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Hydrology and Water Quality Of the Carmel and Salinas Lagoons Monterey Bay, California 2002/2003

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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. Additional information was provided by the Monterey Peninsula Water Management District (MPWMD) as well as the National Marine Fisheries Service (NMFS).

This work was done in collaboration with a companion study by Hagar Environmental Science on the impact of lagoon breaching on steelhead trout in the Carmel and Salinas Lagoons, also commissioned by MCWRA.

Cover Photo: The Carmel Lagoon hours after a manual breach on February 24, 2003. Photo taken by Don Kozlowki.

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1 Introduction

1.1 Background

Lagoons, or estuaries, are valuable and essential habitats for many aquatic organisms, including the production of juvenile steelhead (*Oncorhynchus mykiss*) (Smith, 1990). In 1997, the National Marine Fisheries Service (NMFS) listed the South Central Coast steelhead trout as a threatened Evolutionary Significant Unit (ESU). The species is anadromous, spawning in the headwaters of both the Carmel and Salinas watersheds.

The lower reaches of the Carmel and Salinas rivers are non-perennial. During periods of higher streamflow, juvenile steelhead migrate down through the watersheds on their way to the ocean. Between late spring and the following winter, the lagoons are often blocked from the ocean by sandbars. In the Carmel Watershed, juvenile steelhead migrate downstream to the lagoon where they rear throughout the summer before entering the ocean in winter. Conversely, juvenile steelhead generally do not use the Salinas Lagoon for rearing in summer due to the great distance between the lagoon and the nearest spawning/rearing tributary (MCWRA and USACE, 2001). Instead, juvenile steelhead in the Salinas Watershed rear in larger tributary streams (i.e. Arroyo Seco) and eventually migrate downstream during periods of higher streamflow.

By late fall, the lagoons are usually brackish. They receive salt water from high ocean waves that overtop the sandbars, and freshwater from the inflowing rivers. Sometime in winter, usually after the first major runoff event, the water elevation in the lagoons rises significantly and either a natural or artificial breaching event ensues. It is when the sandbar is breached, or open, that anadromous fish such as steelhead and Pacific lamprey (*Lampetra tridentate*) migrate in from the ocean, through the lagoons, and up to their natal spawning tributaries; and vice versa.

The Carmel River supports a large restored run of many hundreds of up-migrating adult Steelhead each year¹. The Salinas River once supported such a run (Snyder, 1913; Casagrande et al., 2003), but is now limited.

¹ See MPWMD web page: <http://www.mpwmd.dst.ca.us/fishcounter/fishcounter.htm>

Residential (Carmel) and agricultural (Salinas) development has 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, or the physiological change prior to life in the ocean. 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). Artificial breaching can also occur at other critical times of year. Smith (1990) concluded that the prevention of summer artificial breaching and sufficient incoming river flows required for converting a lagoon to freshwater were essential for lagoon management; with respect to the production of juvenile steelhead.

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. This report is the third in an annual series of CCoWS reports on the effects of artificial breaching on water quality and hydrology in the Carmel and Salinas Lagoons.

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 following the lagoon's closure. The objectives were not to study or analyze fish population and response to changing conditions – this being the topic of a separate study (HES, 2002; HES, 2003, in prep.), or make judgments as to optimal lagoon management.

1.3 General Methodology

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

- Temperature
- Salinity
- Dissolved oxygen
- Depth
- Secchi Disk Depth



Figure 1.1 MCWRA crew using heavy equipment to breach the Salinas Lagoon. Photo: Fred Watson, 17 Dec 02

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)
- Nutrient concentrations: nitrate, phosphate, & ammonia
- Cover from predators
- Food
- Turbidity
- Hydraulic diversity
- Invasive species
- Fish population estimates
- Fish age–distribution estimates

1.4 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.

1.5 Changes since last years report

1.5.1 Errata

We gratefully acknowledge the critical review of J. Smith (pers. comm.) who alerted us to the fact that the hyper–saline data from the Salinas Lagoon (December 4, 2001) were most likely due to calibration error. Subsequent analysis concluded that this was almost certainly the case.

In addition, an error was made in the estimated distance from the sandbar to the Twin Bridges in the Salinas Lagoon. The previous estimate was noted as approximately 900 m, however a re–estimate of this value confirmed that the distance is approximately 2700 m.

