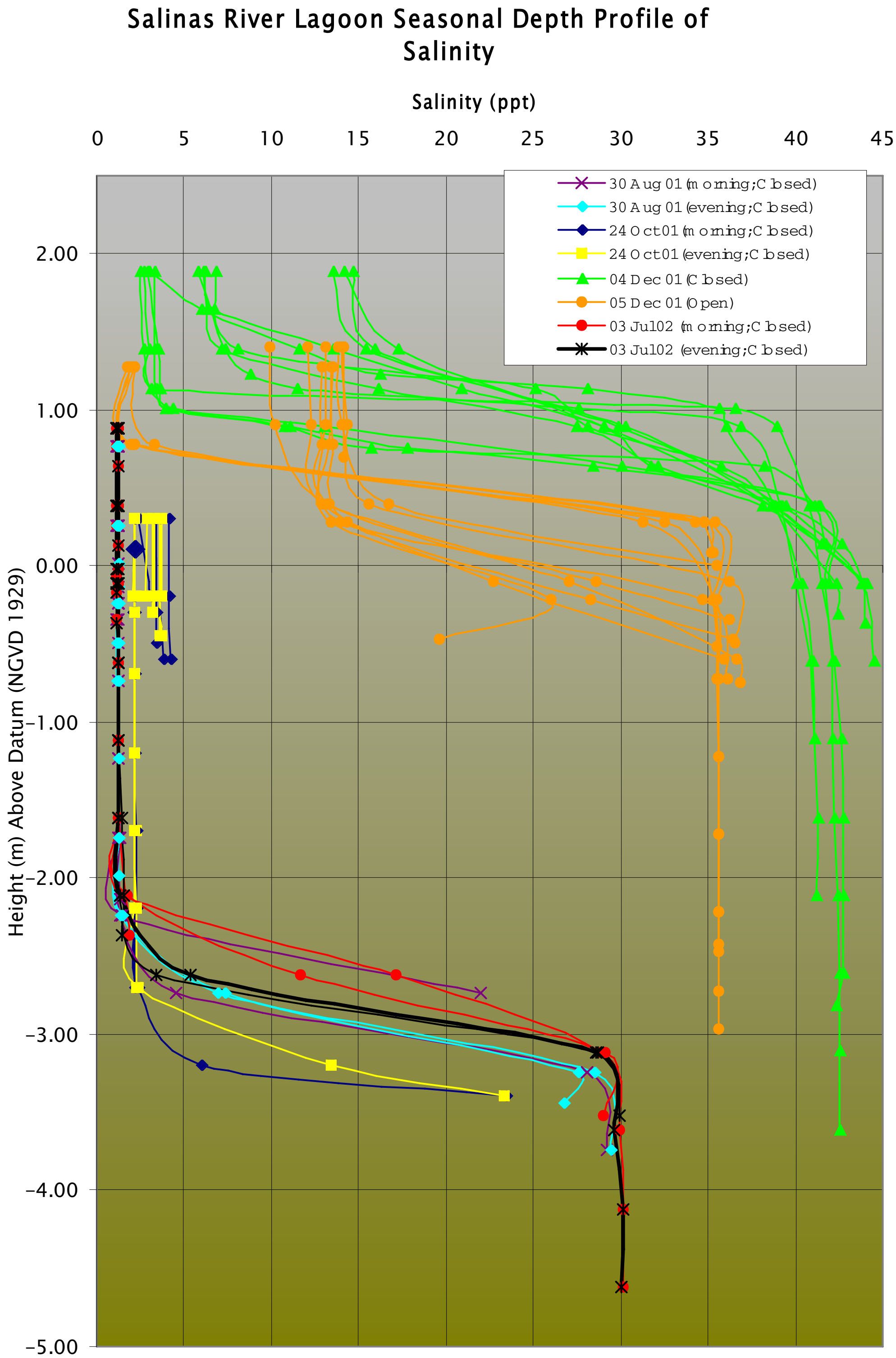

Figure 5.11 Salinas River Lagoon depth profiles of salinity for all seasonal and lagoon conditions.

5.7 Water Quality Post Reclosure

July 3, 2002

As with the Carmel Lagoon, the summer profile patterns were restored by July. A monotonic thermocline existed with high diurnal fluctuation in warmer water overlying a colder bottom, accompanied by moderate diurnal fluctuation in dissolved oxygen. Fresh water persisted for 3 m above an anoxic, saline sump. Of the three monitoring events during the warmer months, conditions in October were indicative of extremely high algal production, while July and August monitoring suggested more moderate production. Unlike the Carmel Lagoon, there was no mid-water peak in temperature or dissolved oxygen, which is suggested to be due to the open country and more-pronounced wind-forced mixing regime of the Salinas Lagoon.

As expected based on previous dates, the warmest surface water occurred at inland sites, but the highest oxygen levels and the highest oxygen fluctuations were measured in the center of the lagoon closer to the ocean.

6 Habitat relations

6.1 Schematic diagrams

The spatial dynamics of physical water quality parameters for both lagoons are summarized in Figures 6.1 to 6.3. These diagrams provide a schematic illustration of the various habitats within each lagoon.

The Carmel Lagoon is depicted longitudinally, with streamflow entering from the left through an avenue of riparian trees. Conceptually we also consider the extensive aquatic monocot habitats to be included in this part of the diagram. In the center of the Carmel diagram, the main stream remains shallow (as indicated by the red dashed line), but the off-line South Arm sump is depicted as well. The granite cliffs seaward of the sump are also shown. In the dry-season and pre-breach diagrams, the sand bar is drawn at full height. The post-breach diagram omits the sand bar, and shows a clear passage to the ocean.

The Salinas Lagoon is a more linear feature, with no off line habitats – the sump beneath the bridges (shown) being in the direct line of River flow. As with the Carmel Lagoon, tall riparian trees abut the lagoon along the inland portions, but the 900 m stretch from the bridges to the ocean is relatively free of cover.

Each diagram shows a variety of parameters, including symbols for a scale of salinity (crosses), temperature (lines), oxygen (circles), and benthic substrate (grains) values. Diurnal photosynthesis/respiration cycles inferred from oxygen fluctuations are indicated as concentric 'oxygen' circles, with the outer circle indicating the maximum dissolved oxygen concentration during the cycle.

Based on the above parameters, and also the water depth, presence of cover, and difficulty of predator access (illustrated using symbols for birds and pinnipeds), a local habitat optimality for steelhead smolts is indicated. The conditions for steelhead are generally not globally optimal for the species in these lagoons, so a 'local optimum' is indicated at the most-likely preferred habitats in a given season. While these indications are inferred based on habitat, and are not based on steelhead survey data, they broadly agree with knowledge obtained from survey data, such as by Hagar Environmental Science (2002). Thus, a symbol for steelhead smolts is placed on the diagrams whenever temperature is below 20 °C, oxygen is above 5 mg/L, salinity is below 20 ppt, and cover is provided either by deep water or vegetation. These numbers are meant to be broad indications of habitat suitability, approximating the vaules reoprted by Pennell and Barton (1996), Alley (1997), and Dettman (1984). In cases where such 'suitable' habitats do not exist, symbols are placed at the locations of likely best refugia.

Three seasonal stages are illustrated: dry-season, pre-breach, and post-breach. Dry season data are drawn from surveys conducted from July through October. Pre-breach data are drawn from surveys conducted once lagoon water levels had risen to near-breaching point. Post-breach data are combined from survey on

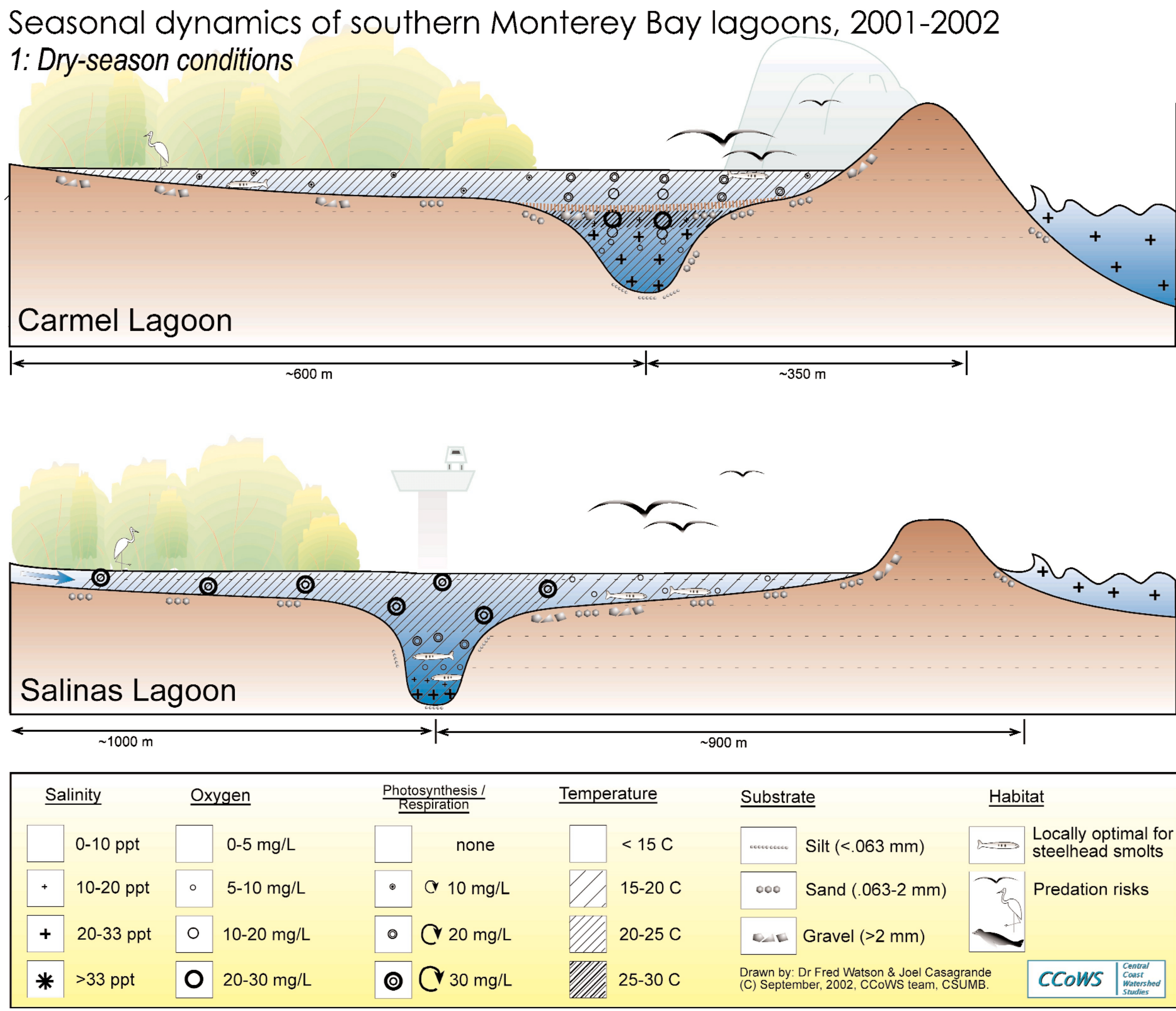

Figure 6.1. Dry season dynamics of the Carmel and Salinas Lagoons, 2001–2002

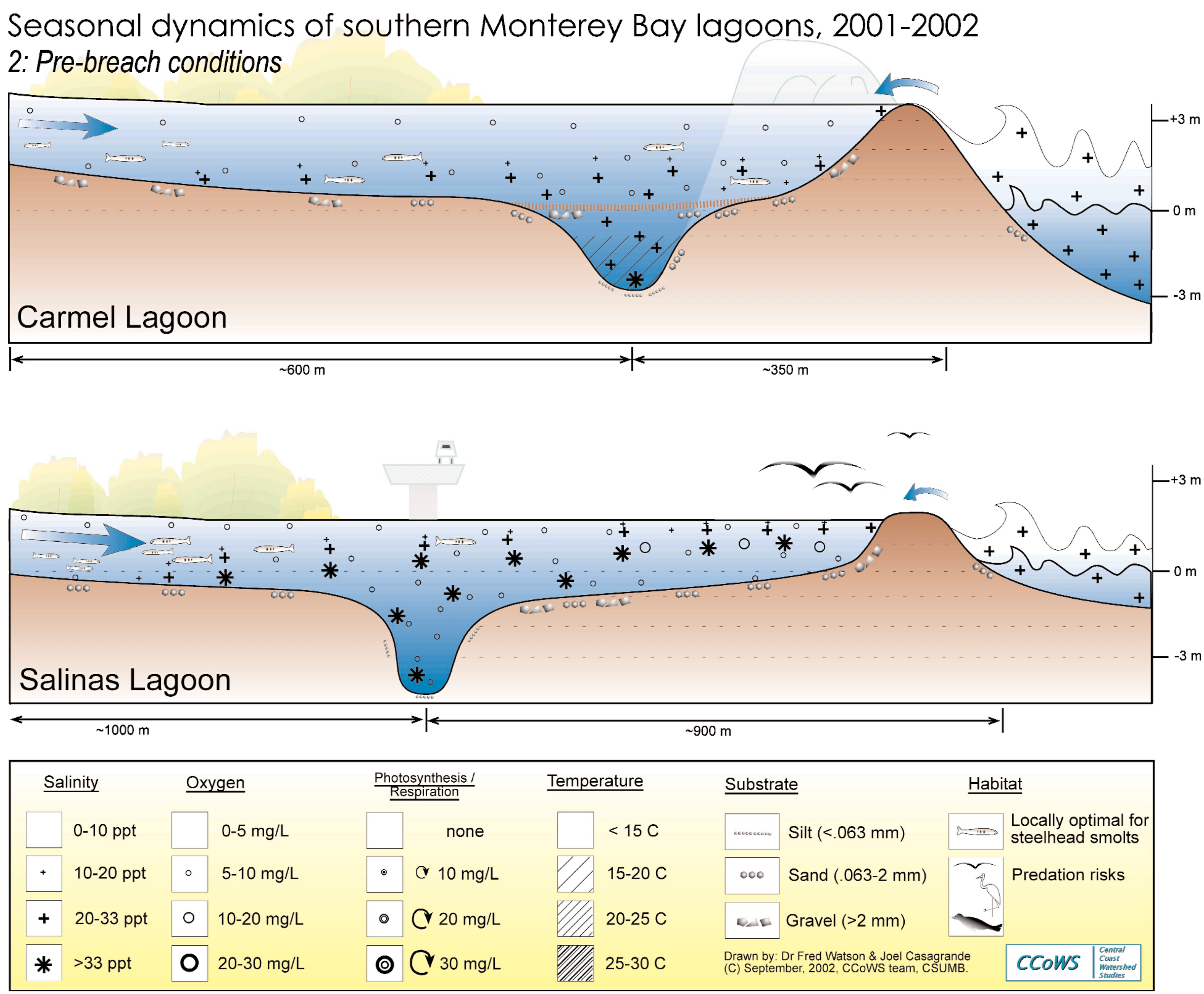

Figure 6.2. Pre-breach dynamics of the Carmel and Salinas Lagoons, 2001-2002

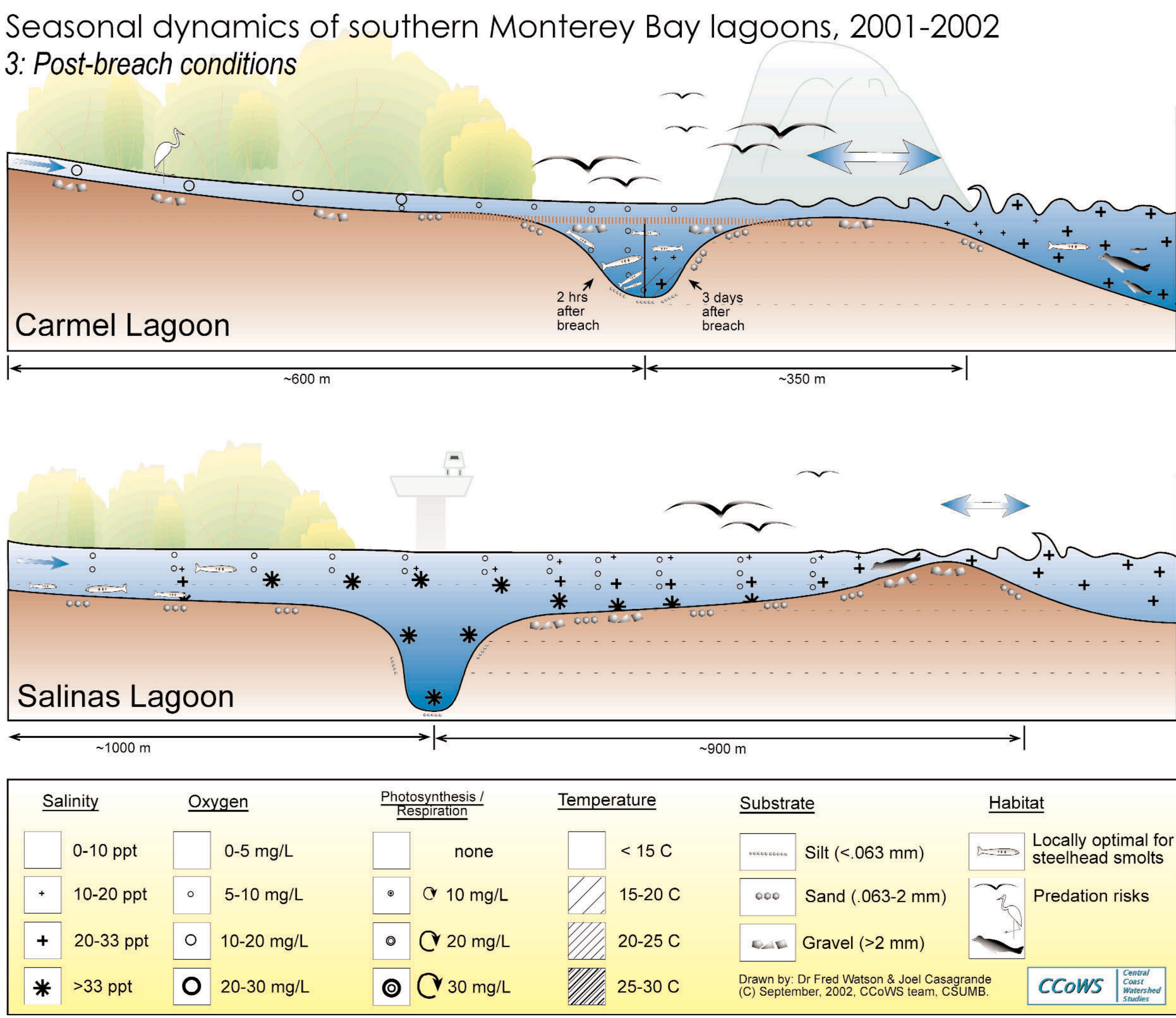

Figure 6.3. Post-breach dynamics of the Carmel and Salinas Lagoons, 2001–2002

the day of a breach, through to a few days after a breach.

6.2 Habitat Inferences

With respect to typical habitat parameters recognized for steelhead smolts, the physical water quality in the dry season was worse than at other times. The volume of both lagoons was very low, and the water was warm to hot. This was particularly so in the Carmel Lagoon, where the coolest water was measured in exposed water right at the surface, and where steelhead were seen schooling the summer of 2002 (Frank Emerson, pers. comm.). The only cool refugia would be in the few remaining areas where trees overhang at low water. Oxygen was not limiting at these times, due to high primary production that is only partly balanced by respiration. High salinity prevented refuge deep in the sump, and an extreme temperature maximum in the mid-waters prevented refuge above the sump. In the Salinas Lagoon, the situation was perhaps slightly better. The open treeless landscape and higher winds in this area appeared to cause increased latent and sensible heat flux near the lagoon mouth, leading to colder profiles in this area, although this was of course at the cost of reduced cover from predators. These winds also may have played a role further inland in preventing the Salinas Lagoon from developing the same hypothesized positive feedback between temperature and production that the Carmel Lagoon experienced at mid-depths in summer. The causal relationships may simply involve mixing deeper water up to atmospheric exposure at the surface, or biological effects such as turbulence-induced tissue damage in certain mid-water autotrophs. Finally, wind-forced mixing, and a large body of overlying freshwater may also explain why the Salinas Lagoon sump was less saline than the Carmel Lagoon sump in summer. There may thus be a tradeoff between cover provided by trees, and cooling and mixing provided by unabated winds.

Leading up to winter, ocean waves washed into both lagoons. By the time the first storm flows arrived and filled the lagoons, the habitat was greatly changed. Prior to the rains, many months of evaporation had concentrated the sump water to greater salinity than seawater. The result was then a large influx of freshwater that overlay a hypersaline sump with a sharp halocline at the boundary. A large volume of cool, oxygenated, partly saline water provided perhaps the best steelhead habitat of the season. The sump remained de-oxygenated, and hypersaline at its very bottom, but with the lagoon stage over two meters higher than in the dry-season, numerous new refugia were available. In the Salinas Lagoon, hypersaline conditions were maintained over a surprisingly large area, extending well downstream from the sump. Note that conductivity measurements taken around this time well upstream in the Salinas River and nearby tributaries indicated total dissolved solids of a few parts per thousand at most, thus removing the inflow as a possible explanation for the hypersalinity. Steelhead smolts might then be expected to migrate upstream toward less saline water, as the River flow evidently washed a significant amount of hypersaline water out of the sump to all areas downstream. The freshwater remained as a significant, buoyant surface layer above the salt water only as far as the bridges. Given that the bridges probably offer shade and other forms of predator cover, the surface waters beneath the bridges may have provided habitat.

The breaches observed in the two lagoons differed in severity. The Carmel Lagoon was breached manually, resulting in rapid and complete draining. The Salinas Lagoon breached naturally, resulting in only moderate and incomplete outflow. The post-breach water quality reflects this. The residual waters of the Carmel Lagoon were completely mixed by turbulence associated with the breaching process, although stratification was rapidly restored. In contrast, the residual waters of the Salinas Lagoon retained a large volume of post-evaporative, hypersaline water in the middle sections, with freshwater influences upstream, and seawater influences downstream. As observed in the previous year (Watson et al., 2001), the hypersaline sump in the Salinas Lagoon is a very persistent feature, destroyed only by the larger flows. In the Carmel, the mixed conditions allowed the fish to access the deep water in the sump, which was now oxygenated, cool, and relatively fresh. However, this was short-lived. Three days later, monitoring showed that tidal seawater had re-occupied the sump, which was also warming up, most likely due to heat transfer from the substrate and associated groundwater. This is likely to have brought fish closer to the surface, and to predation by birds such as the egrets observed by Hagar Environmental Science (2002). In the Salinas Lagoon, any smolts that may have been avoiding salt water were restricted in that regard to sites at least 200 m upstream from the bridges. Suitable habitat may have continued for some distance, as the backwater from the Salinas Lagoon (not monitored) is several kilometers long when the River is flowing.

7 Conclusions

This report described the seasonal changes in the physical water quality and associated steelhead habitat of the Carmel and Salinas lagoons, particularly before and after the late 2001 breaching of the lagoons at the onset of River flow. The aim was to provide supporting physical data and interpretation for an ongoing policy development process relating to the potential that manual breaching may adversely affect the steelhead trout runs of the Carmel and Salinas Rivers.

In broad terms, desirable water quality parameters for the lagoons include: large volume, low temperatures, high dissolved oxygen, low salinity, and cover from predators.