1.5.2 Compilation of previous data

In the months following the publishing of last year's lagoon studies (Casagrande et al., 2002) further water quality and fisheries data have been collected for both the Carmel and Salinas River Lagoons (Casagrande et al., 2003, in prep; HES, 2003; in prep). In addition, all previously published water quality data known to exist for each of the lagoons was collected and compiled into a growing and comprehensive Microsoft Access database (See Section 10). The database, still in draft form, will be available on the web and will serve as a public access tool for anyone seeking water quality data for the two lagoons. The following is a list of all known published reports containing water quality and fisheries data for each of the two lagoons.

1.5.2.1 Carmel Lagoon

Dettman, D. (1984)

Includes water quality and fisheries data from April through October of 1982.

Alley, D. (1997)

Includes water quality data from October and November of 1996.

Watson et al., (2001)

Includes water quality data from 2000–01 fall and winter seasons.

Casagrande et al., (2002)

Includes water quality data from 2001–02 fall and winter seasons.

Hagar Environmental Science (HES). (2002)

Includes water quality and fisheries data from the 2001–02 fall and winter seasons.

Casagrande et al., (2003, in prep.)

Includes water quality data from 2002–03 winter and spring seasons.

Hagar Environmental Science (HES). (2003, in prep.)

Includes water quality and fisheries data from the 2002–03 fall winter and spring seasons.

1.5.2.2 Salinas Lagoon

Habitat Restoration Group et al., (1992) – Dr. Jerry Smith

Includes water quality and fisheries data from 1987–1991.

Watson et al., (2001)

Includes water quality data from 2000–01 fall and winter seasons.

Casagrande et al., (2002)

Includes water quality data from 2001–02 fall and winter seasons.

Casagrande et al., (2003, in prep.)

Includes water quality data from 2002–03 winter and spring seasons.

Hagar Environmental Science (HES). (2003, in prep.)

Includes water quality and fisheries data from the 2002–03 fall winter and spring seasons.

2 Study Area

2.1 Carmel Lagoon

The Carmel Lagoon (Figs 2.1 to 2.5) lies at the end of the Carmel River between two residential areas: Carmel By The Sea and Mission Ranch to the north and Carmel Meadows to the south. The Carmel Lagoon is much smaller than the Salinas Lagoon. However, the surface area of the lagoon expands and contracts with seasonal inputs into the lagoon. In the fall, the lagoon receives wave overwash, which can raise the lagoon water elevation by several feet. In the winter, the lagoon will expand with the addition of increased streamflow, inundating both aquatic and 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.

The northern backwater (North Arm) section of the lagoon is approximately circular in shape (c. 300 m diameter) and comprises a system of channels and islands filled with aquatic vascular vegetation (Fig 2.2).

The smaller Southern Arm of the lagoon is much more linear and confined (c. 200m long) (Fig. 2.3). The original geomorphology of the South Arm is poorly understood. 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 Odello West area. The granite is the outcrop of a larger up thrown block beneath the lagoon. This upthrown block, on the Cypress Point Fault, protects the Carmel Valley aquifer from seawater intrusion (Johnson, 2000; Logan, 1983 as cited in SGD, 1989) 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). The 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 United States Geological Survey (USGS) gauging station just upstream from the

Highway 1 Bridge at Via Mallorca Rd. Also, the Monterey Peninsula Water Management District (MPWMD) has a streamflow gage at the Highway 1 Bridge. In the lagoon, water levels are gauged using two NGVD² staff plates located in the northern and southern arms respectively.



Figure 2.1 The Carmel Lagoon, surrounding residential areas and the Wastewater Treatment Facility.

² NGVD refers to National Geodetic Vertical Datum 1929; the standard vertical datum for topographic survey.



Figure 2.2 The northern backwaters (North Arm) of the Carmel Lagoon at high water elevation – Mission Ranch and Carmel By the Sea in the background. Photo: Joel Casagrande, 15 Dec 02.



Figure 2.3 The southern backwaters (South Arm) of the Carmel Lagoon. The Odello Property (Odello West) is in the background. Photo: Fred Watson Dec 2001.



Figure 2.4 The main body of the Carmel Lagoon during high water looking east. Photo: Joel Casagrande, 15 Dec 02.