In the absence of manual breaching, the contemporary cycle of the lagoons is limited in the dry-season by low volume, high temperatures, high salinity due to evaporation, and lack of deep-water cover from predators. At the onset of the flow season, the lagoons reach optimal rearing conditions, with high volume, high oxygen, low temperatures, and deep-water access to cover. Salinity at this time may vary, depending on the relative influence of new stream water versus hypersaline water that is residual from the dry-season. A number of natural breaching events may occur during a season. Generally, these reduce habitat quality for any steelhead that attempt to remain in the lagoon in order to complete smoltification, mainly by way of the reduction in volume. All other monitored parameters would be expected to remain suitable during the post-breaching flow season.

Historically, prior to consumptive groundwater extraction and headwater impoundments in reservoirs, the flow season was longer and the dry-season was shorter. During the present project, a progressive degradation of physical water quality was observed as the dry-season progressed. So it is inferred that dry-season water quality and water volume would not have become as degraded in historic times as it does at present.

The impact of manual breaching should thus be evaluated in the context of both natural breaching impacts, and the historic alteration of the overall flow regimes of the respective watershed systems.

In the present project, the water quality changes surrounding two breaching events were monitored – a manual breaching of the Carmel Lagoon, and a natural breaching of the Salinas Lagoon. The manual breaching caused a rapid and complete draining of the Carmel Lagoon. This had both positive habitat effects due to the flushing of the warm, hypersaline, anoxic water of the deep sump in the South Arm of the lagoon, and negative habitat effects, due to the significant reduction in Lagoon volume. The natural breaching of the Salinas Lagoon resulted in only a partial draining of the Lagoon volume. With respect to the goal of maintaining lagoon volume for steelhead smolts, this is evidence that natural breaching may have less adverse impact than manual breaching of the type employed at the Carmel Lagoon in late 2001. However, with respect to the goal of minimizing saline habitat, there is also evidence that natural breaching may not lead to sufficient flushing of the residual hyper-saline water from the dry-season, and may infact may disperse saline water throughuot a larger volume. The 2001 natural breach in the Salinas Lagoon appeared to stir up saline sediments and smear hypersaline water out of the sump and downstream into the lower lagoon. In contrast, the 2000 manual breach data indicate that a significant portion of the residual saline water was comlpetely flushed out of the lagoon, leaving behnid only a 2 meter salnie layer in the very bottom of the sump. It could reasonably be argued that, due to the prior circumstance of reduced contemporary Salinas River storm volumes, that a manual breach would actually facilitate a beneficial flushing of the lagoon. This of course would have to be considered with other, perhaps more important factors, such as the benefits of retaining significant residual lagoon depth and volume of any salinity, and the absence of negative impacts due to the difference in timing of manual and natural breaches. An summary evaluation of the balance of these impacts is beyond the scope of the present work.

Another consideration is the potential for involuntary entrainment of fish during rapid breaching. Aspects of the hydraulic regime associated with the rapid drainage of the Carmel Lagoon can be inferred from data on benthic substrate and turbulent mixing. Shear forces imparted by the surface layers as they flowed out to sea were strong enough to mix and entrain hyper-saline water from several meters deep within a side arm of the lagoon. On the other hand, a June 2002 survey of benthic particle size revealed anomalously large amounts of silt in this part of the lagoon that were unlikely to have been entirely due to deposition in the 6 months since the initial breaching. Thus, although the flow at the breach itself was extremely violent, and capable of inducing mixing throughout the lagoon, it was not capable of causing scour in the side arms of the lagoon. It would be expected that any steelhead smolt could swim against a flow that was incapable of removing silt, and could thus swim away from the net flow toward the ocean if so motivated. This is also consistent with Hagar Environmental Science (2001), who re-captured individual smolts before and after the breach, and found no evidence for a net reduction in Lagoon steelhead population as a result of the breach. The evidence from the late 2001 breach data therefore weigh against hypotheses involving fish being involuntarily ‘sucked’ out of the lagoon. Further study of the breachnig hydraulics is required in order to clarify this.

8 Further Work

Understanding of Central Coast lagoons is incomplete. Debate about their management falls victim to uncertainties of fact. Further work should work to remedy this.

1. Locally preferred habitat types should be quantified in more detail by field study. Such studies should quantify maximum smolt density with respect to habitat volume as determined by physical water quality parameters. New technologies, such as remote camera equipment may assist this effort.

2. The spatial dynamics of water quality parameters would be better understood if measurements as described in this report were able to be repeated more frequently. In particular, as many breaching events as possible should be monitored and documented in detail in order to better understand the differences between the effects of natural breaches and various types of manual breach.

3. A detailed field study of the hydraulic regime immediately surrounding the breach would clarify the potential role of entraining flow during rapid breach events. This would involved detailed bathymetric survey before and after breaching events, and flow-velocity measurements made during breaching events.

4. A study of algal production and respiration systems would contribute to the understanding of oxygen dynamics, and secondary temperature effects. It would also help quantify the food habitat requirements for steelhead.

5. A study of deep sediment cores in the lagoon may quantify the historical volume of the lagoon, which is thought to have been substantially larger than at present. Such a study could relate modern sediment deposition and scour to a background of global estuarine in-filling associated with Holocene sea level changes.

6. A well-calibrated hydrodynamic simulation model would provide a greater capability to explore the consequences of various management scenarios. It would assist in the estimation of the timing of natural breaches that at present are precluded by manual breaches.

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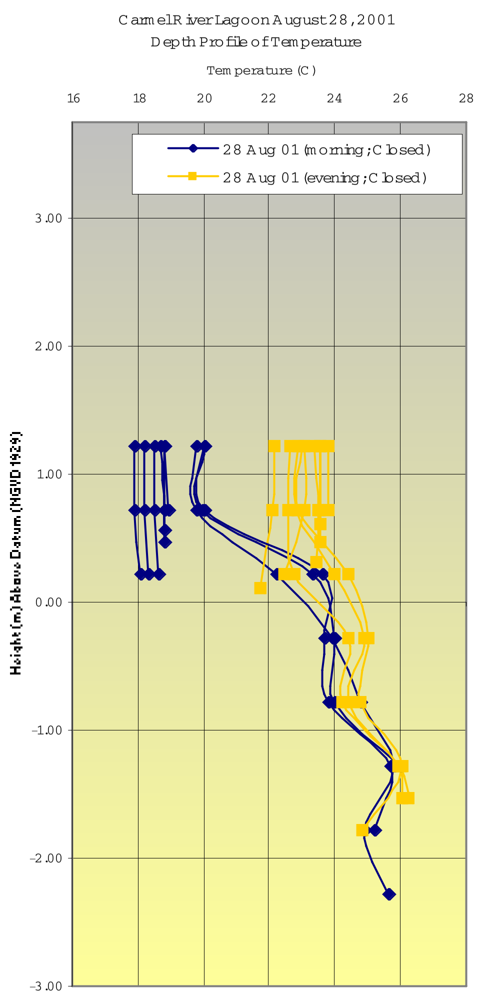
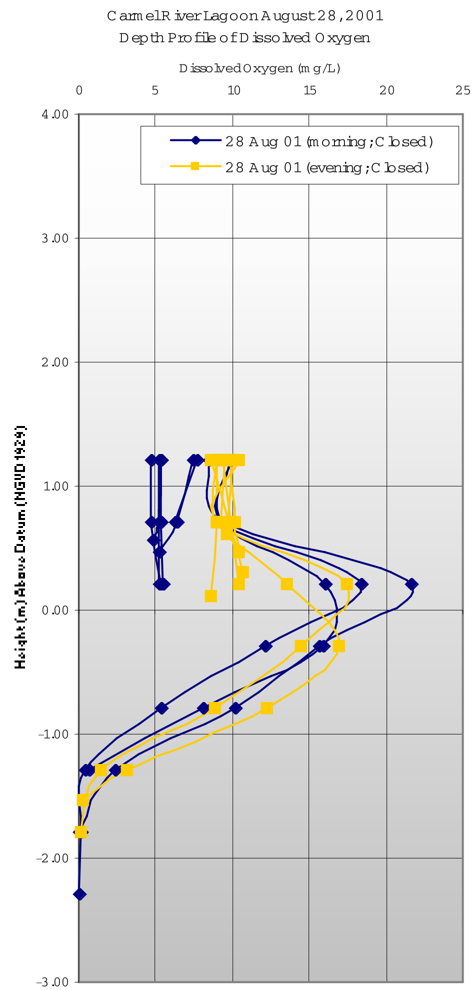
Appendix A: Carmel River Lagoon Water Quality Monitoring Events

Figure A.1 illustrates, separately, temperature, dissolved oxygen and salinity at several locations in the Carmel Lagoon during each monitoring event.

August 28th 2001





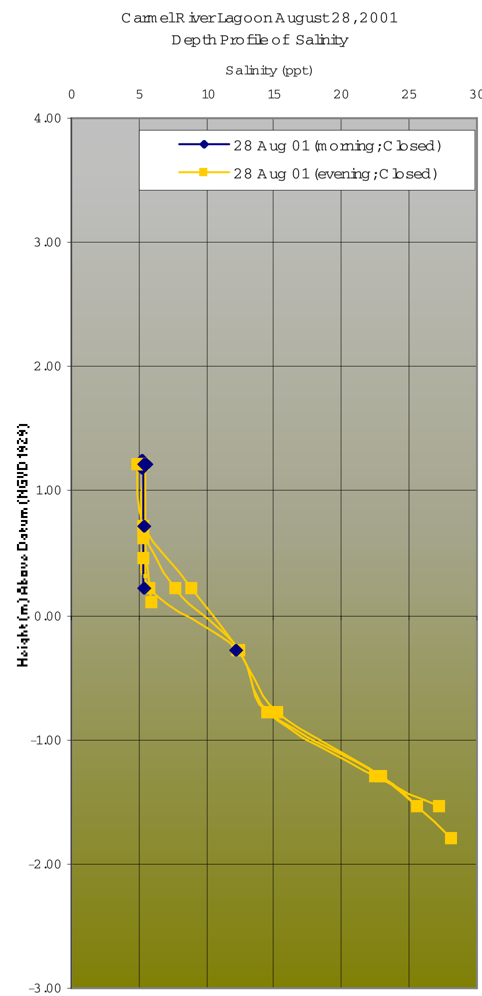
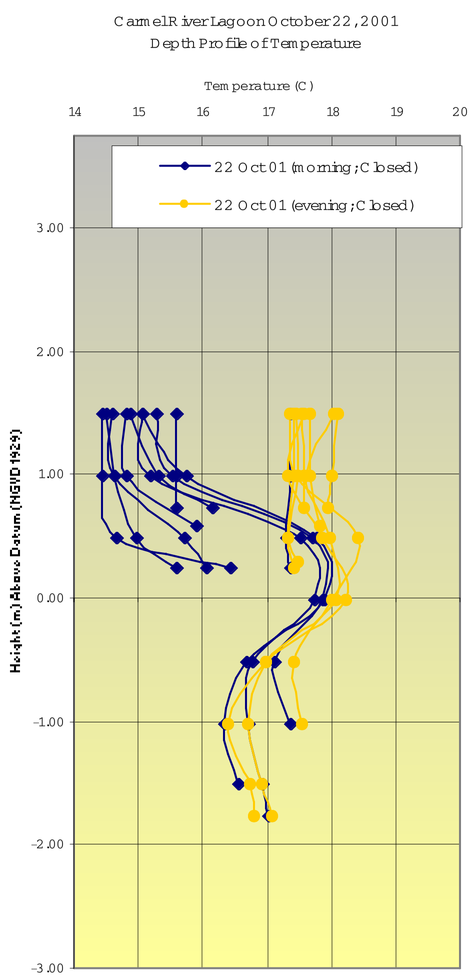
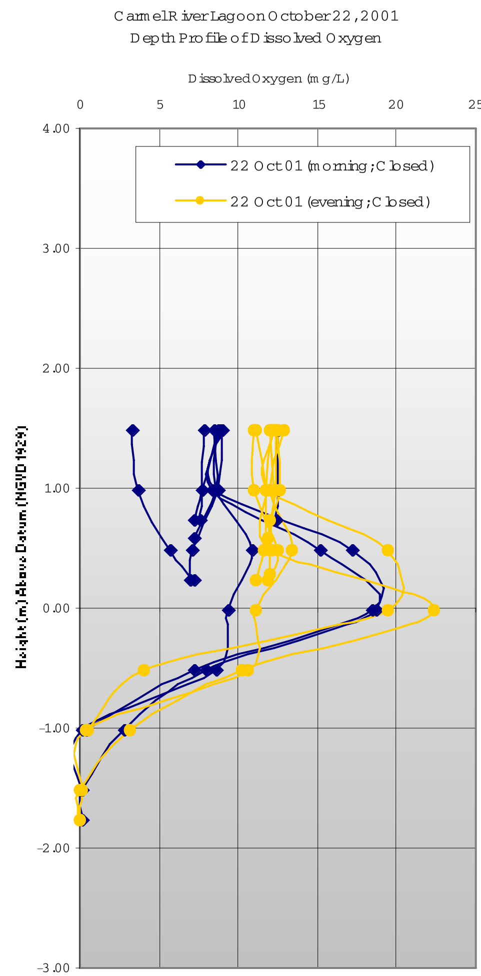
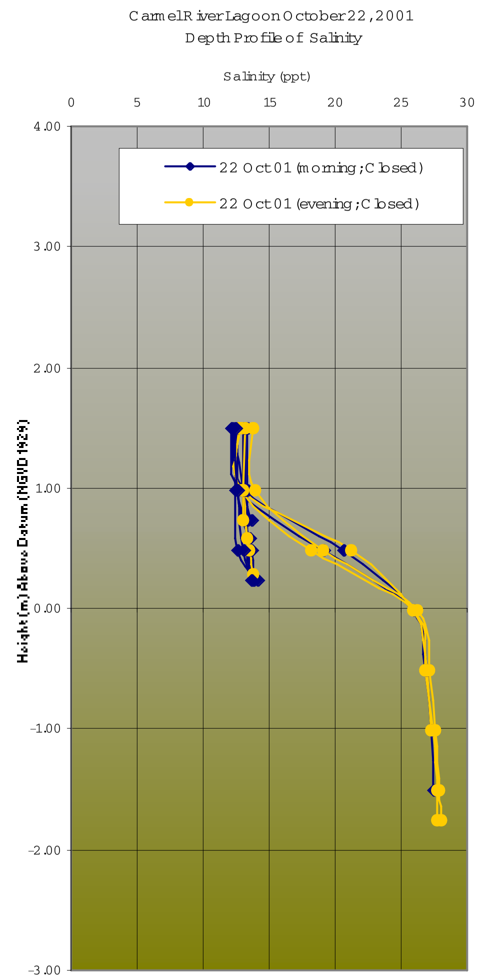


Figure A.1 Analyte profiles for each monitoring event of the Carmel Lagoon

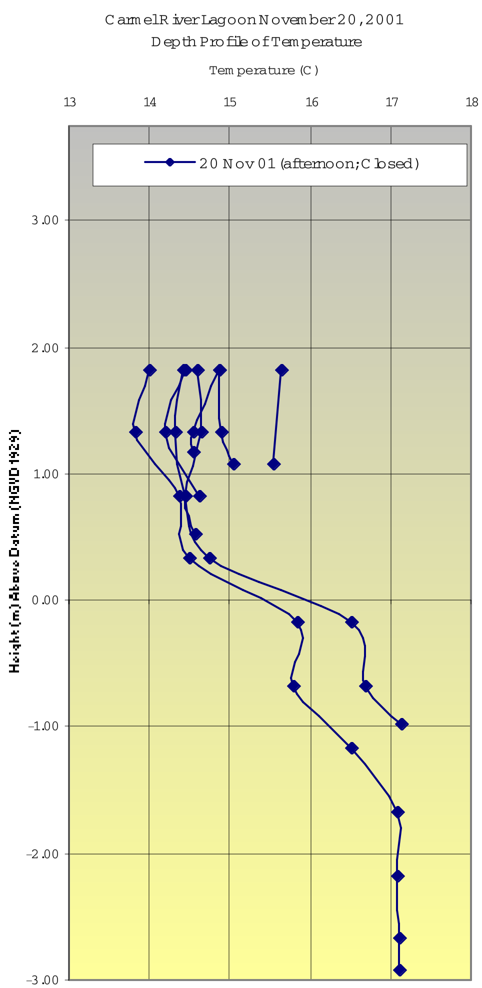
October 22nd 2001

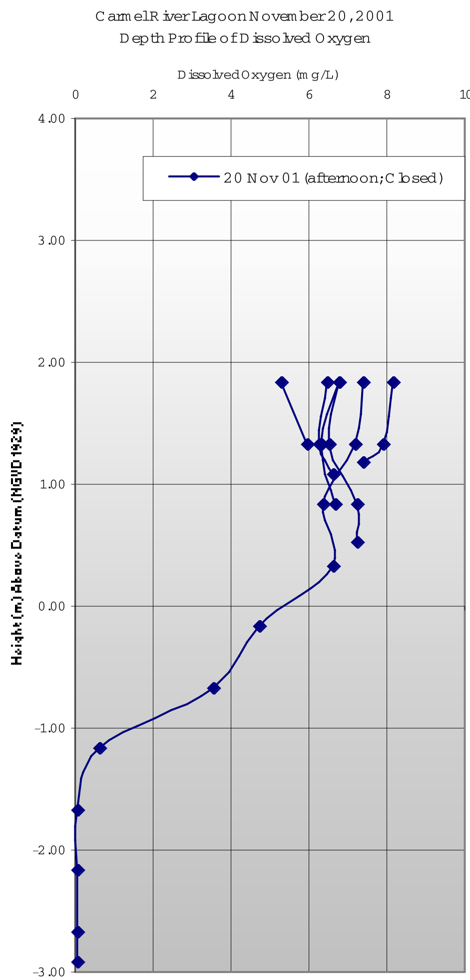


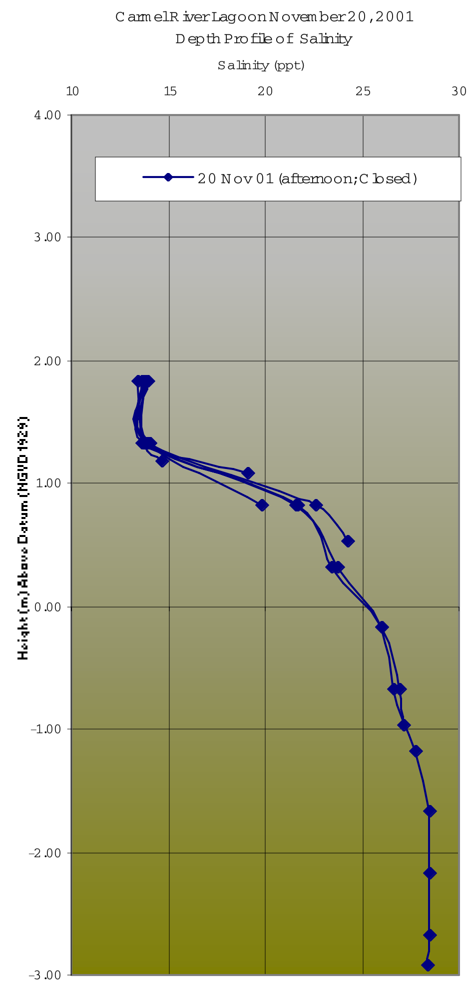




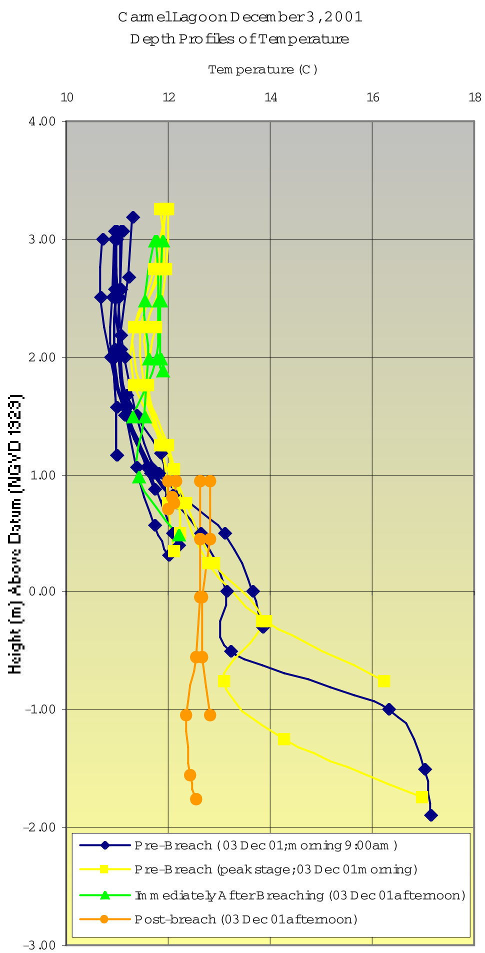
November 20th 2001

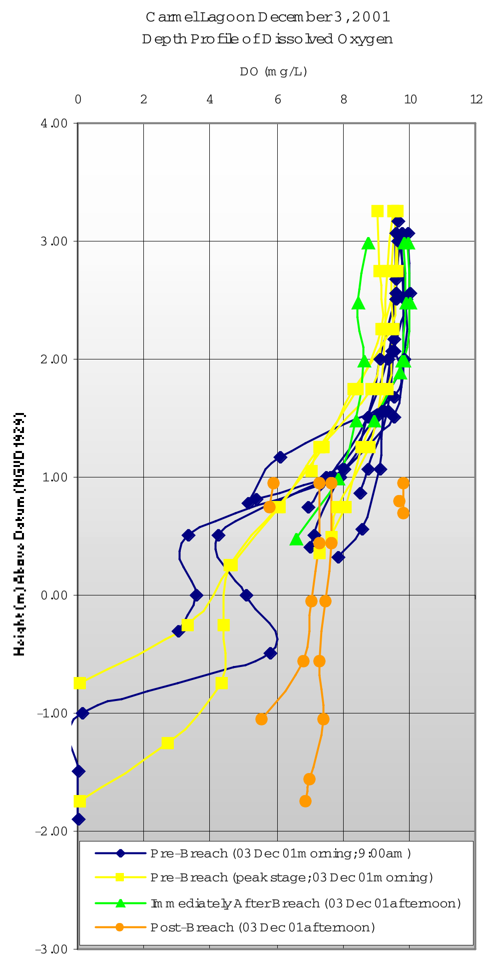


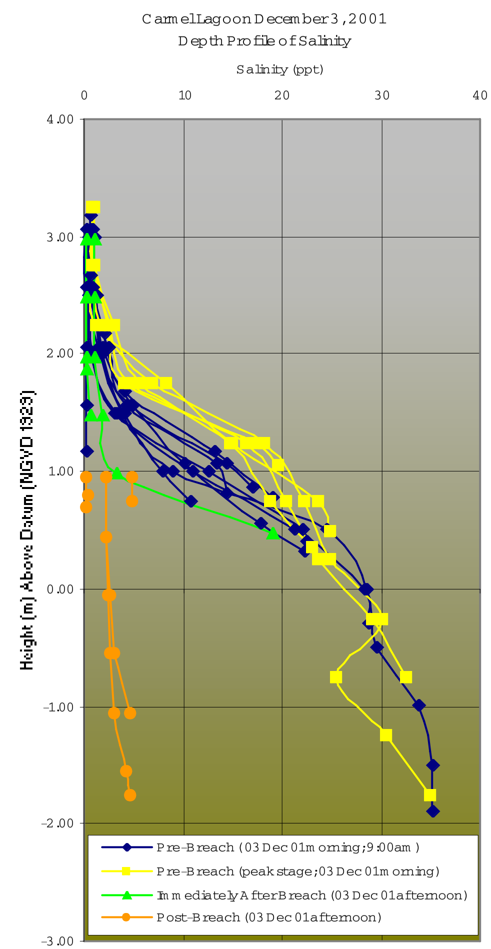




December 3rd 2001







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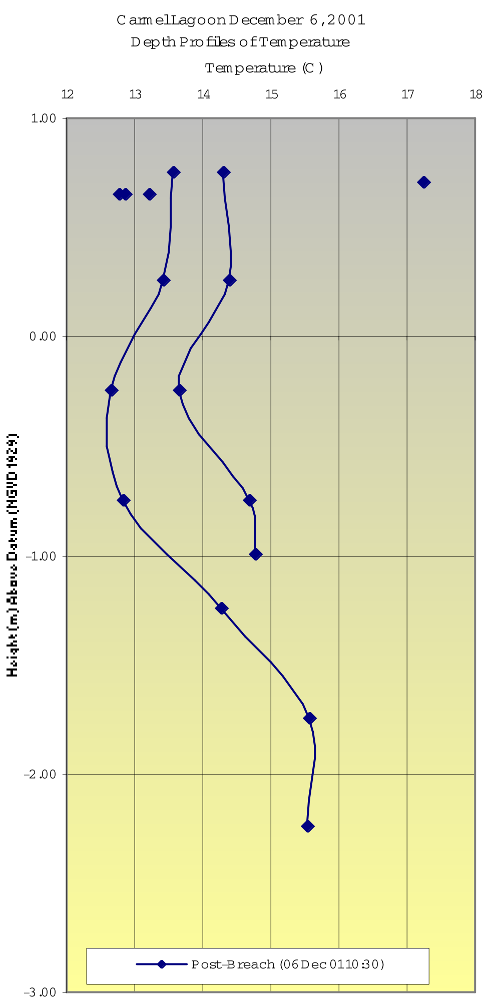
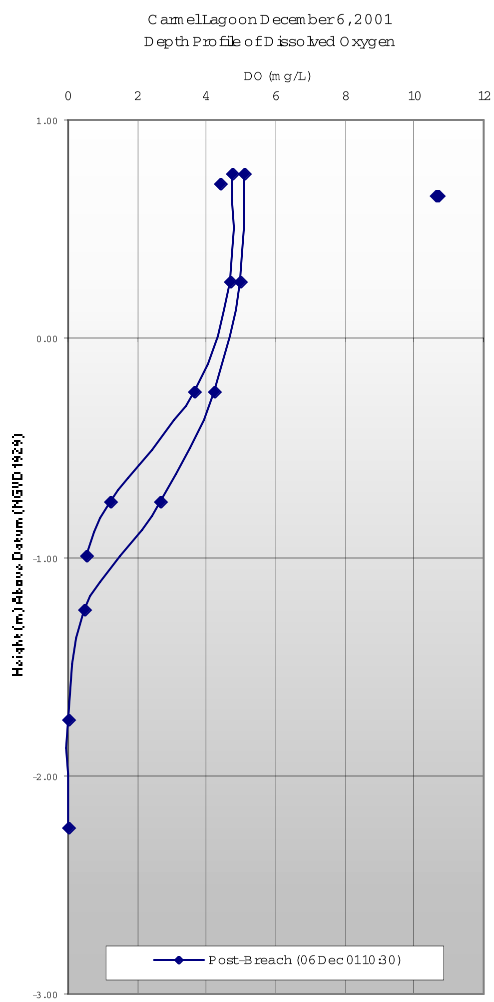
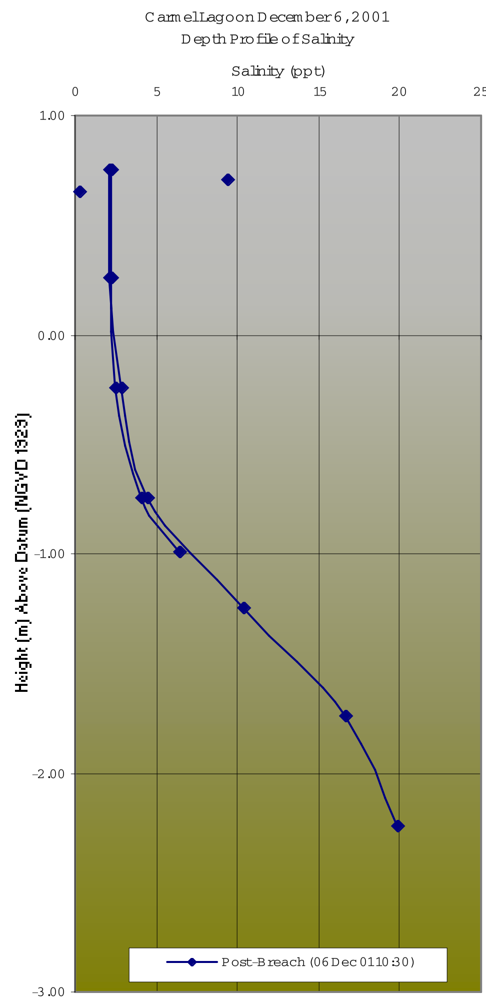
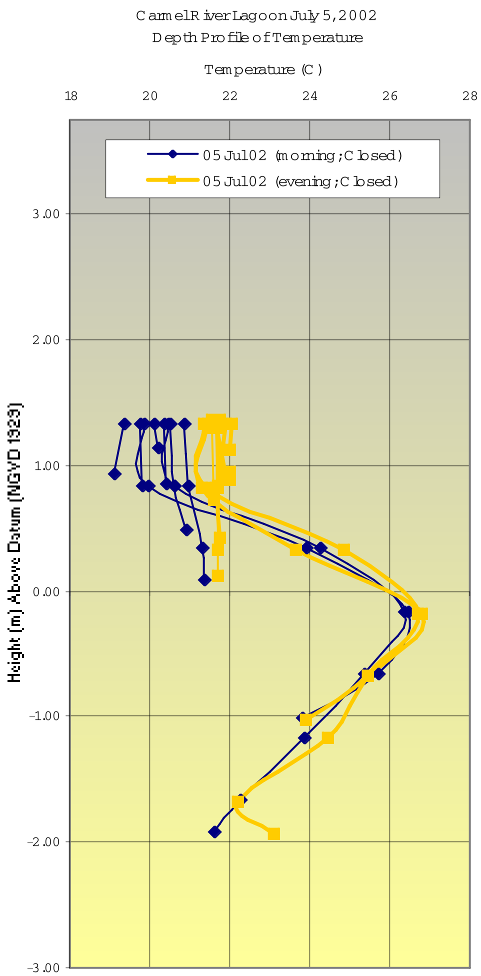
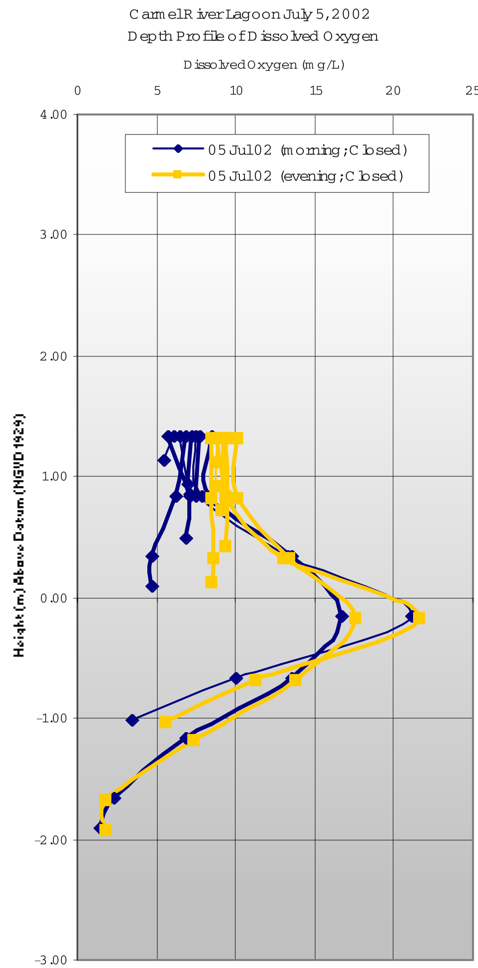


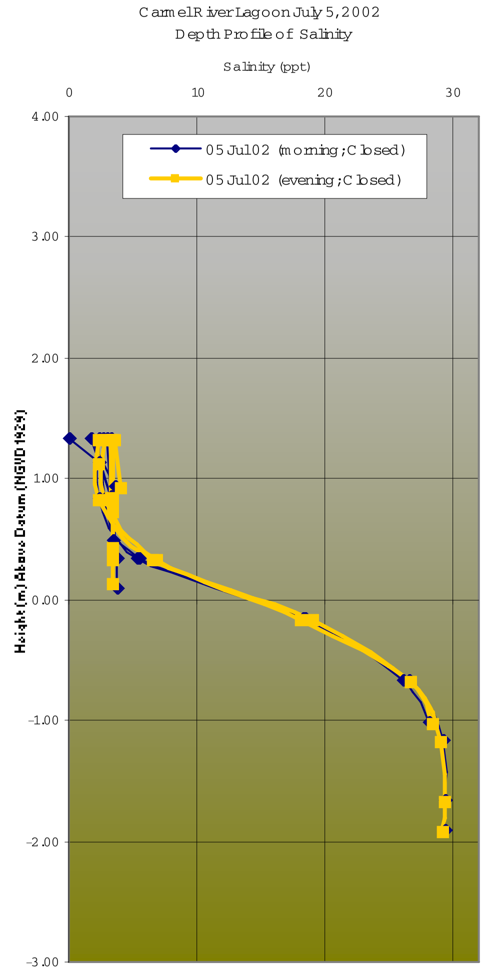




July 5th 2002



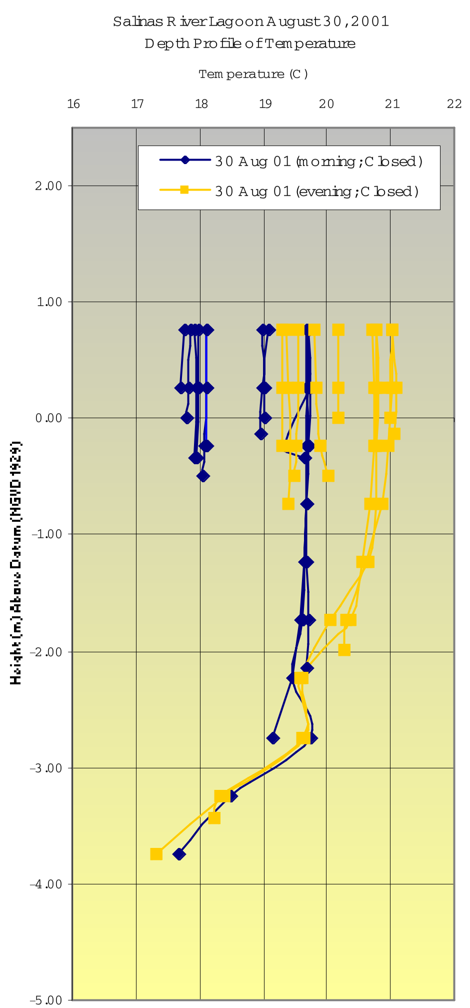


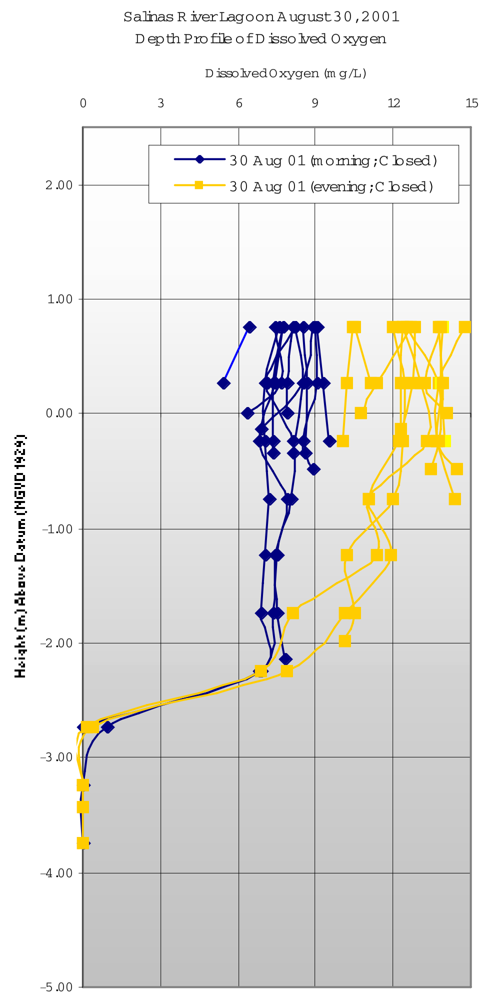


Appendix B:
Salinas River Lagoon
Water Qualtiy Monitoring Events

Figure B.1 illustrates, separately, temperature, dissolved oxygen and salinity at several locations in the Salinas Lagoon during each monitoring event.

August 30th 2001





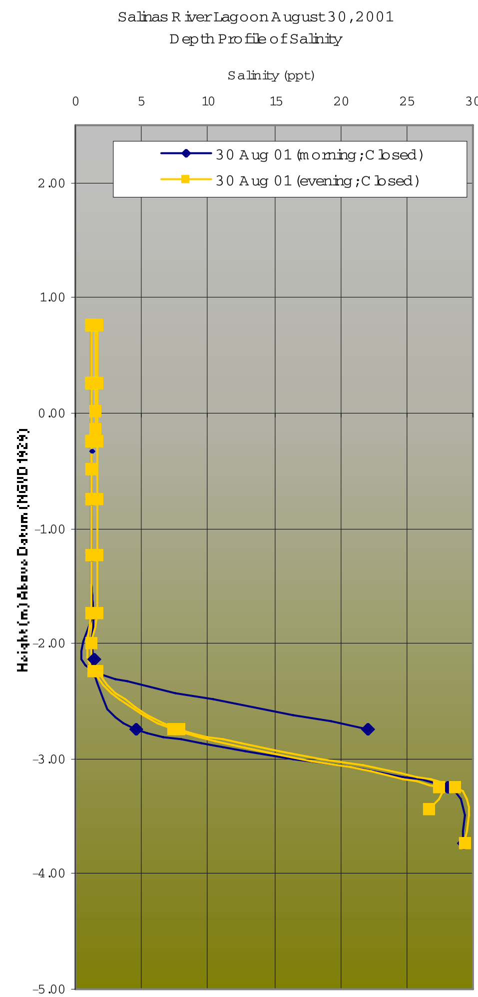
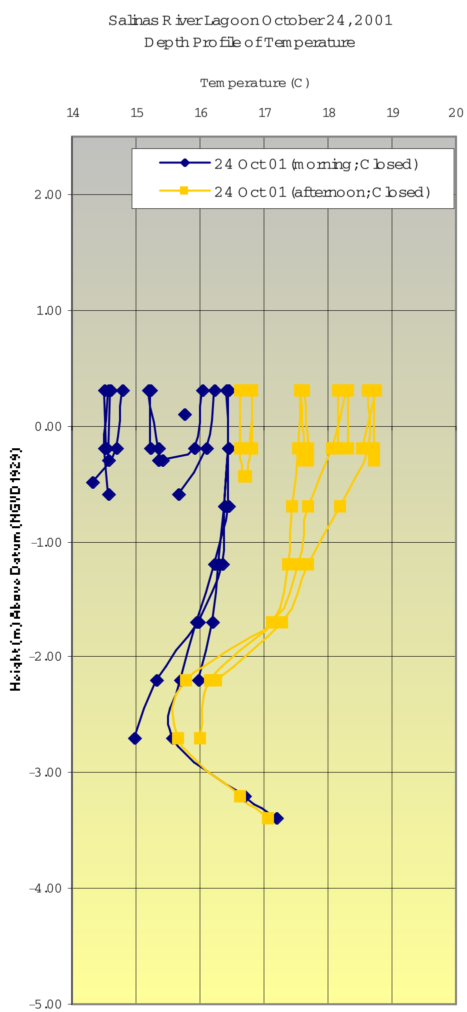
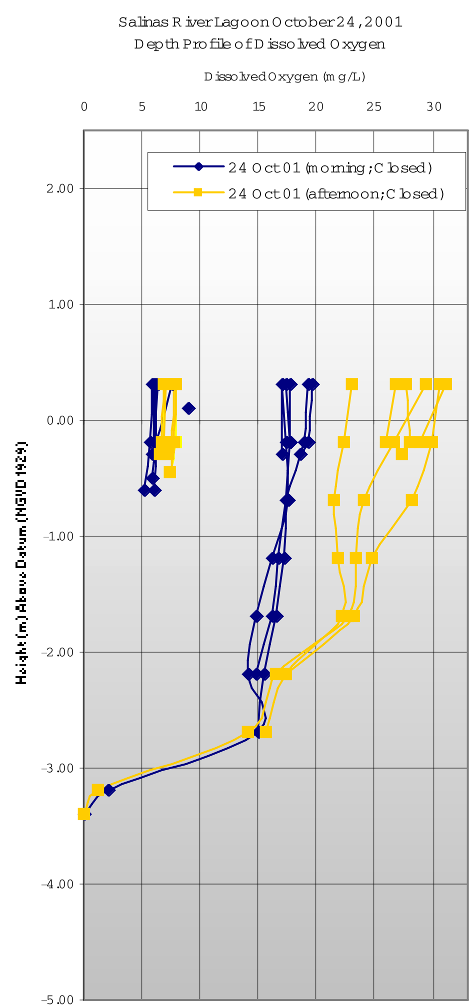
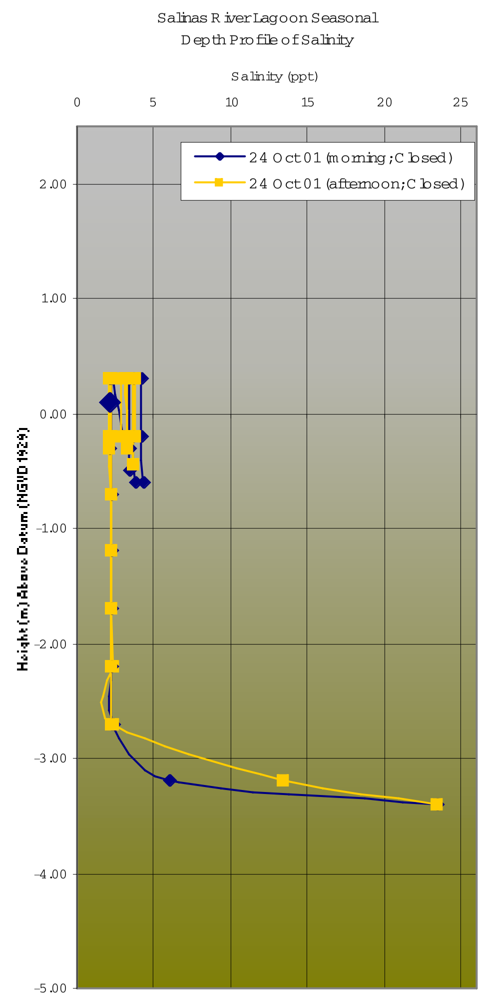