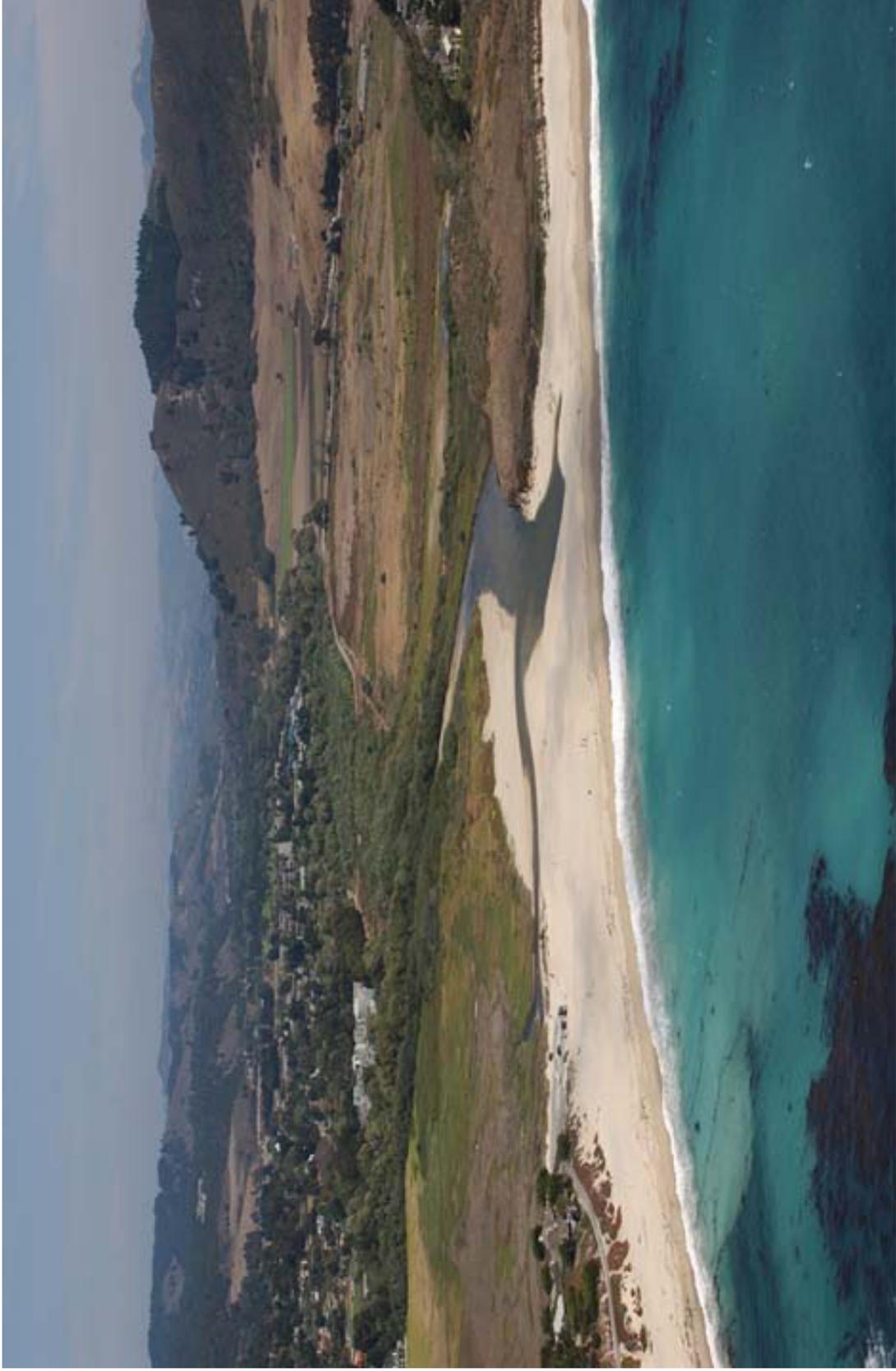


Figure 2.5 A view of The Carmel Lagoon and surrounding area from over Carmel Bay, 29 August 2002.

Photo: Copyright (C) 2002 Kenneth Adelman, California Coastal Records Project, www.californiacoastline.org.

2.2 Salinas Lagoon

The Salinas Lagoon (Figs 2.6 to 2.11) differs from the Carmel Lagoon in size, shape, adjacent land uses, and vegetation. It 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 as much during the summer. It has a tapered linear outline, sinuously narrowing inland from its widest point of roughly 300 m near the mouth until it becomes the Salinas River itself approximately 12.5 km upstream (7.5 miles). The northern bank is well vegetated with riparian and phreatophytic vegetation. Large woody debris is found scattered throughout the lagoon, but mainly along the northern and western shores. *Arundo donax*, giant perennial grass, also found throughout the lagoon, is invading large sections of the northern banks. The southern banks are actively eroding and have a nearly vertical slope in many places. Currently, riparian restoration efforts are in place along a large portion of the southern bank located in the Salinas River National Wildlife Refuge as well as the 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) (Fig 2.8). The nearest active USGS streamflow gauge is located approximately 22.2 km (13.3 miles) upstream from the lagoon at Highway 68 at Spreckels. However, low streamflow volumes recorded at this gage may not actually reach the lagoon due to the distance and the porosity of channel substrates between the lagoon and the gage site.