Figure B.1 Analyte profiles for each monitoring event of the Salinas Lagoon

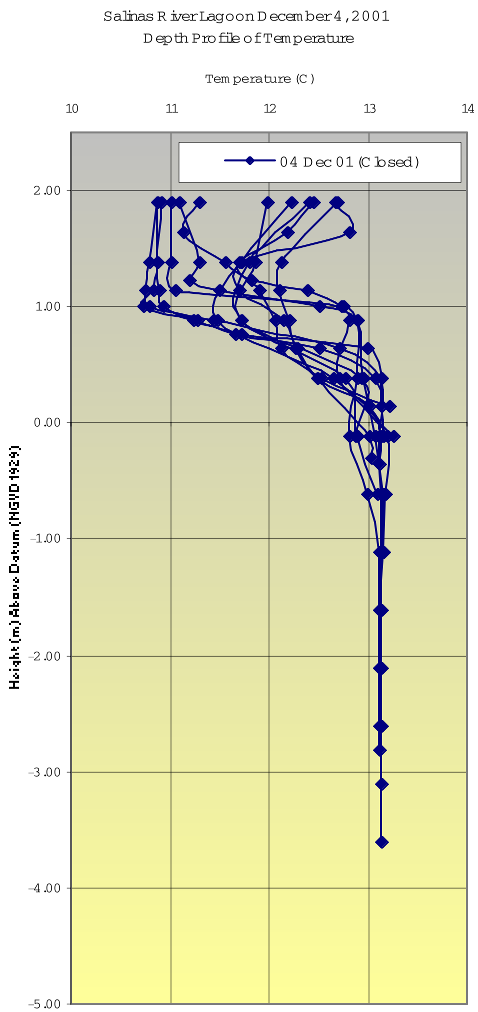
October 24th 2001

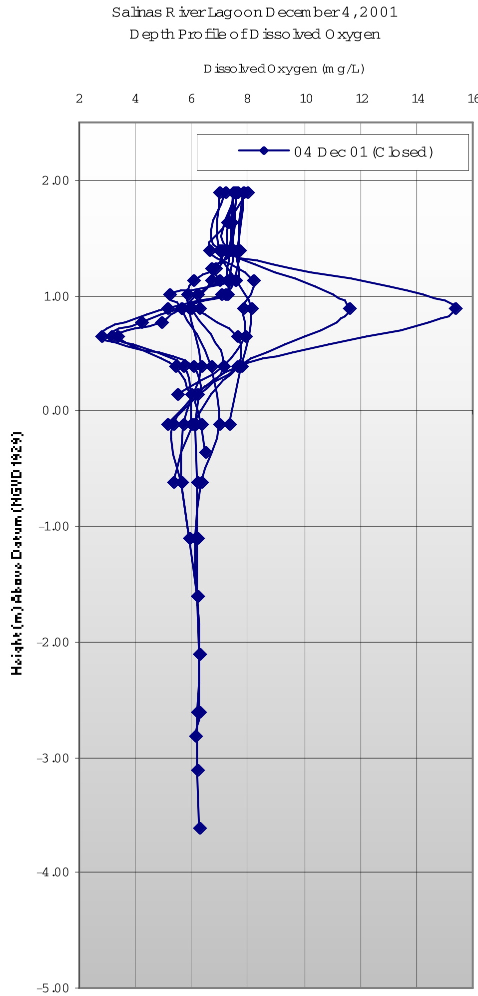


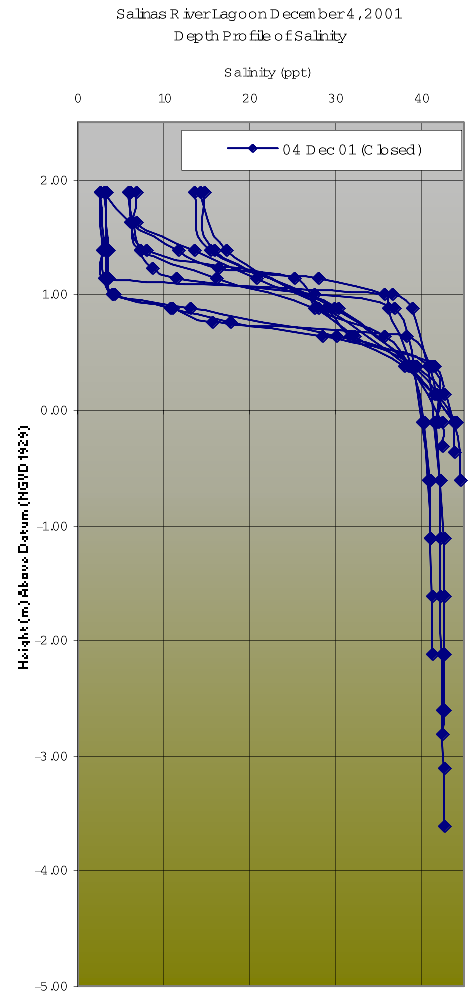




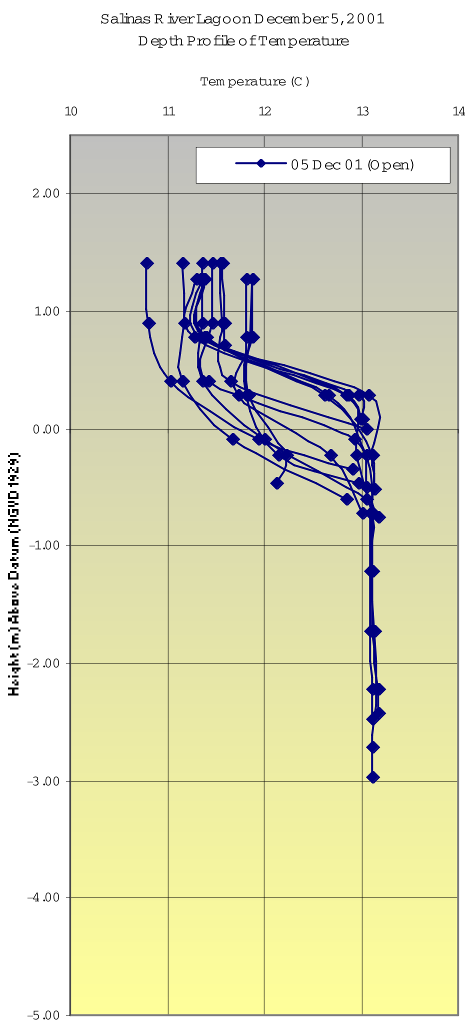
December 4th 2001

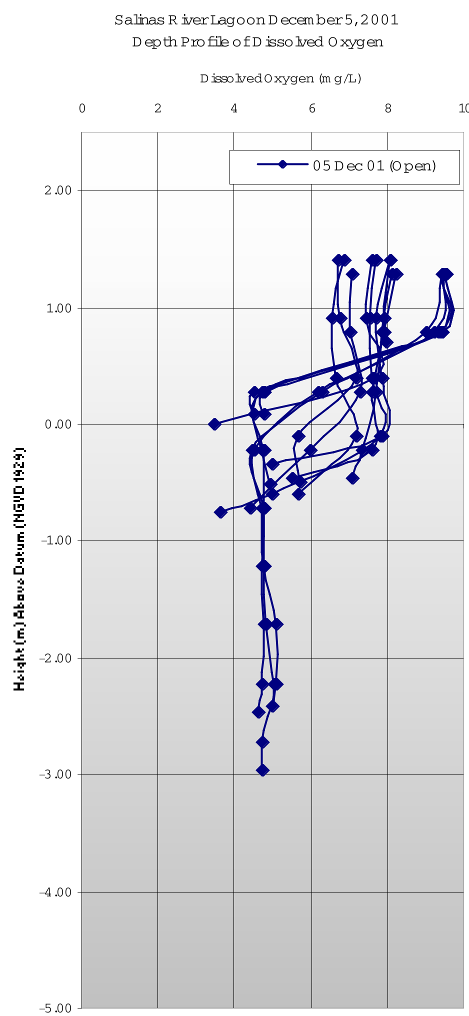


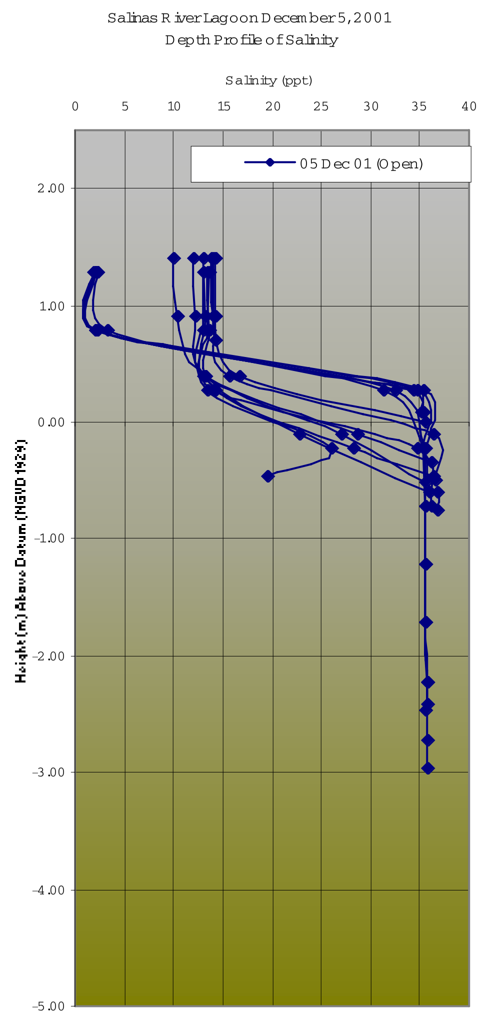




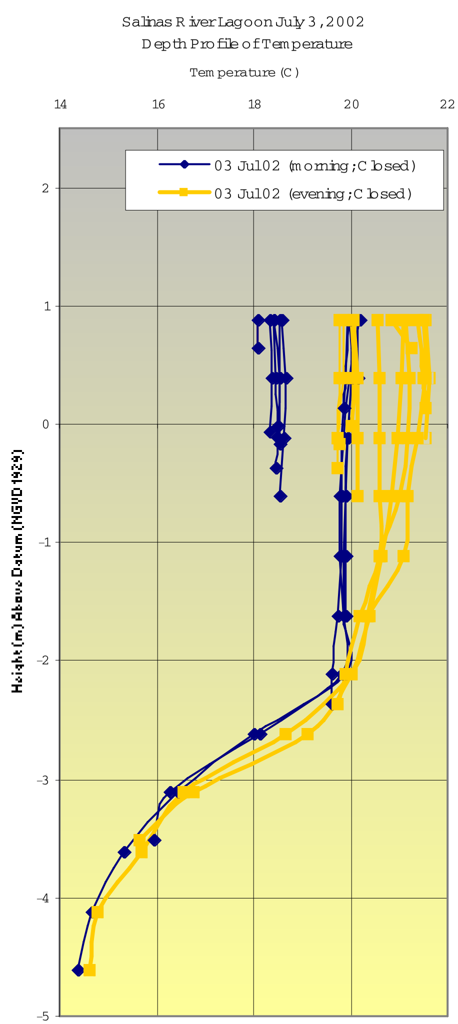
December 5th 2001

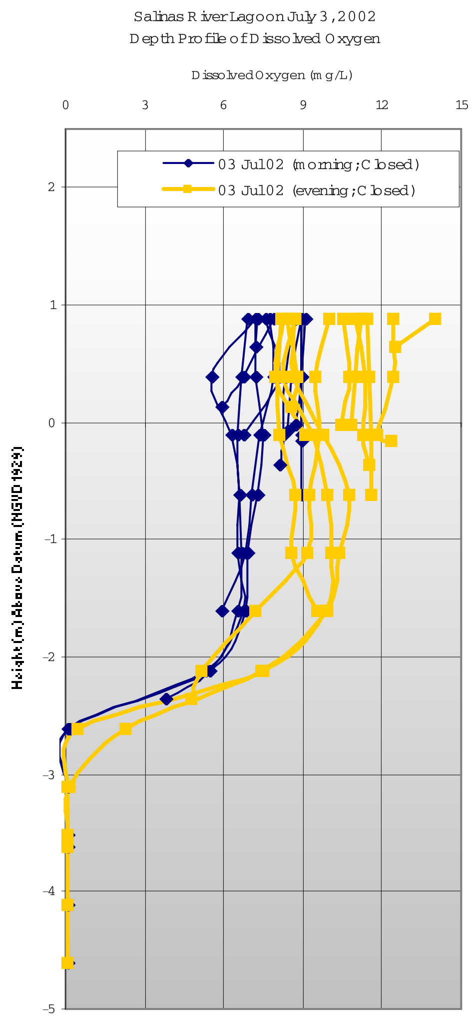


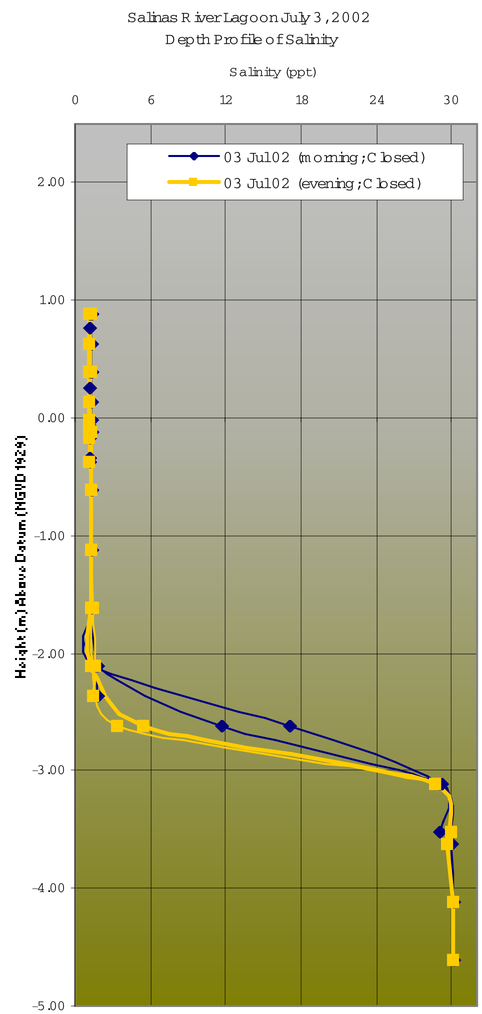




July 3rd 2002



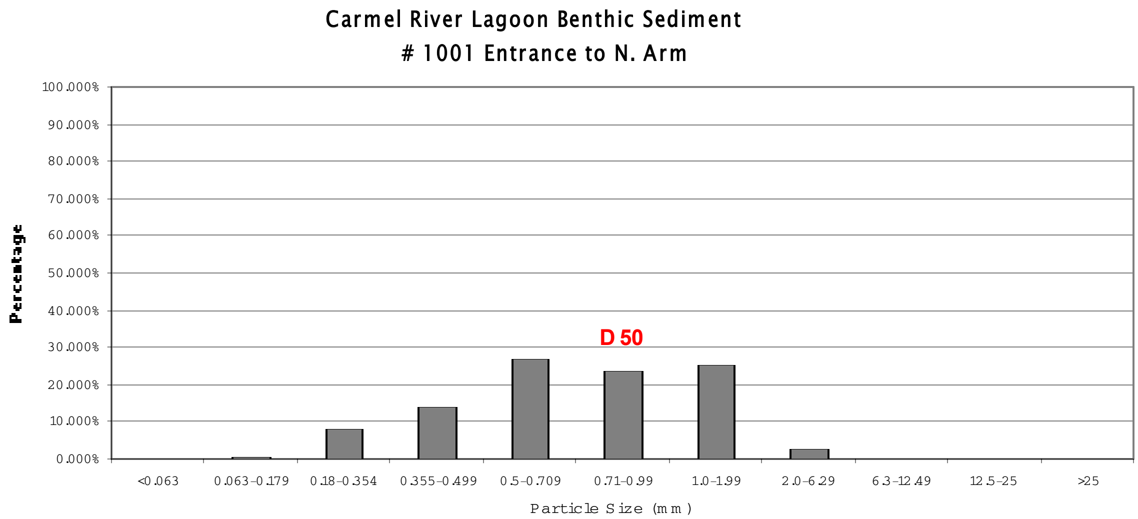


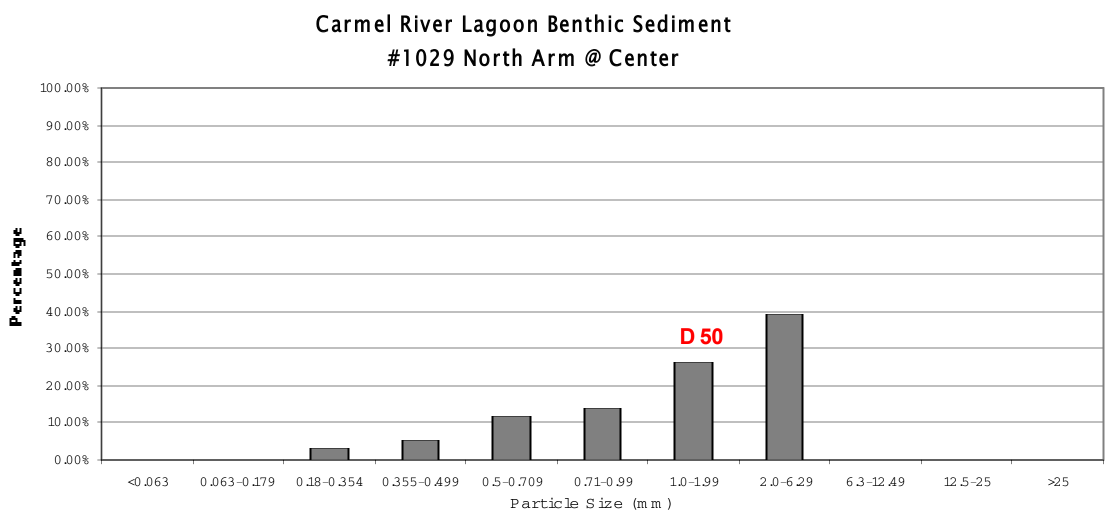


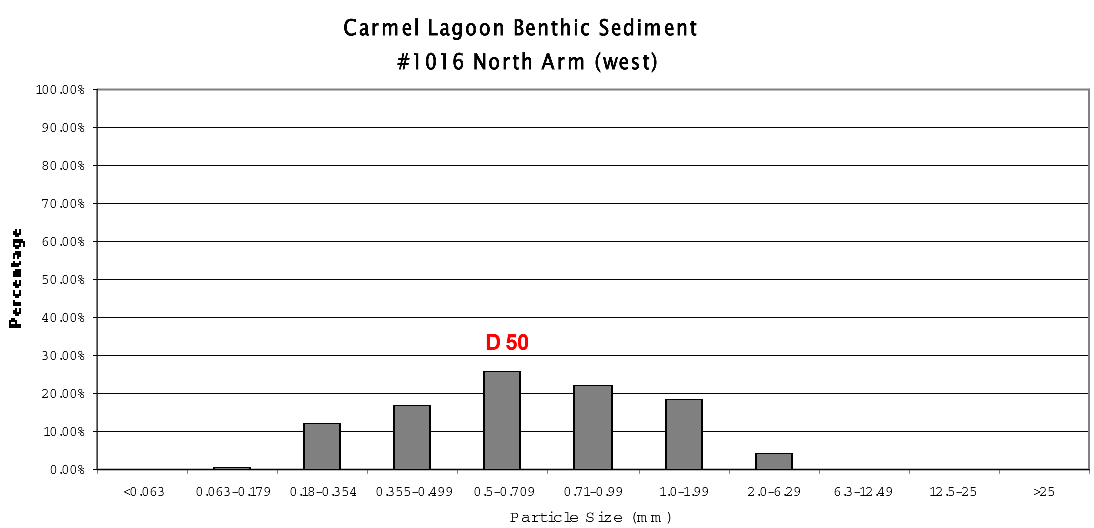
Appendix C
Carmel River Lagoon Benthic Sediment Particle Size Distribution

Figure C.1 illustrates the particle size distribution for benthic sediments collected in various locations of the Carmel Lagoon. General location for each sample is detailed in the title of each graph.

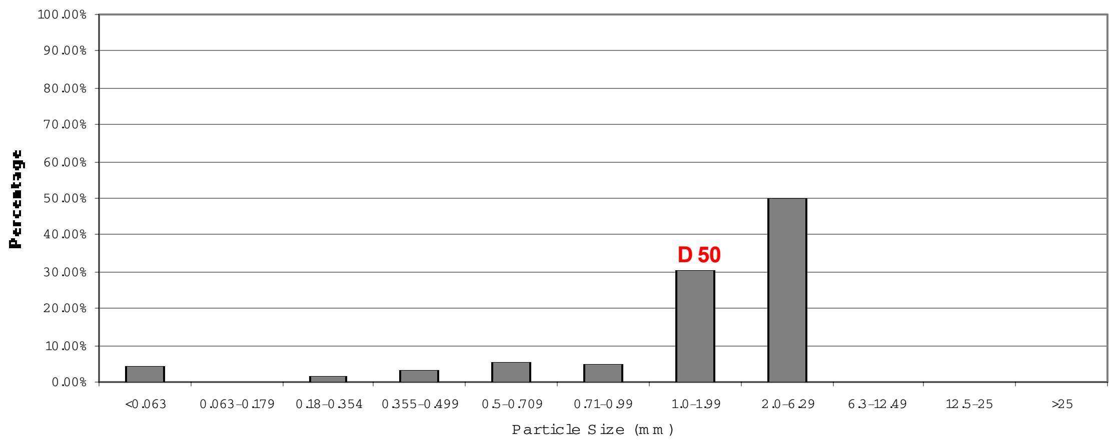
Figure C.1 Particle size distributions at different locations in the Carmel Lagoon.



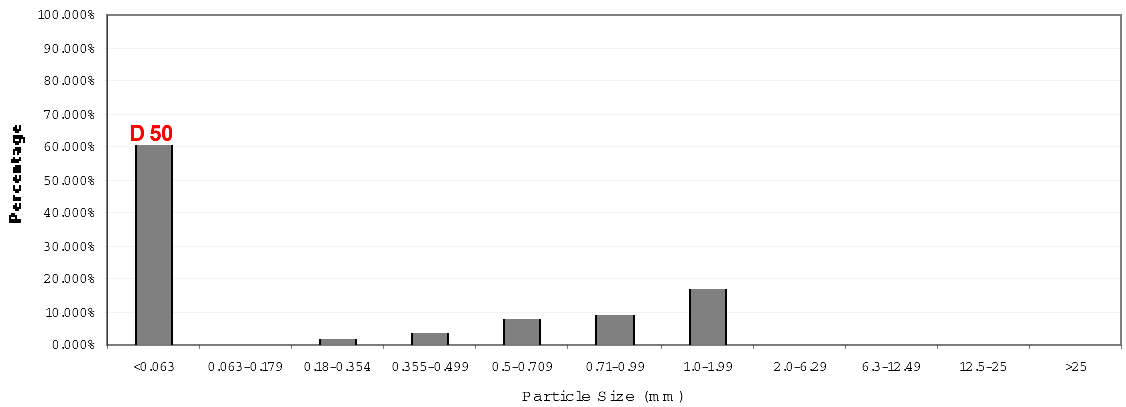




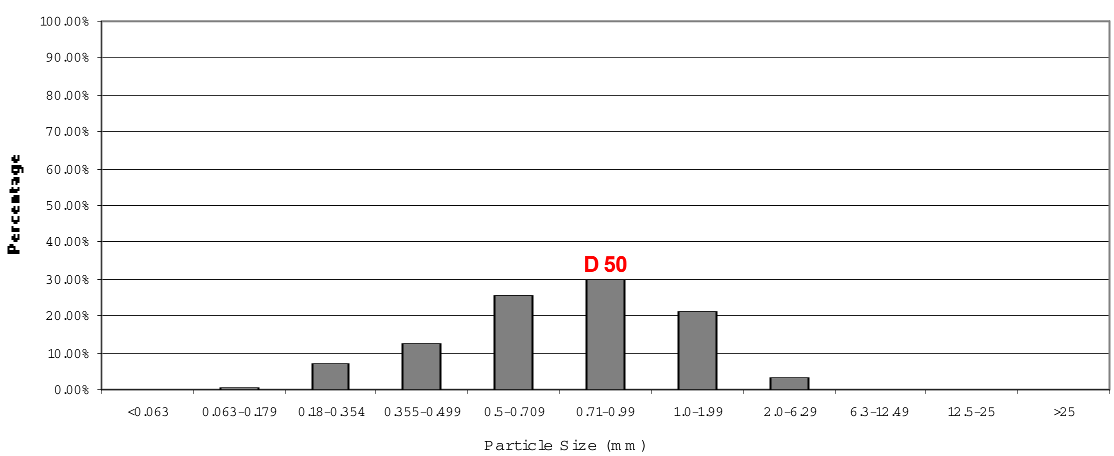
Carmel River Lagoon Benthic Sediment
#1025 North Arm (north)

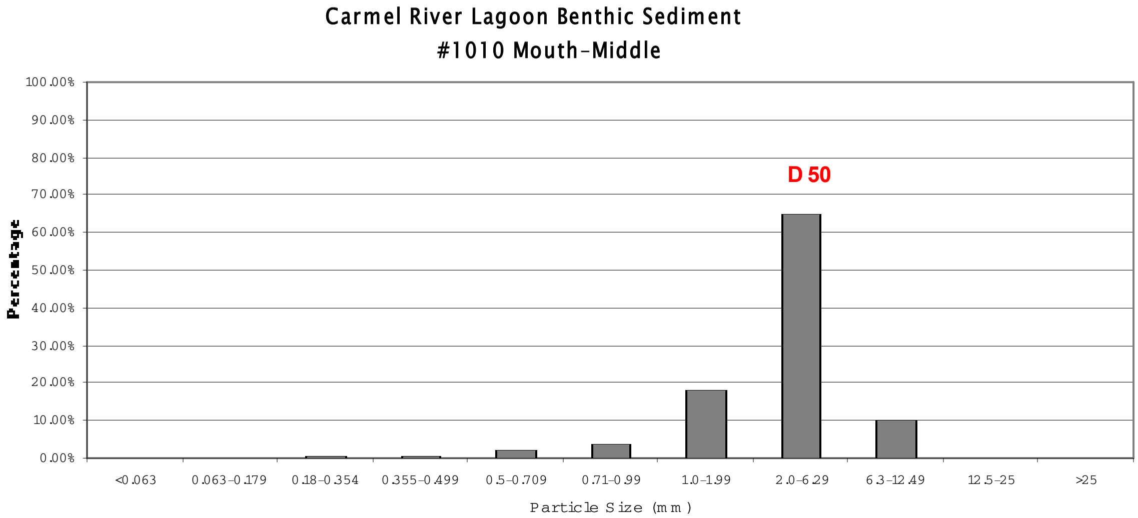


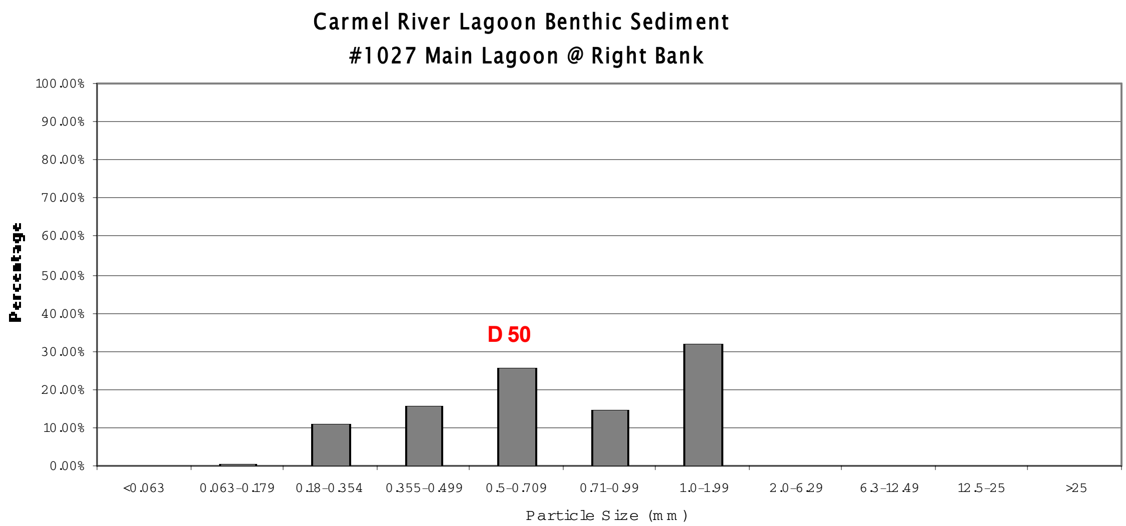
Carmel River Lagoon Benthic Sediment
#1032 North Arm (east)

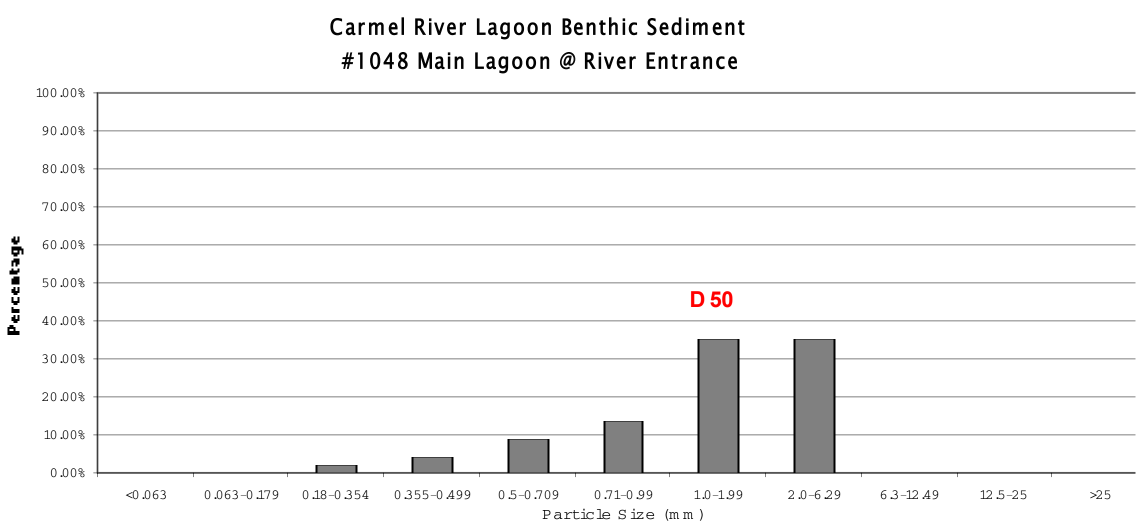


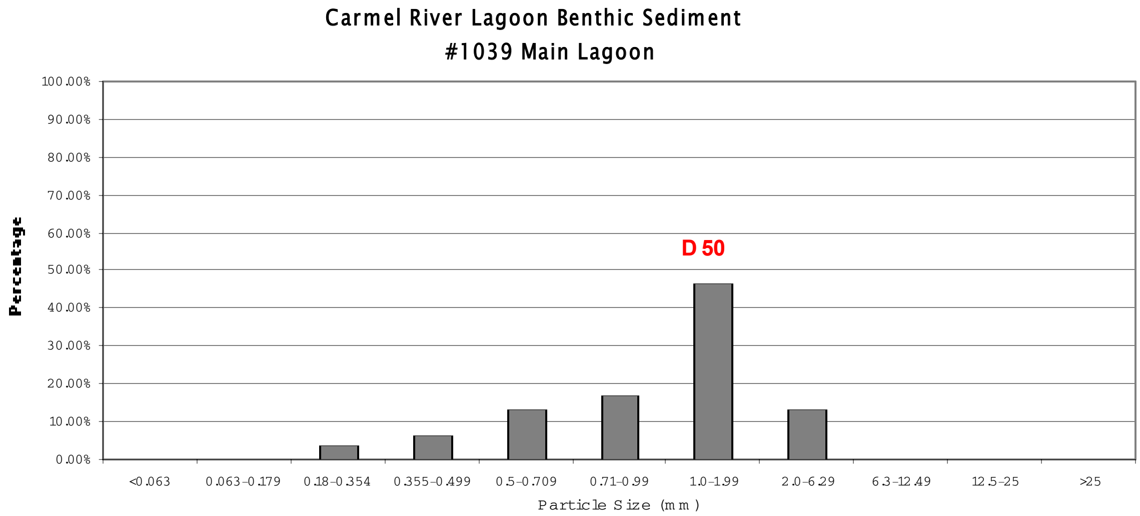
Carmel River Lagoon Benthic Sediment
#1009 Mouth @ Bar

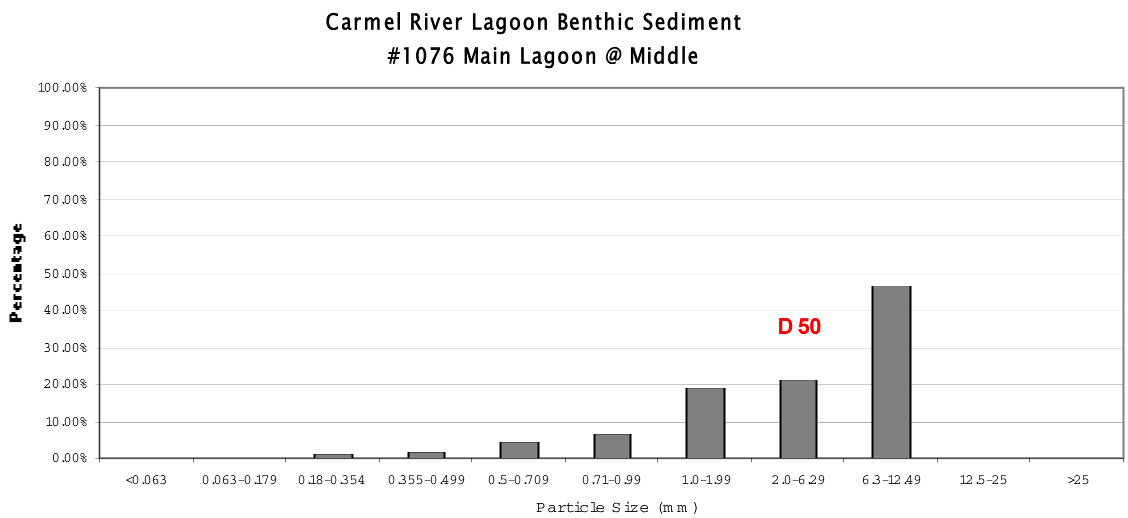


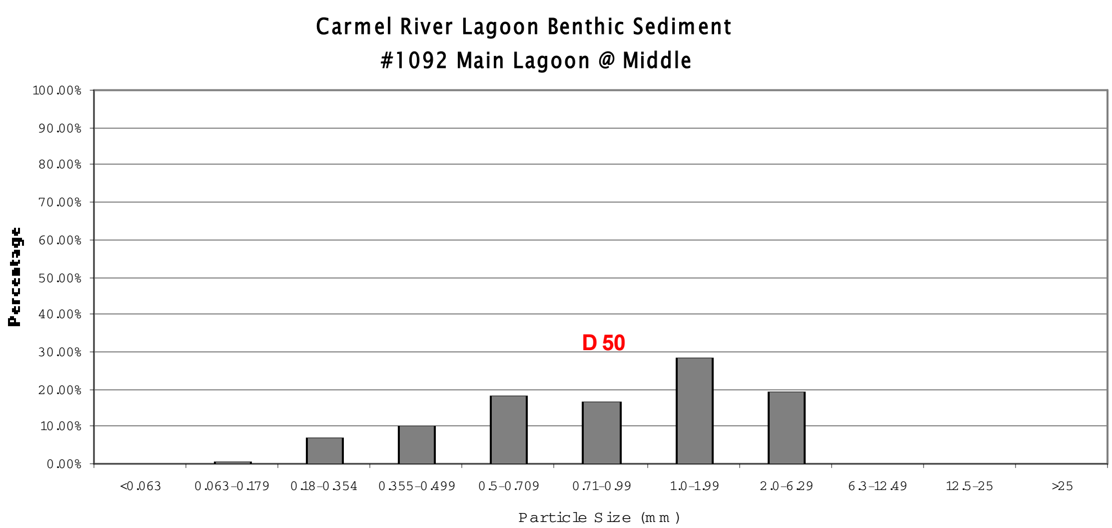

Carmel River Lagoon Benthic Sediment
#1010 Mouth-Middle
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)


Carmel River Lagoon Benthic Sediment
#1027 Main Lagoon @ Right Bank
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

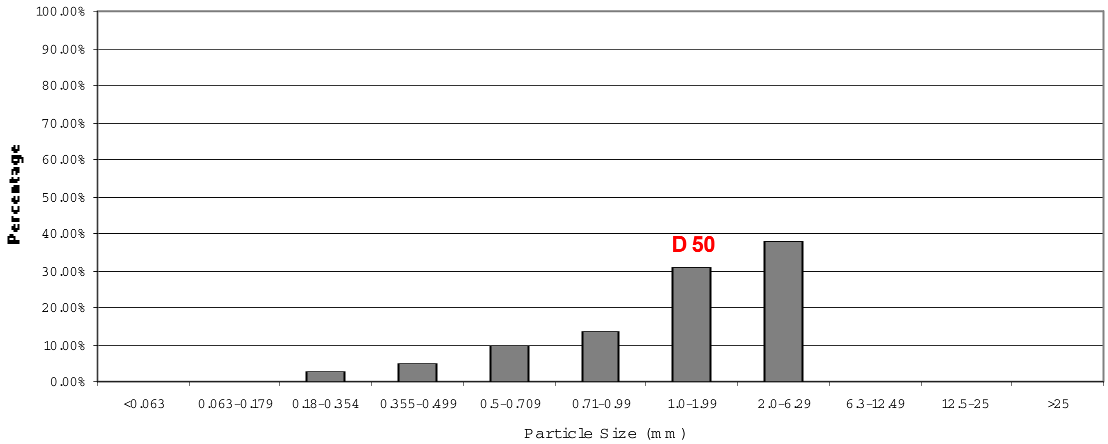

Carmel River Lagoon Benthic Sediment
#1048 Main Lagoon @ River Entrance
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)


Carmel River Lagoon Benthic Sediment
#1039 Main Lagoon
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

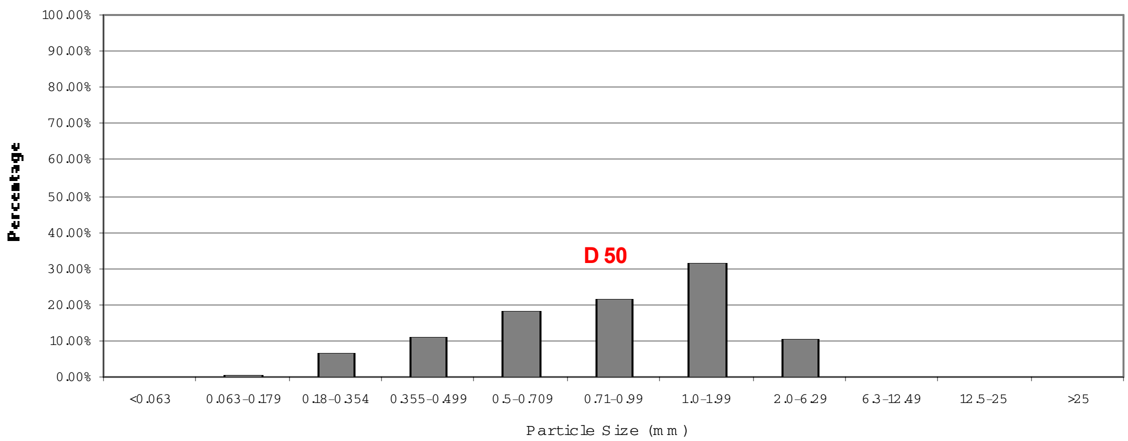

Carmel River Lagoon Benthic Sediment
#1076 Main Lagoon @ Middle
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)


Carmel River Lagoon Benthic Sediment
#1092 Main Lagoon @ Middle
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

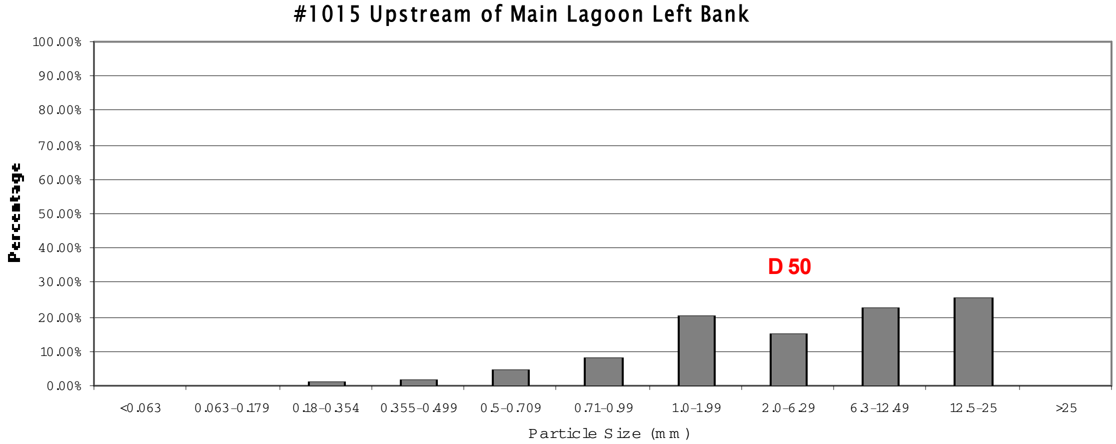
Carmel River Lagoon Benthic Sediment
#1065 Main Lagoon @ Middle



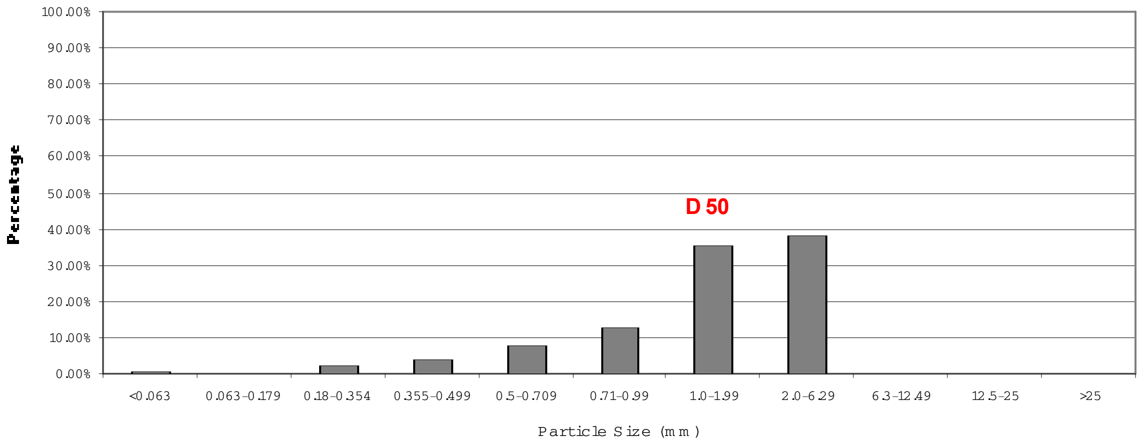
Carmel River Lagoon Benthic Sediment
#1031 Main Lagoon @ Left Bank



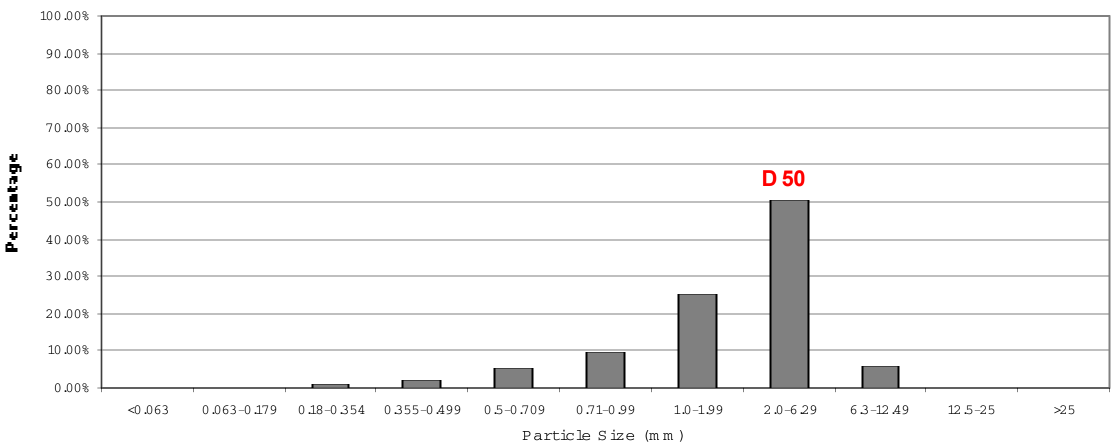
Carmel River Lagoon Benthic Sediment
#1015 Upstream of Main Lagoon Left Bank



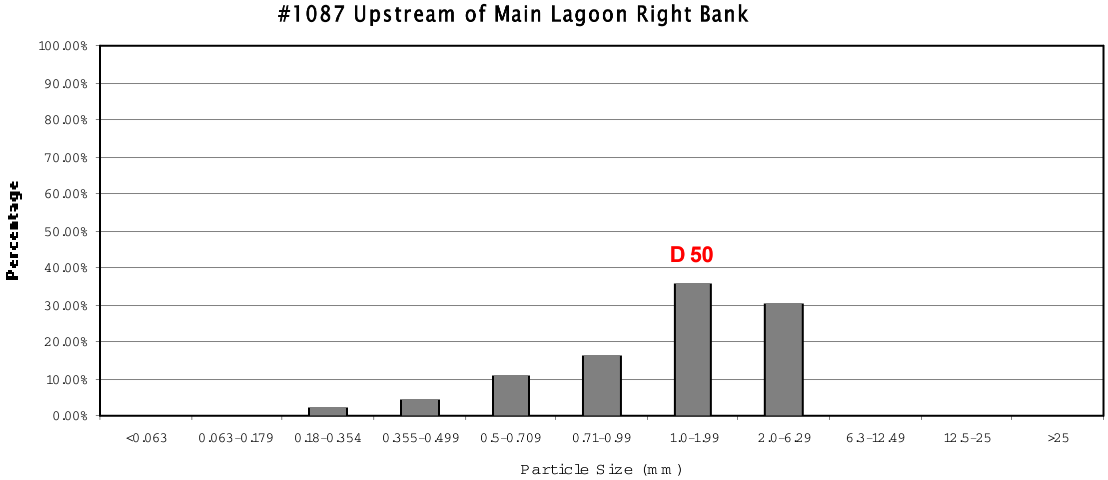
Carmel Lagoon Benthic Sediment
#1006 Upstream of Main Lagoon (mid)

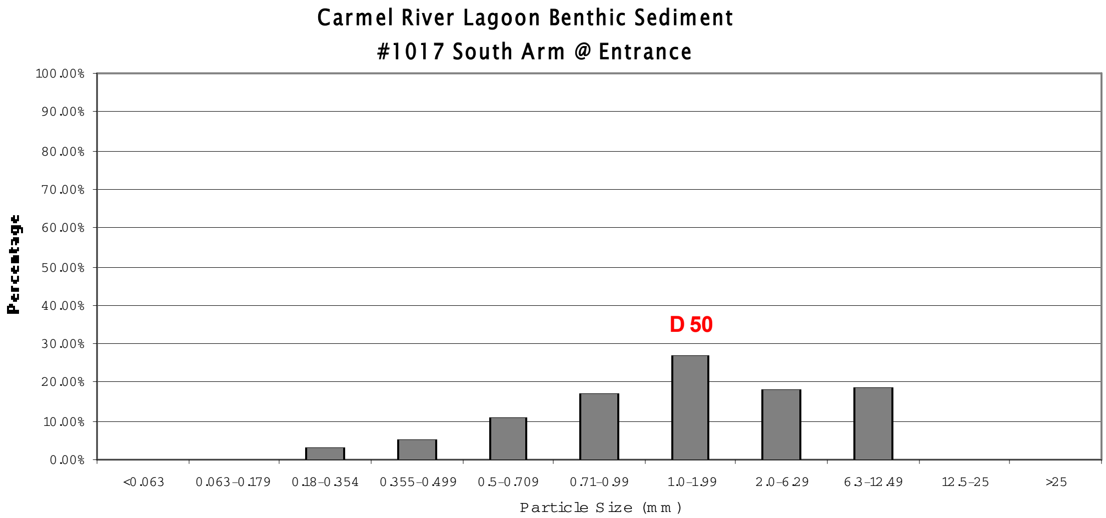


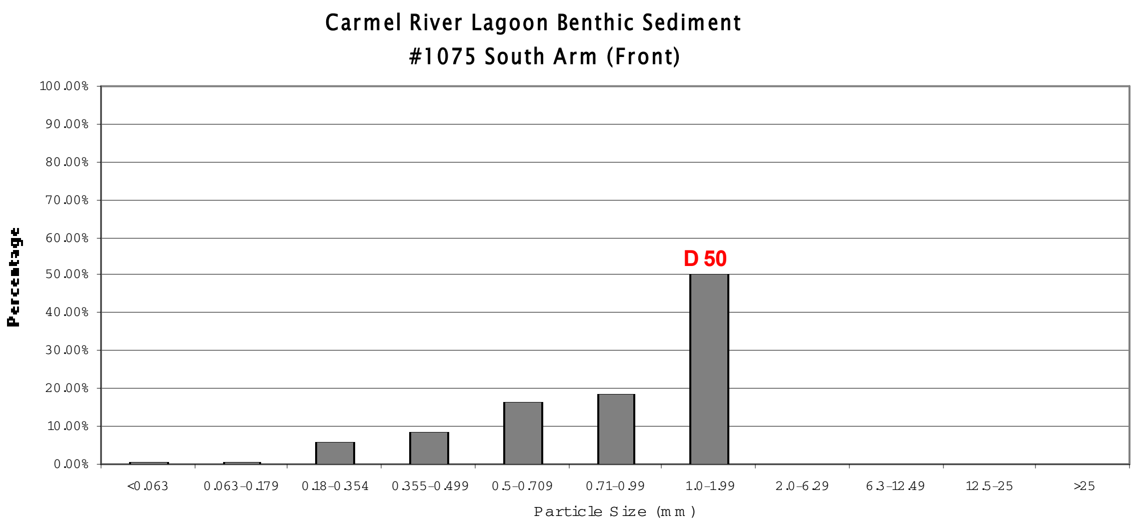
Carmel River Lagoon Benthic Sediment
#1020 Upsteam of Main Lagoon (mid)

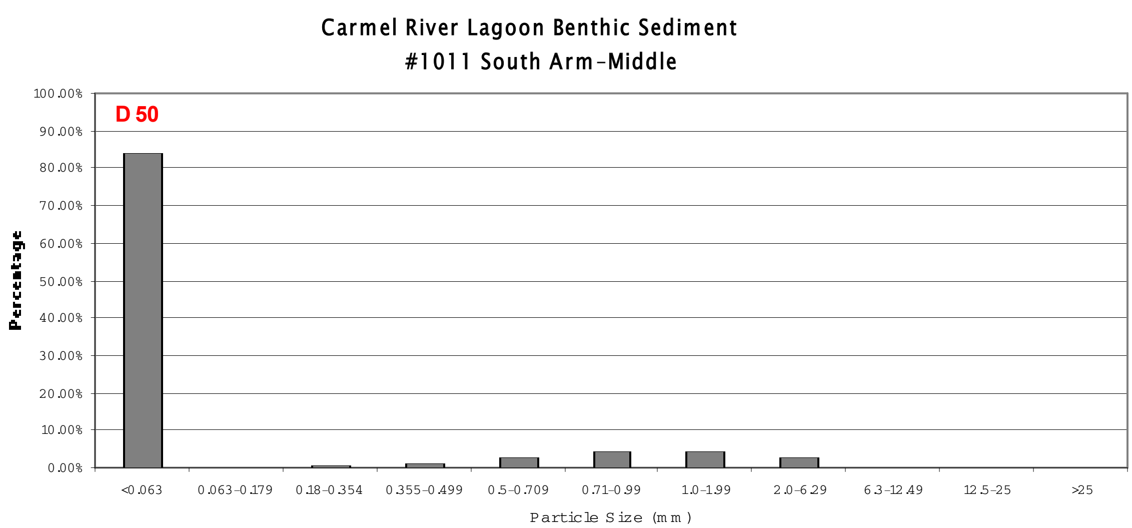


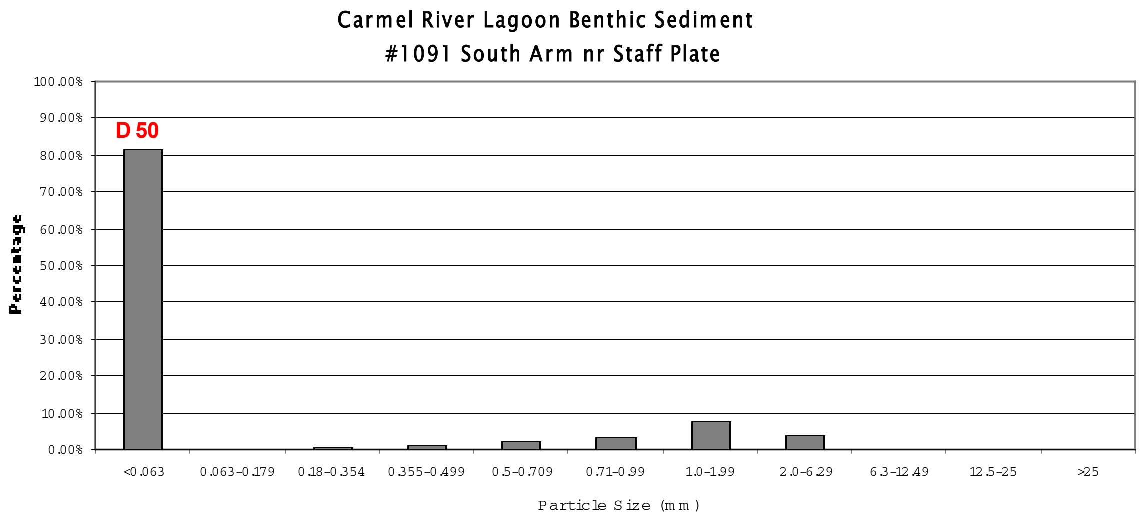
Carmel River Lagoon Benthic Sediment
#1087 Upstream of Main Lagoon Right Bank

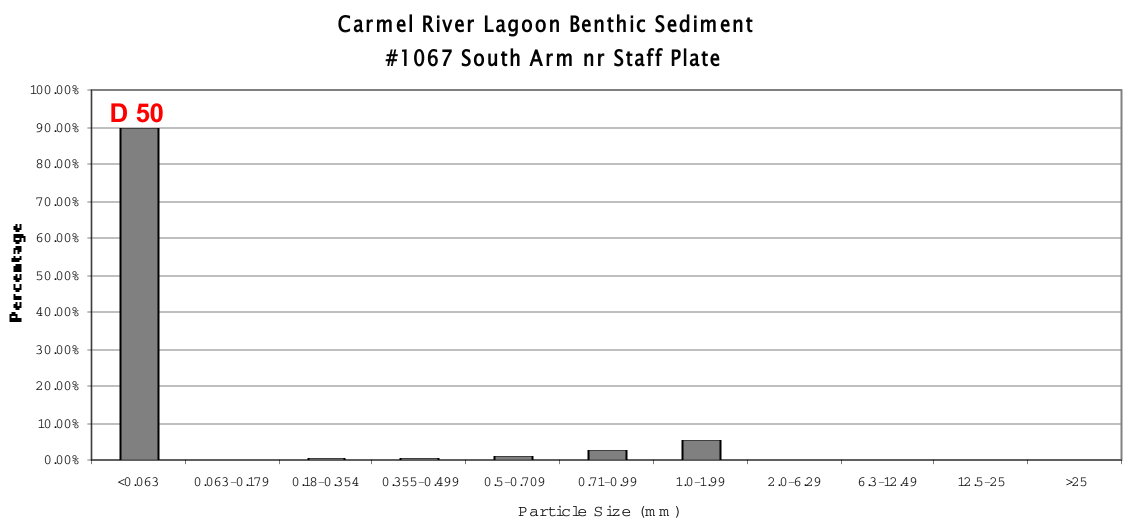


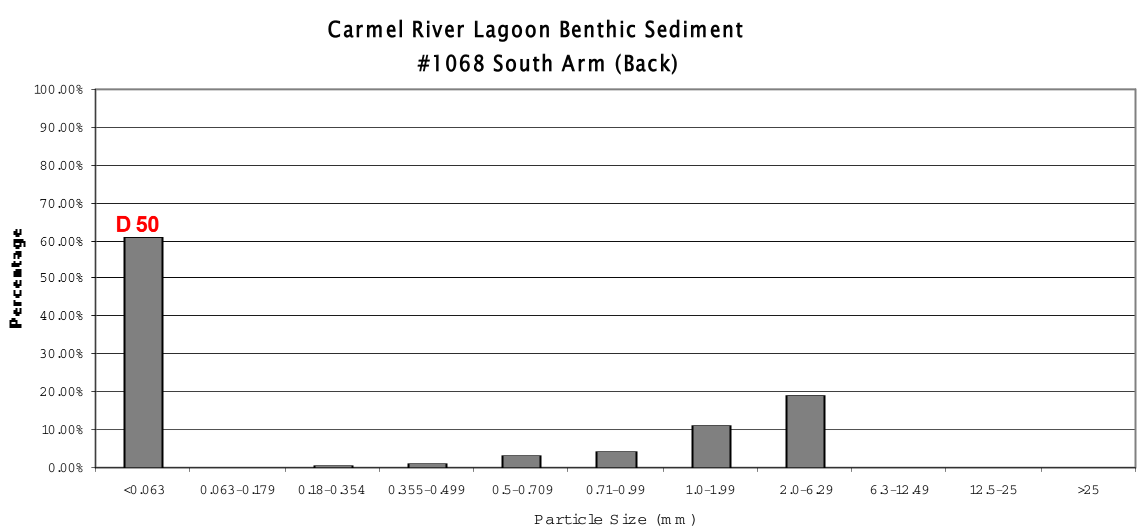

Carmel River Lagoon Benthic Sediment
#1017 South Arm @ Entrance
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

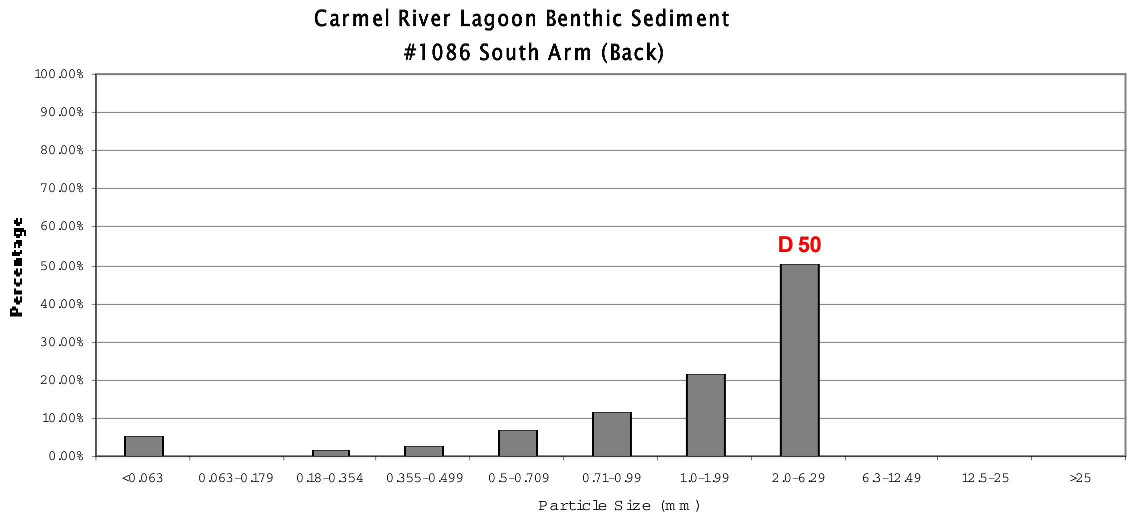

Carmel River Lagoon Benthic Sediment
#1075 South Arm (Front)
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

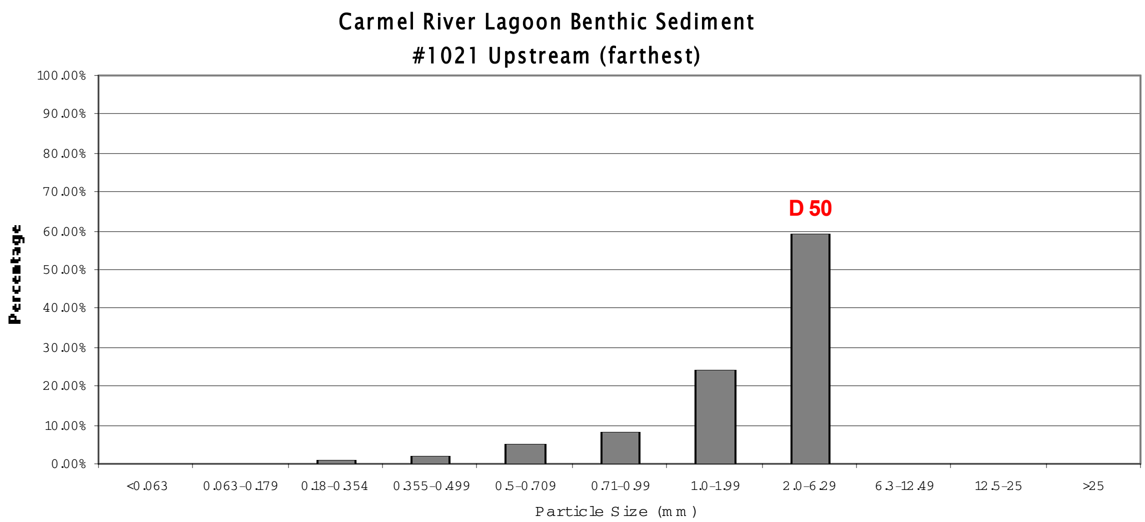

Carmel River Lagoon Benthic Sediment
#1011 South Arm-Middle
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

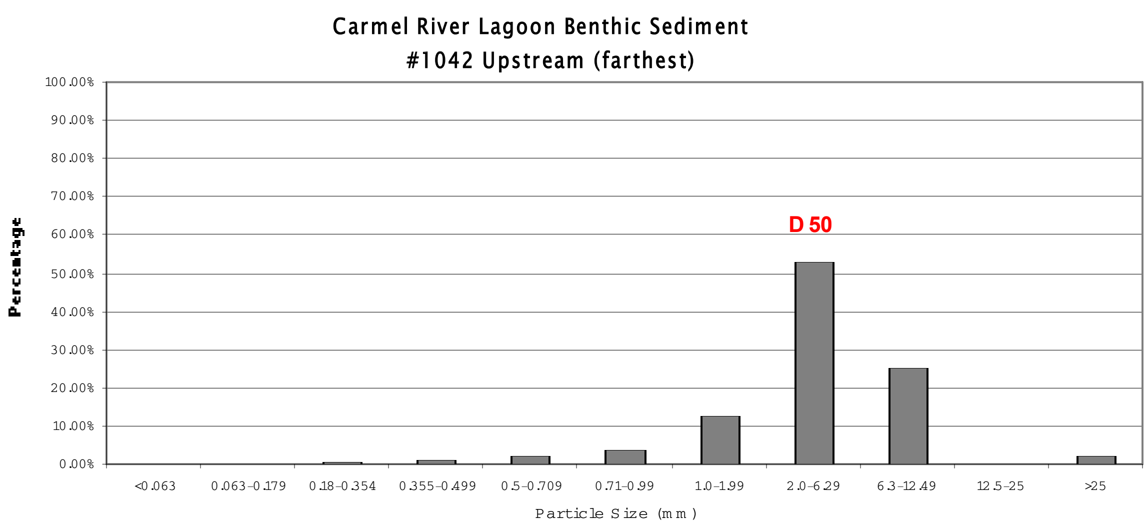

Carmel River Lagoon Benthic Sediment
#1091 South Arm nr Staff Plate
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)


Carmel River Lagoon Benthic Sediment
#1067 South Arm nr Staff Plate
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)


Carmel River Lagoon Benthic Sediment
#1068 South Arm (Back)
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)


Carmel River Lagoon Benthic Sediment
#1086 South Arm (Back)
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

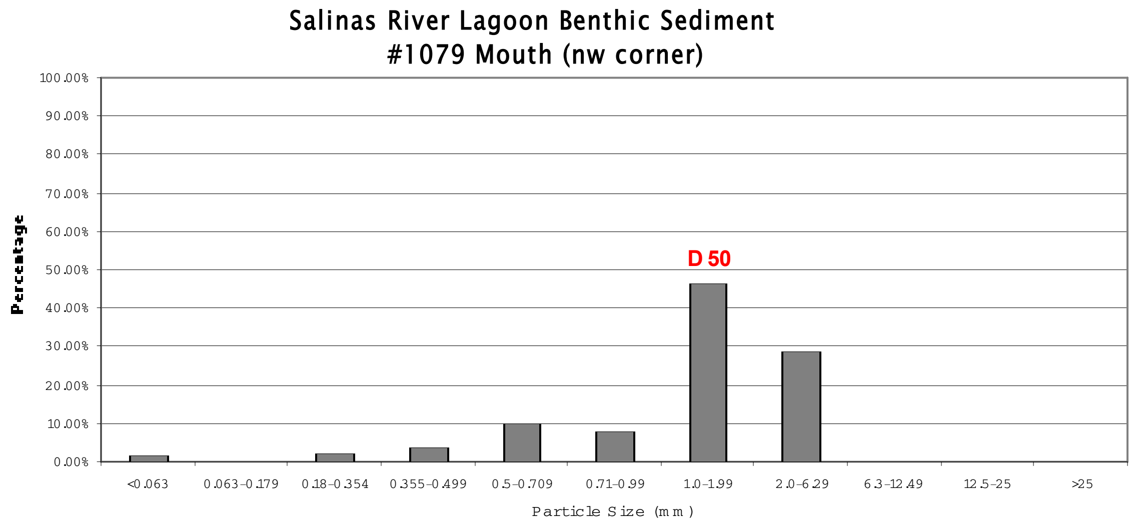

Carmel River Lagoon Benthic Sediment
#1021 Upstream (farthest)
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

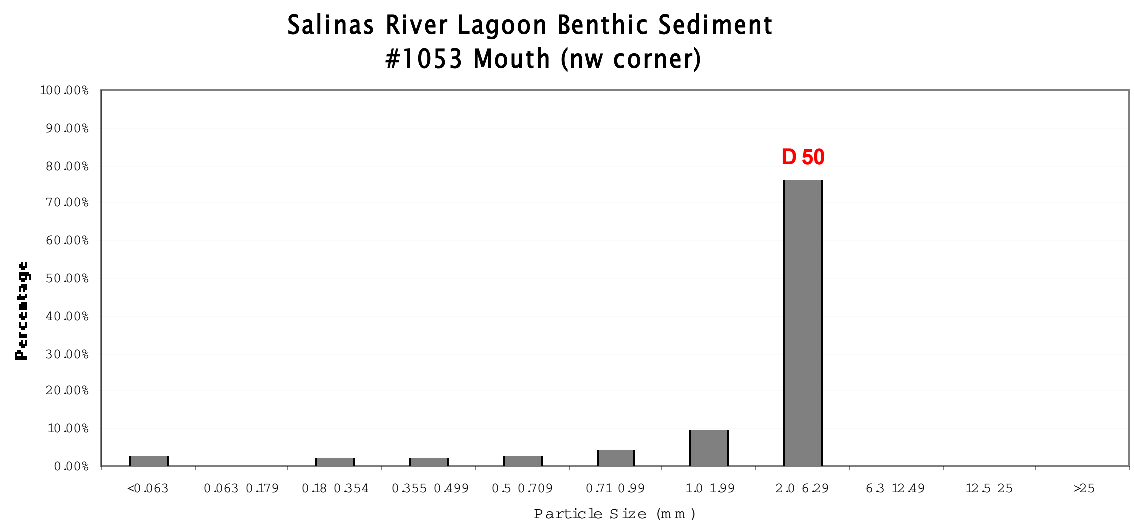

Carmel River Lagoon Benthic Sediment
#1042 Upstream (farthest)
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

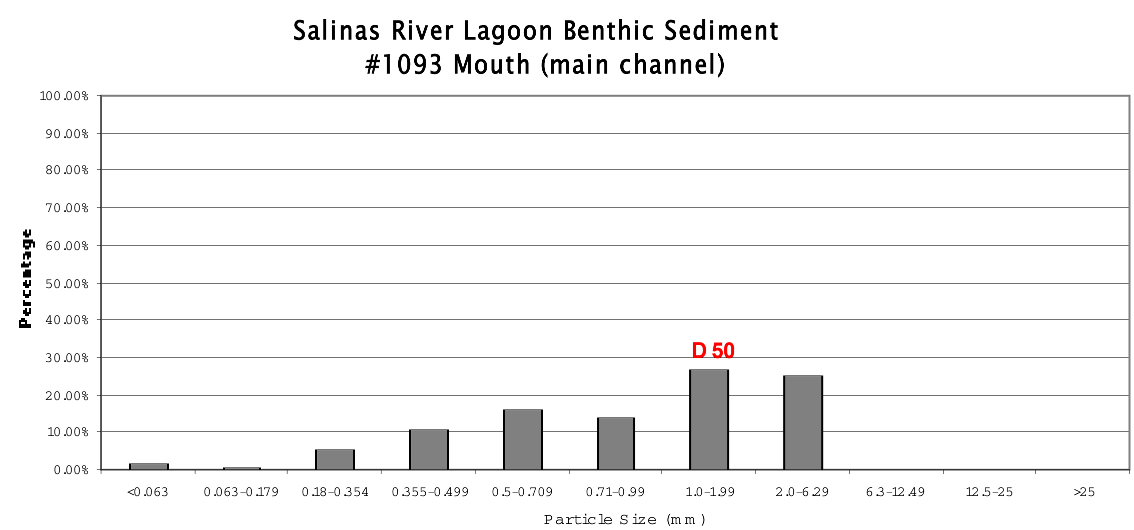
Appendix D
Salinas River Lagoon Benthic Sediment Particle Size Distribution

Figure D.1 illustrates the particle size distribution for benthic sediments collected in various locations of the Salinas Lagoon. General location for each sample is detailed in the title of each graph.

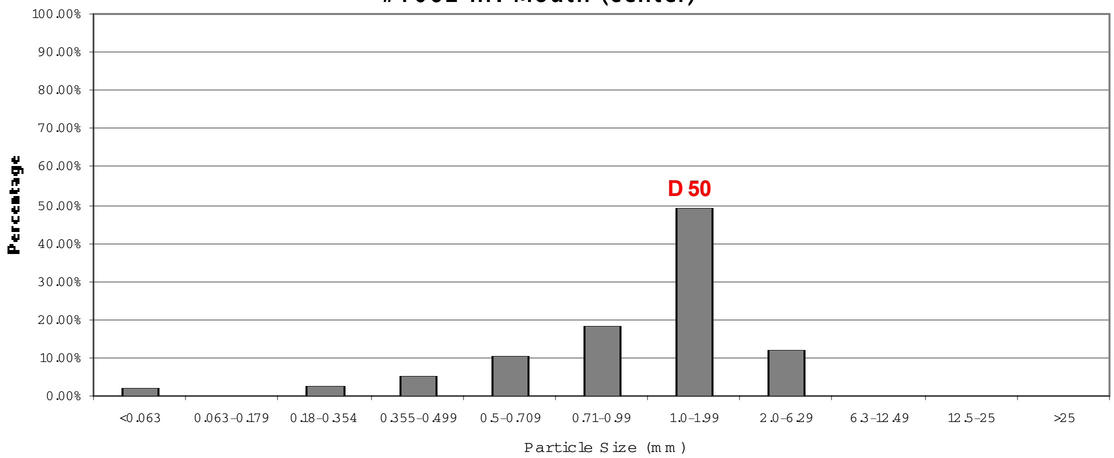
Figure D.1 Particle size distributions at different locations in the Salinas Lagoon.



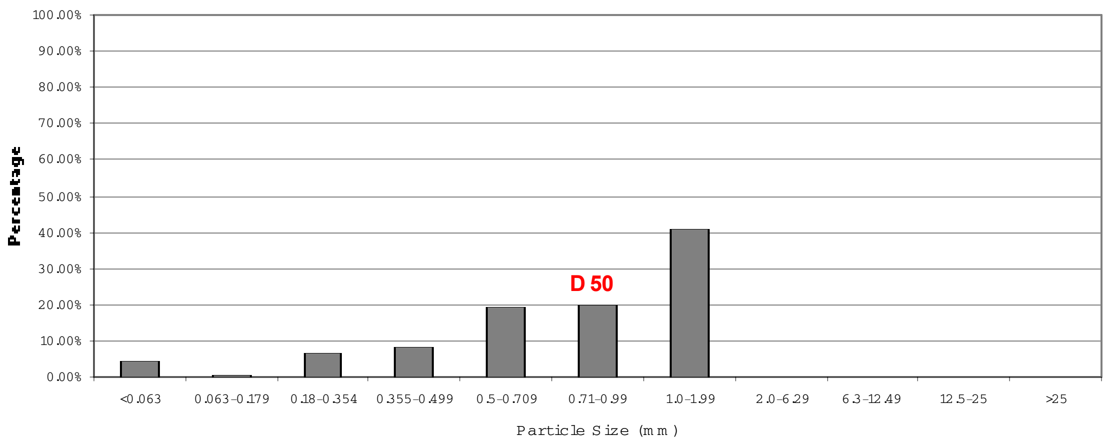




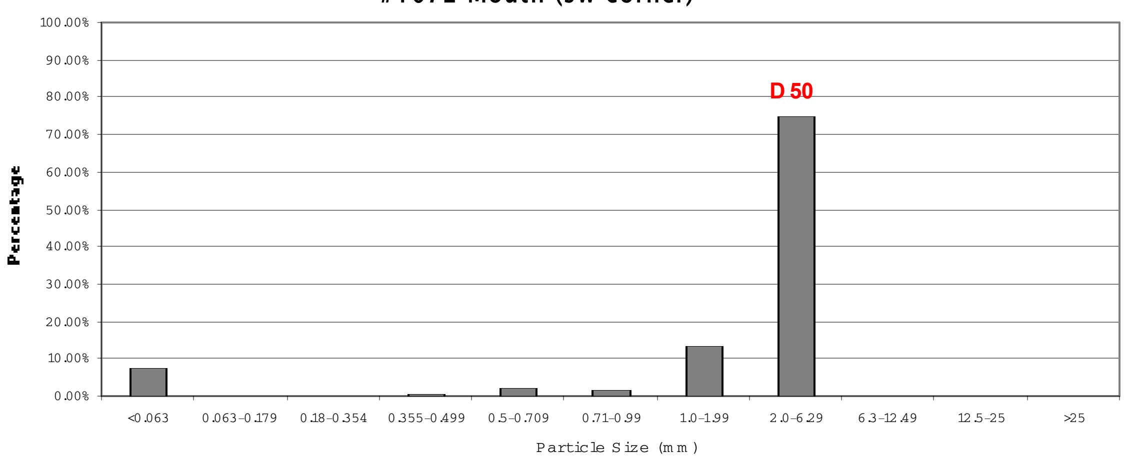
Salinas River Lagoon Benthic Sediment
#1062 nr. Mouth (center)

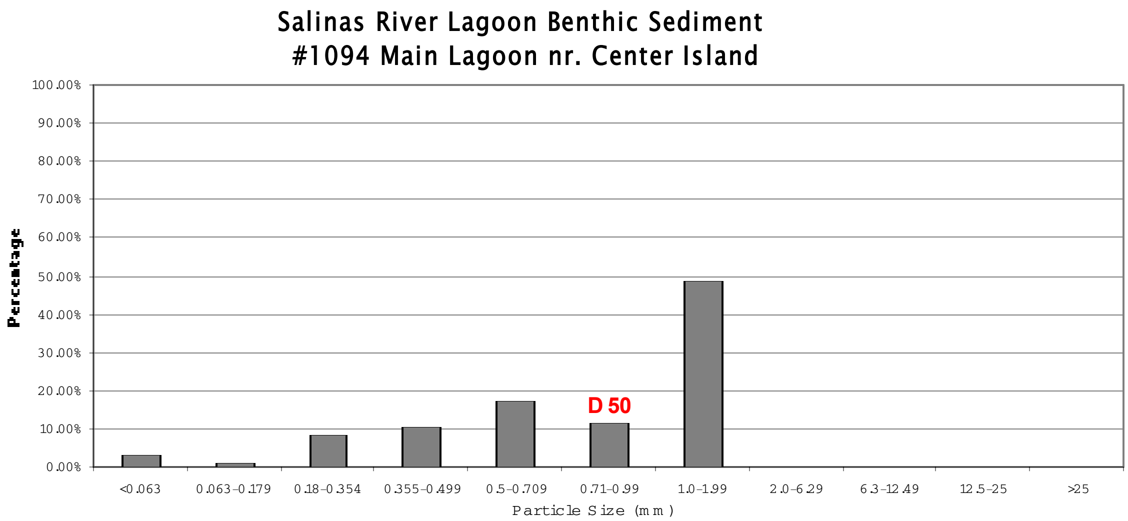


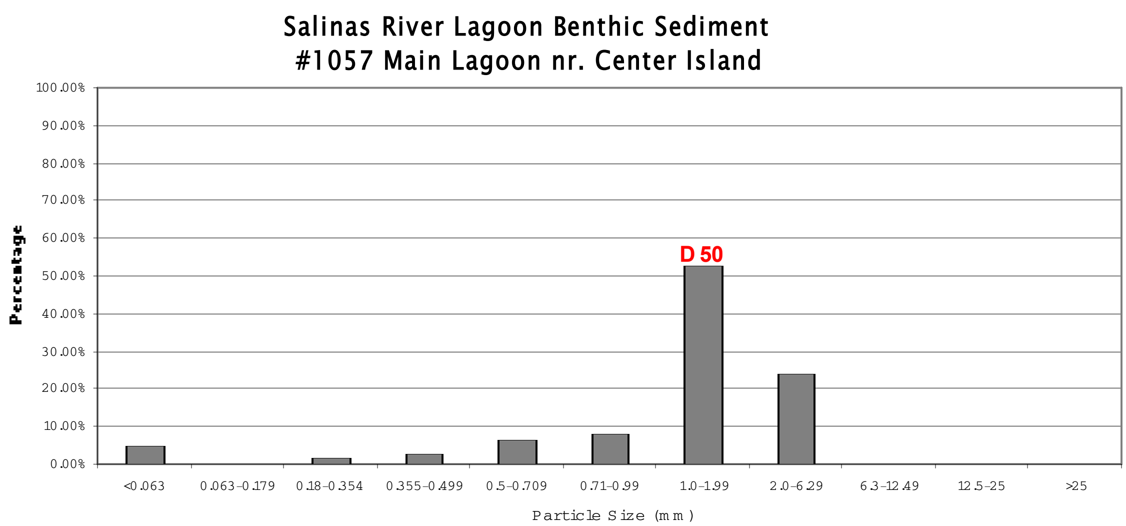
Salinas River Lagoon Benthic Sediment
#1070 nr. Mouth (center)

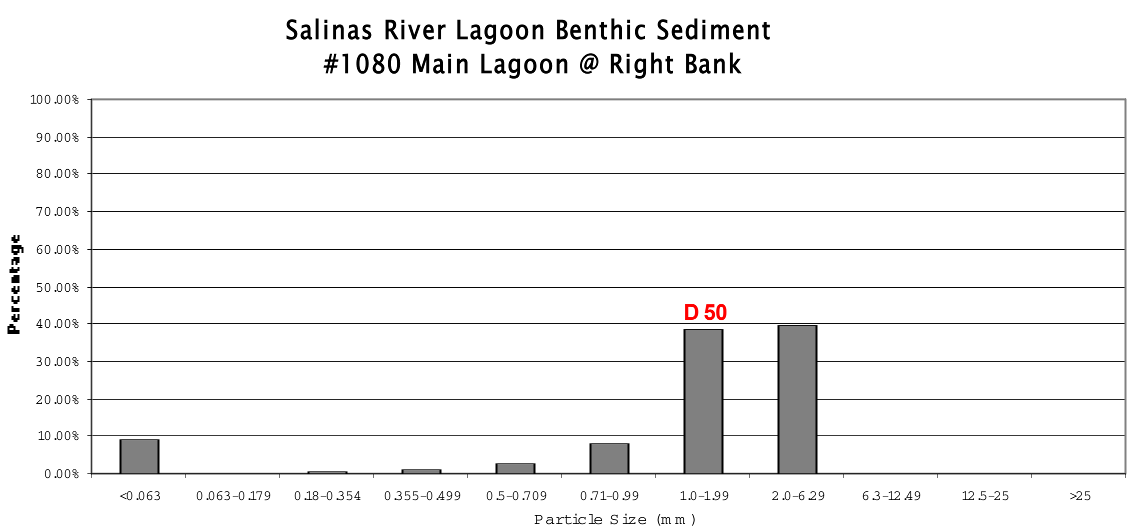


Salinas River Lagoon Benthic Sediment
#1072 Mouth (sw corner)

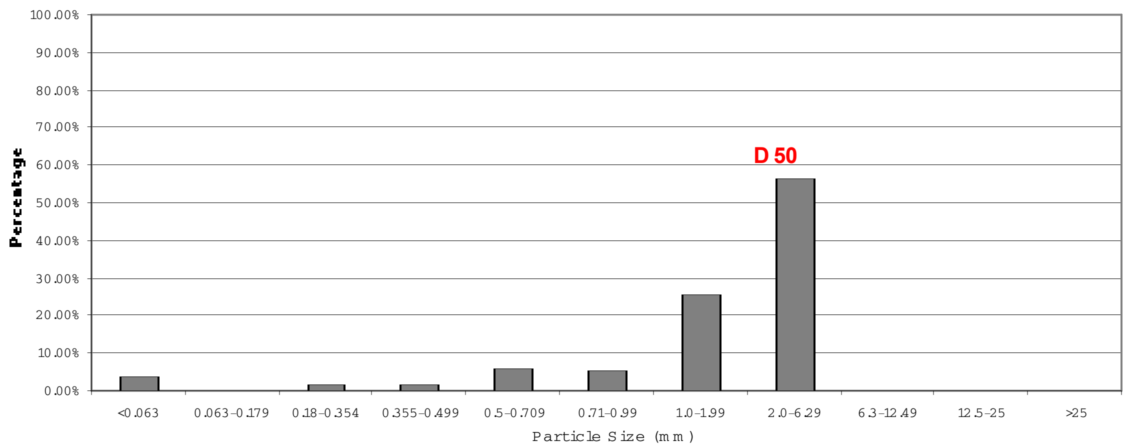



Salinas River Lagoon Benthic Sediment
#1094 Main Lagoon nr. Center Island
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

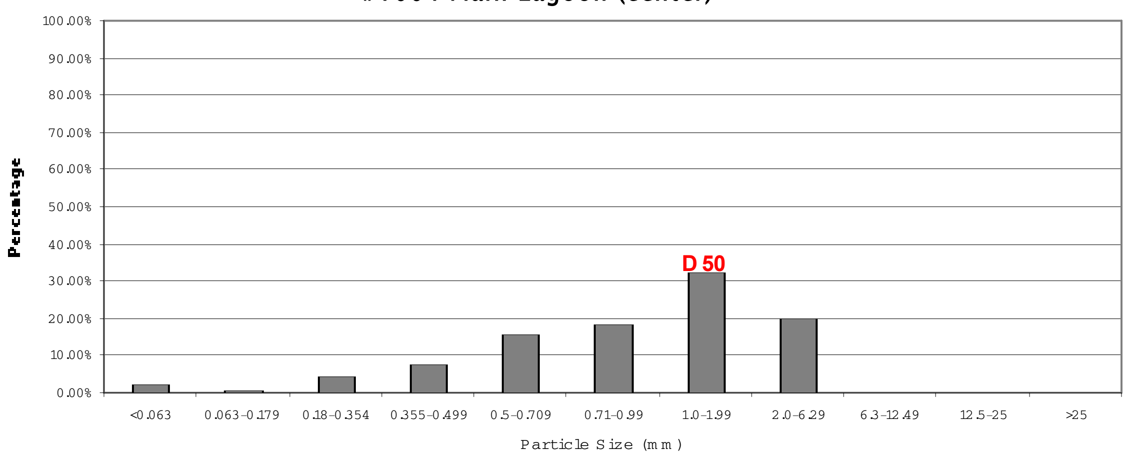

Salinas River Lagoon Benthic Sediment
#1057 Main Lagoon nr. Center Island
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)


Salinas River Lagoon Benthic Sediment
#1080 Main Lagoon @ Right Bank
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

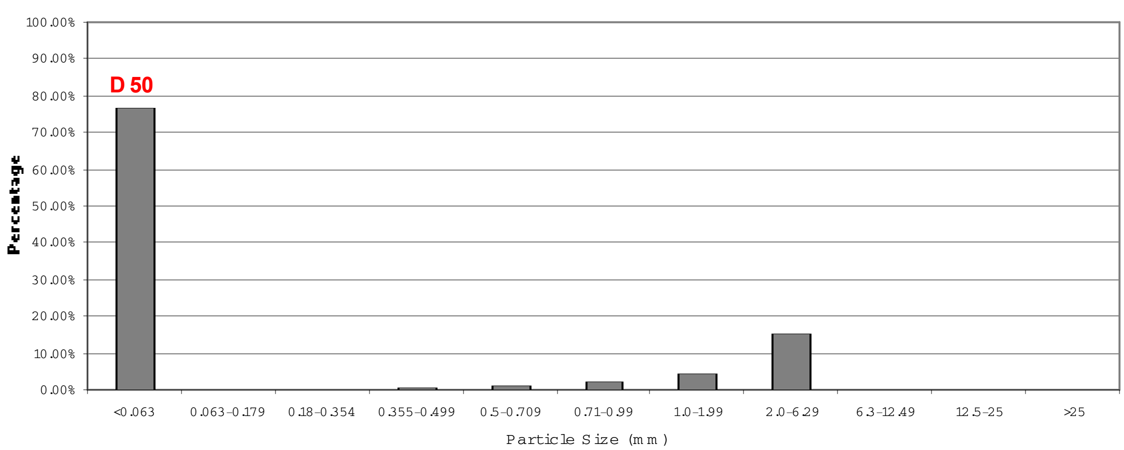
Salinas River Lagoon Benthic Sediment
#1002 Main Lagoon nr Old Salinas River Gates

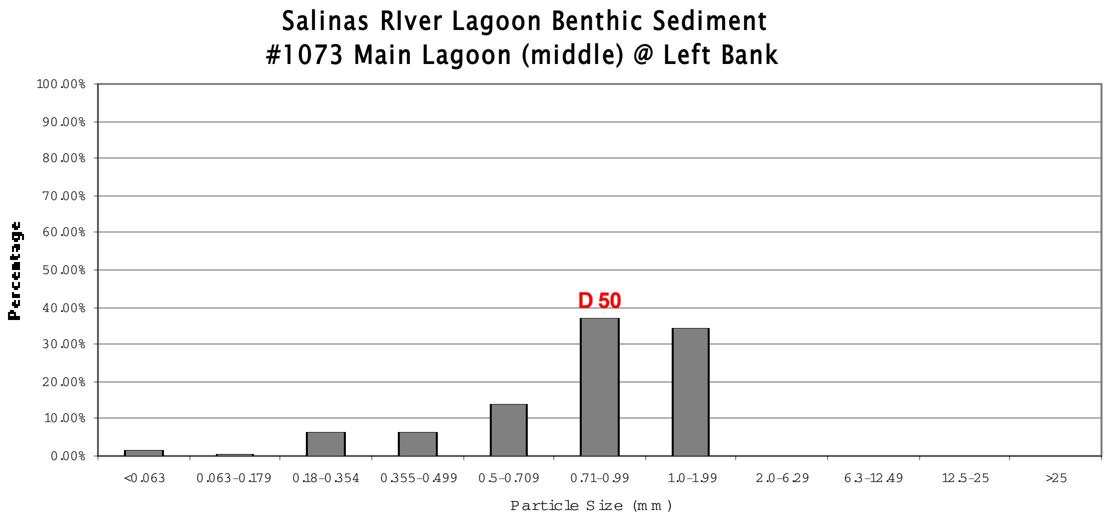


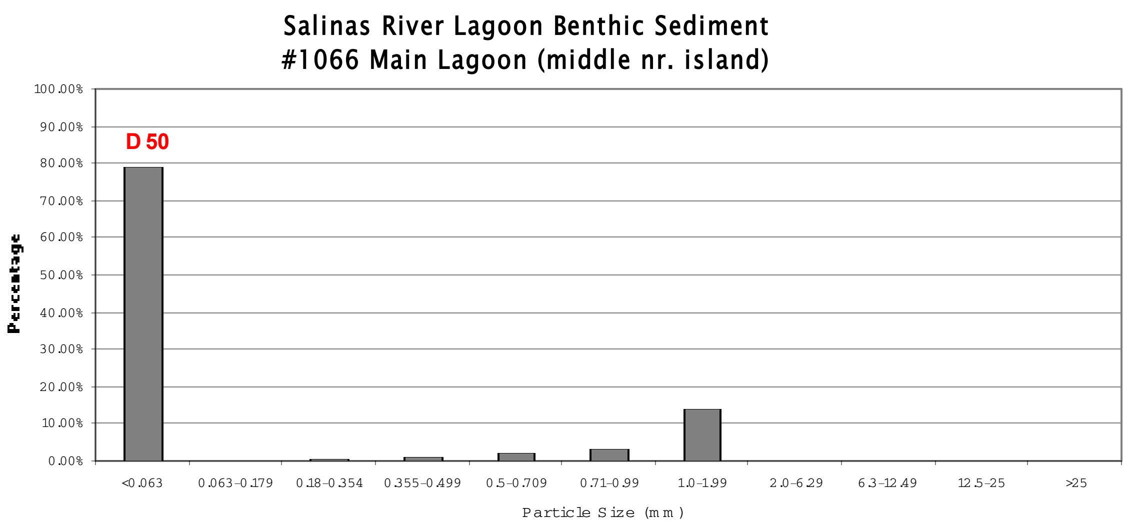
Salinas River Lagoon Benthic Sediment
#1004 Main Lagoon (center)

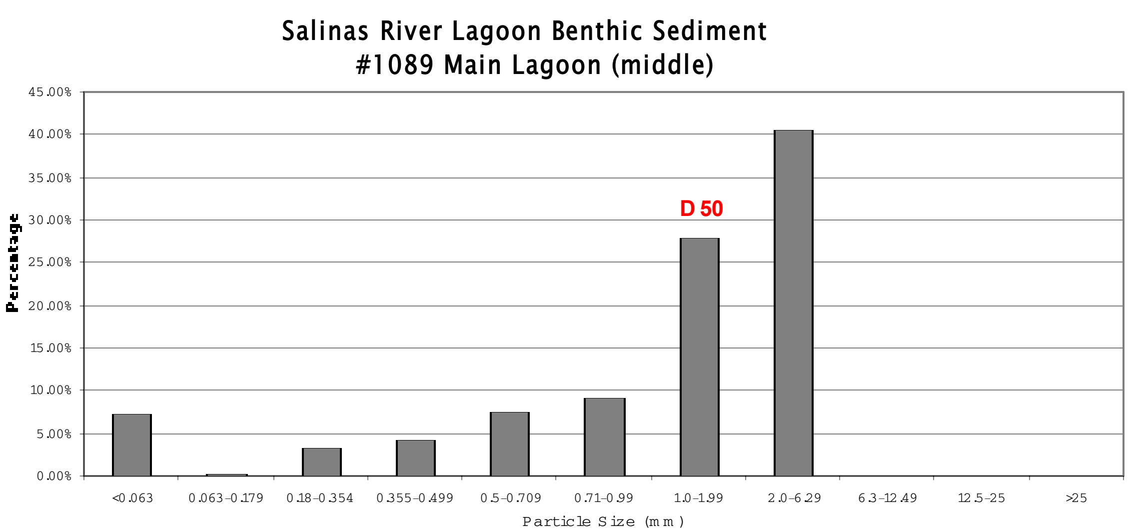


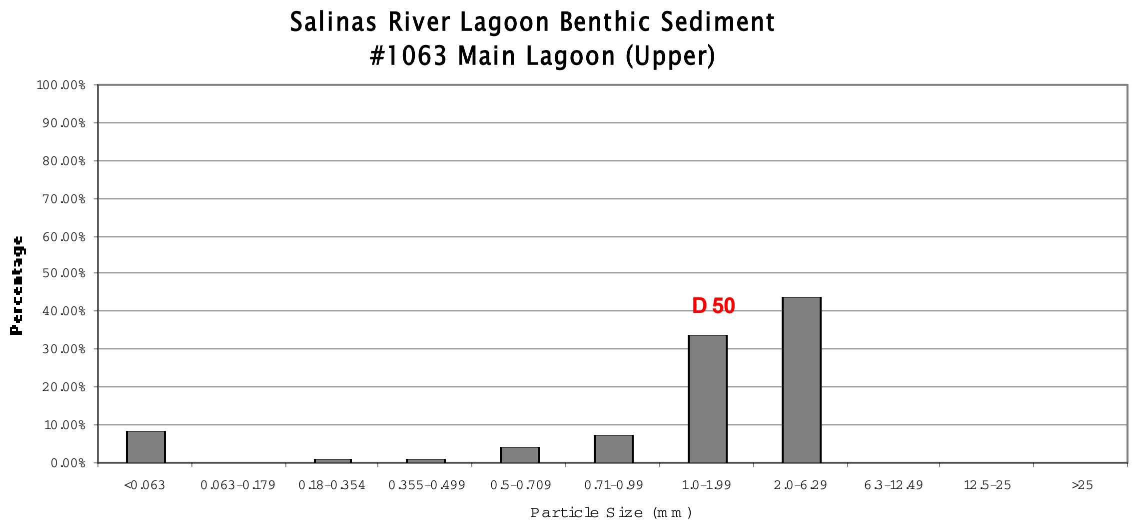
Salinas River Lagoon Benthic Sediment
#1040 Main Lagoon (middle) @ Left Bank

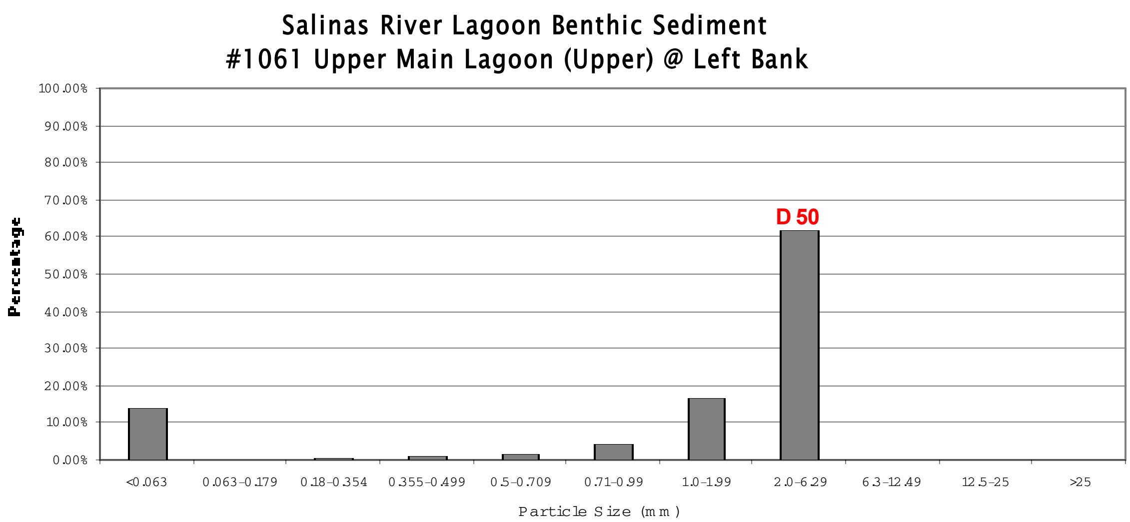


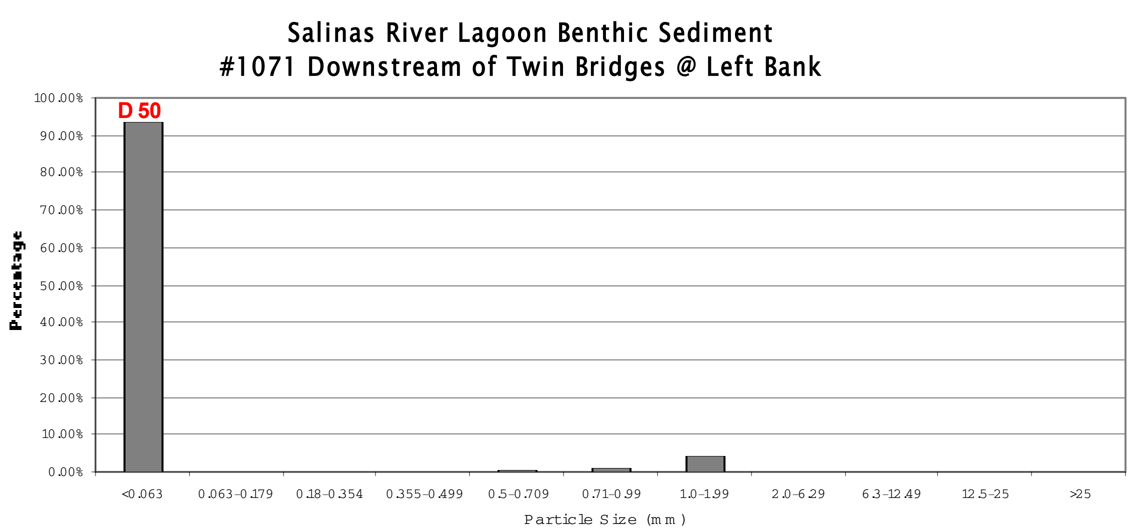

Salinas RIver Lagoon Benthic Sediment
#1073 Main Lagoon (middle) @ Left Bank
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

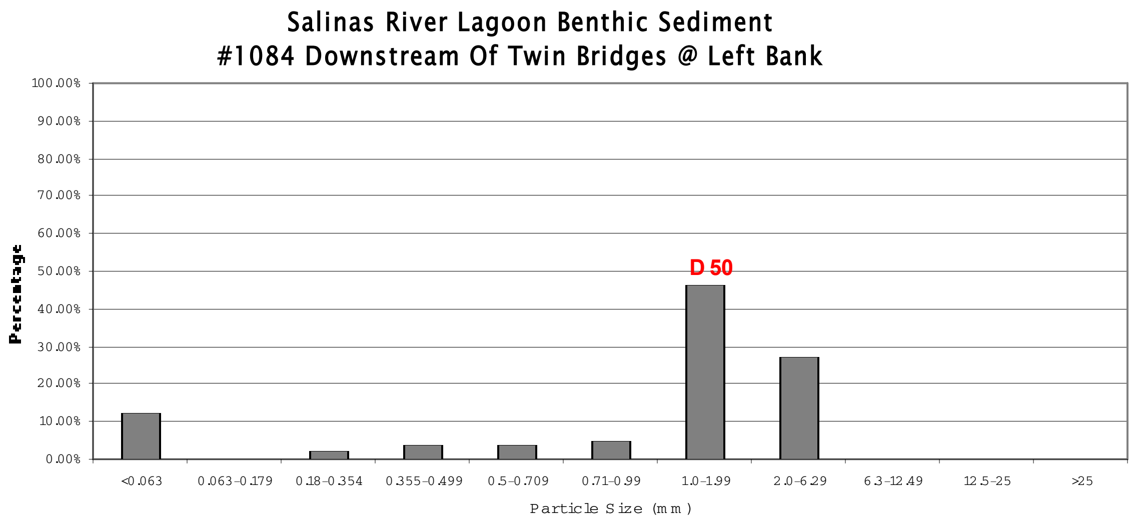

Salinas River Lagoon Benthic Sediment
#1066 Main Lagoon (middle nr. island)
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

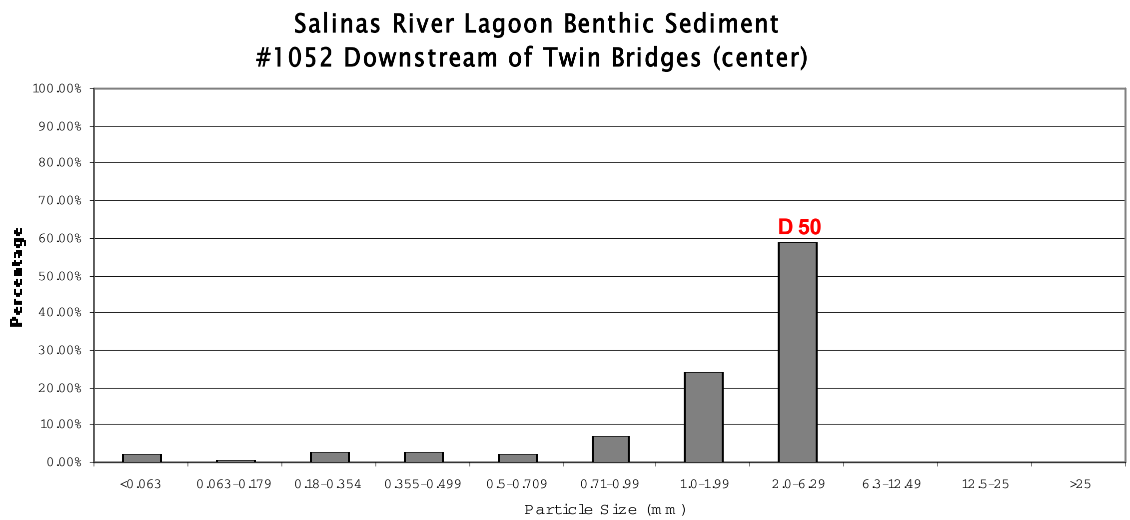

Salinas River Lagoon Benthic Sediment
#1089 Main Lagoon (middle)
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Percentage
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

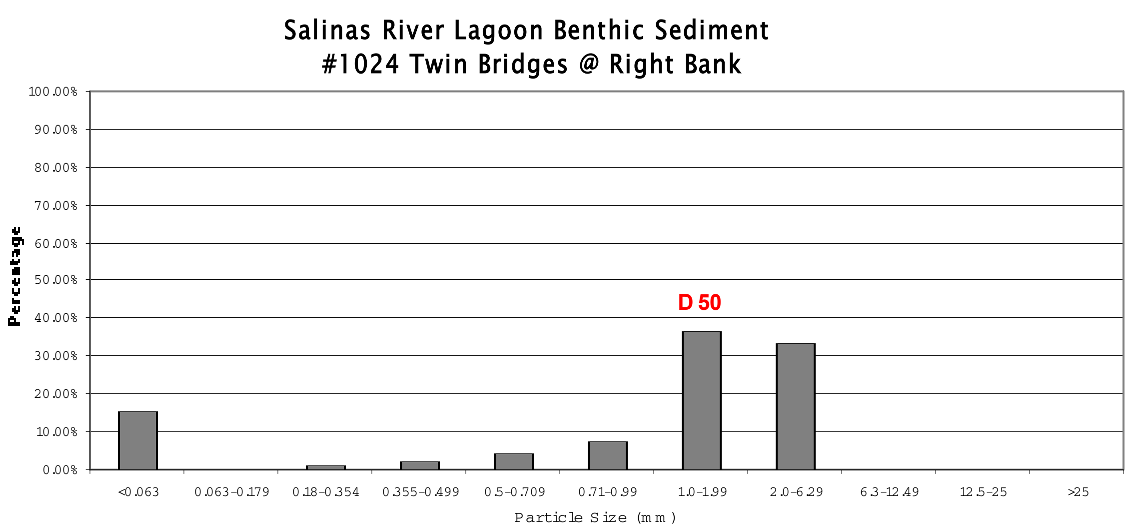

Salinas River Lagoon Benthic Sediment
#1063 Main Lagoon (Upper)
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

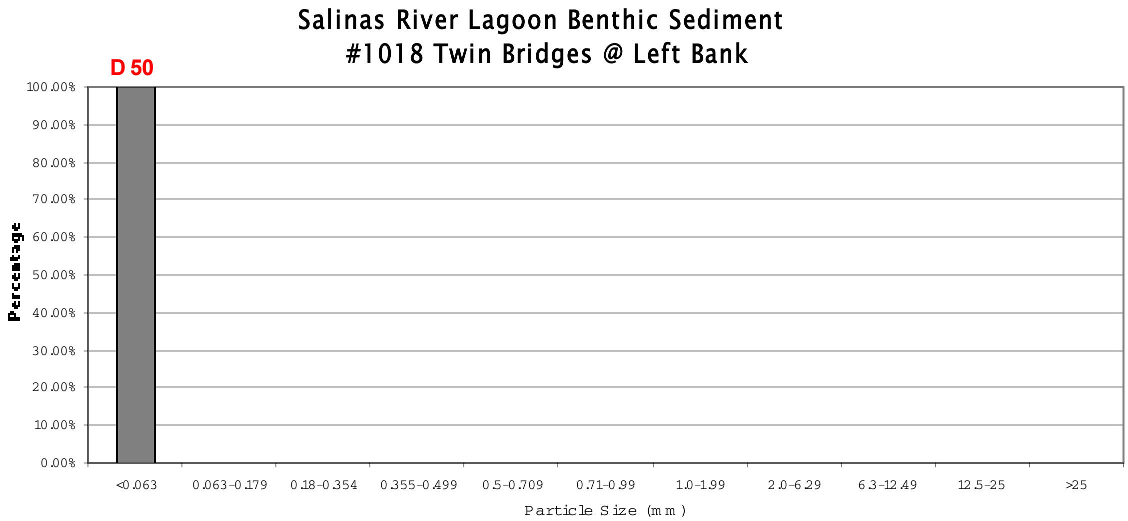

Salinas River Lagoon Benthic Sediment
#1061 Upper Main Lagoon (Upper) @ Left Bank
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

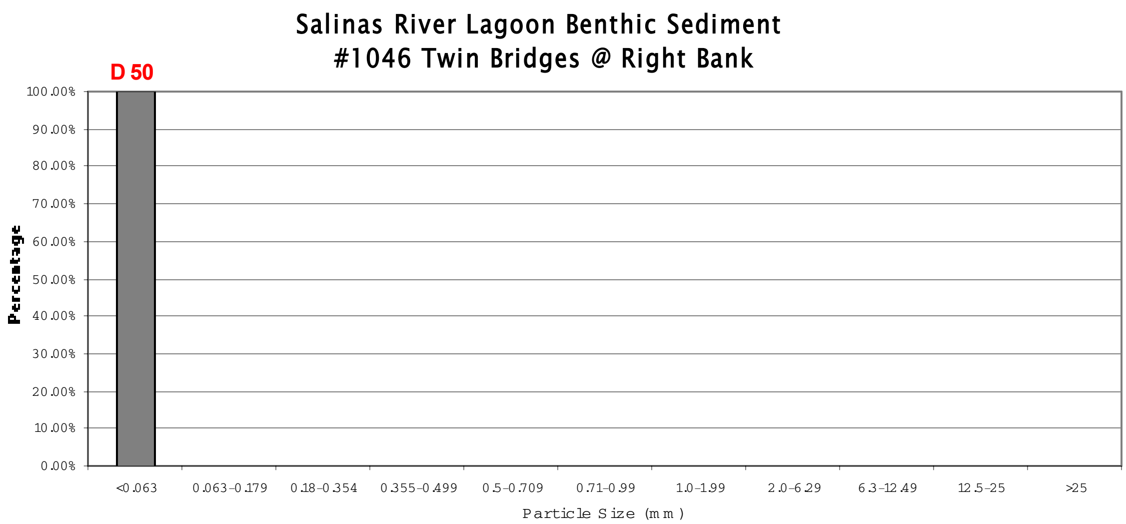

Salinas River Lagoon Benthic Sediment
#1071 Downstream of Twin Bridges @ Left Bank
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

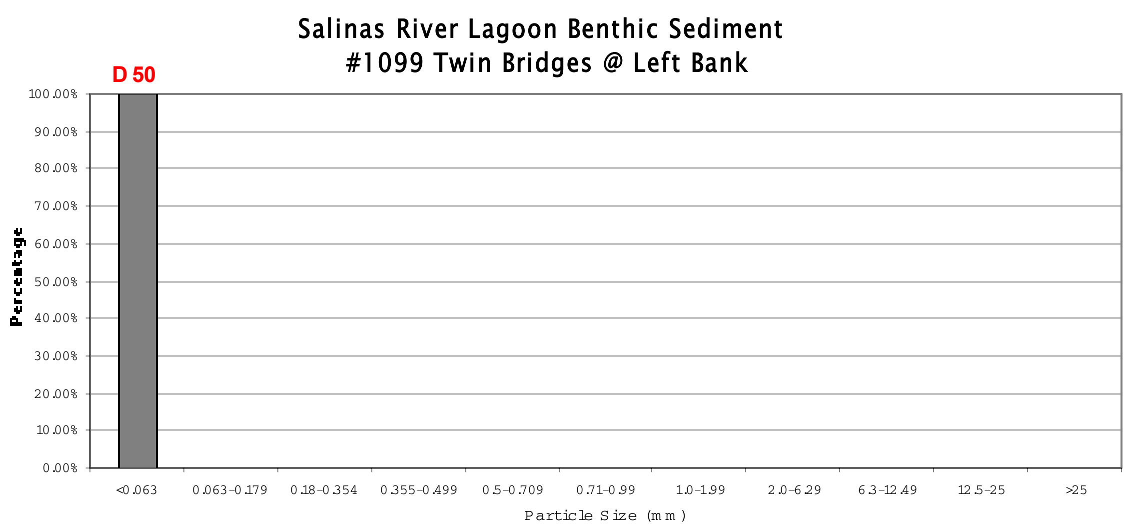

Salinas River Lagoon Benthic Sediment
#1084 Downstream Of Twin Bridges @ Left Bank
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

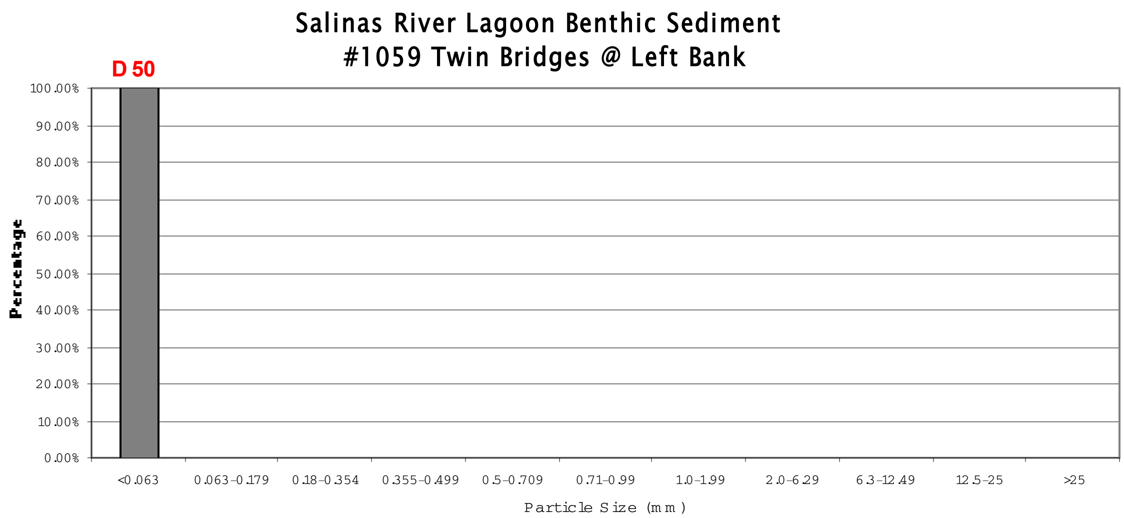

Salinas River Lagoon Benthic Sediment
#1052 Downstream of Twin Bridges (center)
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

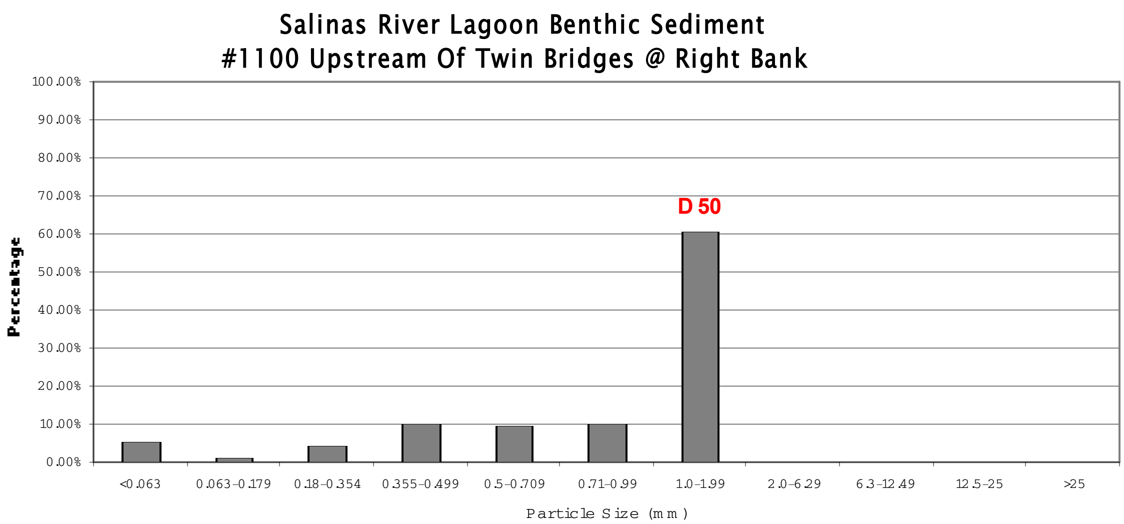

Salinas River Lagoon Benthic Sediment
#1024 Twin Bridges @ Right Bank
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
D 50
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

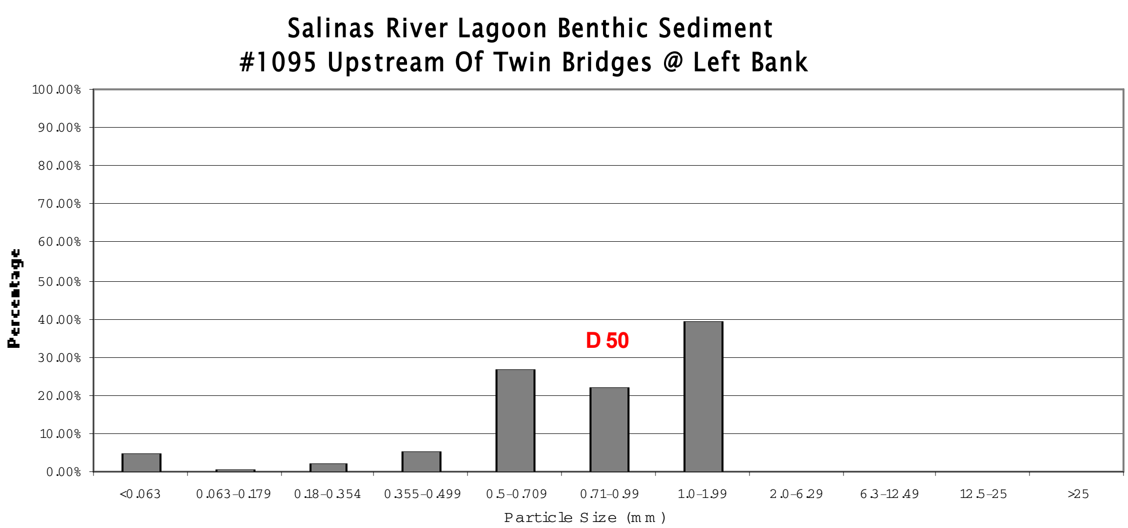

Salinas River Lagoon Benthic Sediment
#1018 Twin Bridges @ Left Bank
D 50
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)


Salinas River Lagoon Benthic Sediment
#1046 Twin Bridges @ Right Bank
D 50
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

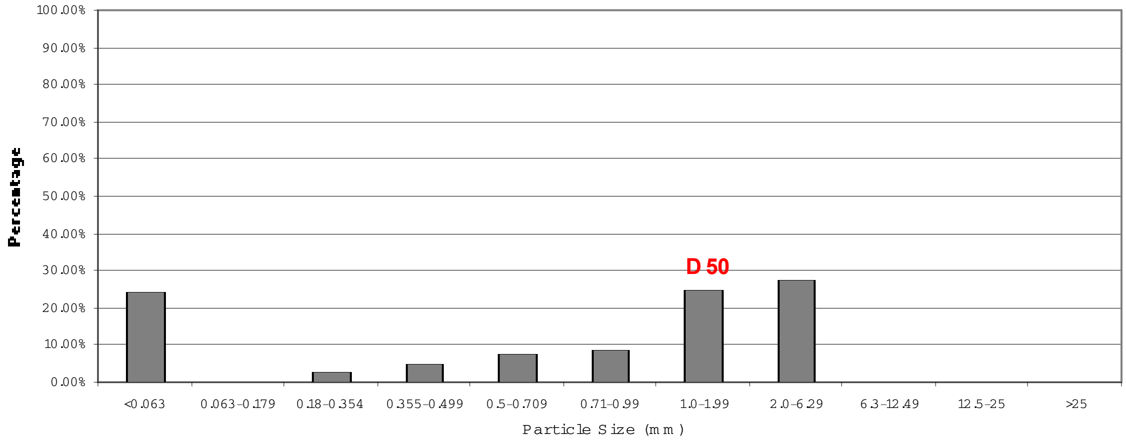

Salinas River Lagoon Benthic Sediment
#1099 Twin Bridges @ Left Bank
D 50
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percentage
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)


Salinas River Lagoon Benthic Sediment
#1059 Twin Bridges @ Left Bank
D 50
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

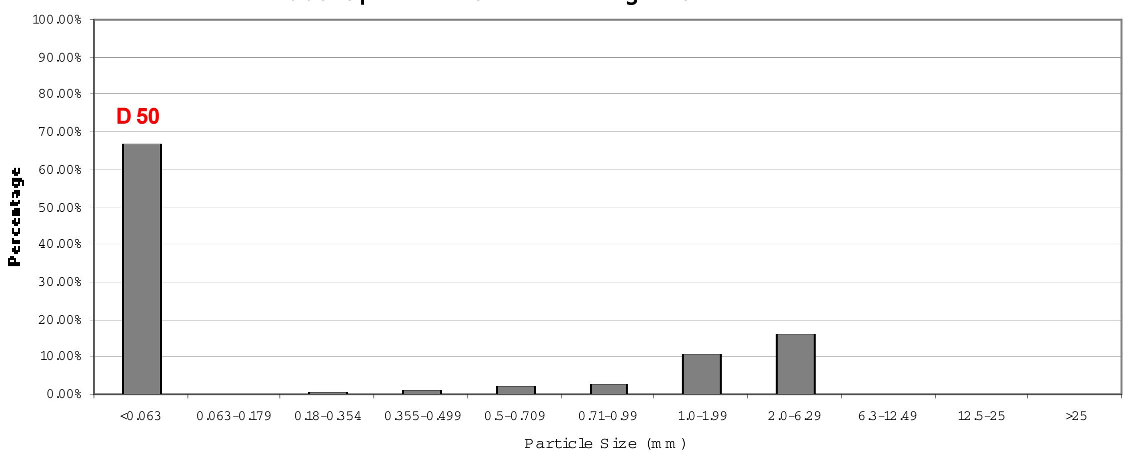

Salinas River Lagoon Benthic Sediment
#1100 Upstream Of Twin Bridges @ Right Bank
D 50
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)


Salinas River Lagoon Benthic Sediment
#1095 Upstream Of Twin Bridges @ Left Bank
D 50
Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
<0.063
0.063-0.179
0.18-0.354
0.355-0.499
0.5-0.709
0.71-0.99
1.0-1.99
2.0-6.29
6.3-12.49
12.5-25
>25
Particle Size (mm)

Salinas River Lagoon Benthic Sediment
#1098 Upstream of Twin Bridges @ Right Bank



Salinas River Lagoon Benthic Sediment
#1069 Upstream Of Twin Bridges @ Middle



Salinas River Lagoon Benthic Sediment
#1081 Upstream @ Main Stem