When the lagoon is closed, water levels in the lagoon are monitored by a county gage and staff plate located at the Old Salinas River outlet gate (Fig 2.10) in the northwestern corner of the lagoon. The county maintains the water elevation in the lagoon (Gilchrist et al., 1997) at an elevation of 3 ft by closing off or releasing flows to 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). In the event a manual breach is deemed necessary, a channel is excavated through the sandbar leaving only a “plug” of sand to be removed at the last minute. After enough hydrostatic head is built up in the lagoon, the plug is removed and the lagoon quickly drains. Once the sandbar has opened, the outlet gate to the Old Salinas River remains closed allowing water to exit the lagoon only through the

breaching corridor (Gilchrist et al., 1997). This is to ensure that excess water doesn't flow down the Old Salinas Channel, which receives substantial runoff from the Gabilan Creek Watershed/Reclamation Ditch and Tembladero Slough drainages.

Perhaps the majority of fresh or brackish water flow entering the Salinas Lagoon during non-event periods comes from the Blanco Drain, which is an agricultural runoff canal, located 8 km (5 miles) upstream from the Salinas River Lagoon. Although this flow depends on the amount of irrigation and urban runoff, it maintains small amounts of perennial fresh or brackish water flow into the lagoon. There are also a number of small agricultural tile drainage systems discharging directly into the lagoon. The amount of water and its effect on water quality in the lagoon are not discussed here.



Figure 2.6 The lower Salinas Lagoon and National Wildlife Refuge (outlined area) and their surrounding features.



Figure 2.7 The main body of the Salinas Lagoon looking east from the sand bar with Toro Peak in the background. Photo: Don Kozlowski 26 Dec. 2001.



Figure 2.8 The middle reach of the Salinas Lagoon at Twin Bridges looking east. Photo: Watershed Institute, 1998 flood.



Figure 2.9 The slide gate to the Old Salinas River Channel and water elevation gage. Photo: Bob Curry, February 2003.



Figure 2.10 The Old Salinas Channel downstream of the outflow gate. The residential Monterey Dunes Colony is shown in the background. Photo: Bob Curry, February 2003.



Figure 2.11 A view of the western portion of the Salinas Lagoon and surrounding area taken from over Monterey Bay, 16 March 2002.
Photo: Copyright (C) 2002 Kenneth Adelman, California Coastal Records Project, www.californiacoastline.org.

3 Methods

3.1 Water quality monitoring

The lagoons were divided into discrete sampling “zones” to facilitate comparison of past and present data where exact coordinates are either absent, or vary only slightly. Figures 3.1 & 3.2 show the sampling zones for each lagoon. The zones enclosed in a circle are the primary sampling zones. There are 9 primary sampling zones on the Carmel and 6 on the Salinas. They were chosen in the field for detailed water quality monitoring. These selections 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)
- Secchi depth readings (not taken during every event)

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. The YSI 556’s accuracy, range and resolution for

measuring temperature, dissolved oxygen and salinity are listed in Table 3.1³. Secchi disk readings were taken during most monitoring events.

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

- Mounted storage bins

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

Sensor	Accuracy	Range	Resolution
Temperature (YSI Percision™ thermistor)	± 0.15 °C	-5 to 45 °C	0.1 °C
Dissolved Oxygen (mg/L) (Steady state polarographic)	0 to 20 mg/L, ±2% of the reading or 0.2 mg/L, whichever 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	0.001 mS/cm to 0.1 mS/cm (range-dependent)
Salinity (Calculated from conductivity and temperature)	± 1.0% of reading or 0.1 ppt, whichever is greater	0 to 70 ppt	0.01 ppt

- Rite-in-the rain notebook
- Weighted transect tape for measuring depth
- Drying bags for bottom sediment
- Camera

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

³ <http://www.yei.com/environmental.htm>

- NO₃-N (Data not presented in this report)
- NH₄-N (Data not presented in this report)
- PO₄-P (Data not presented in this report)

Carmel Lagoon Water Quality Sampling Zones

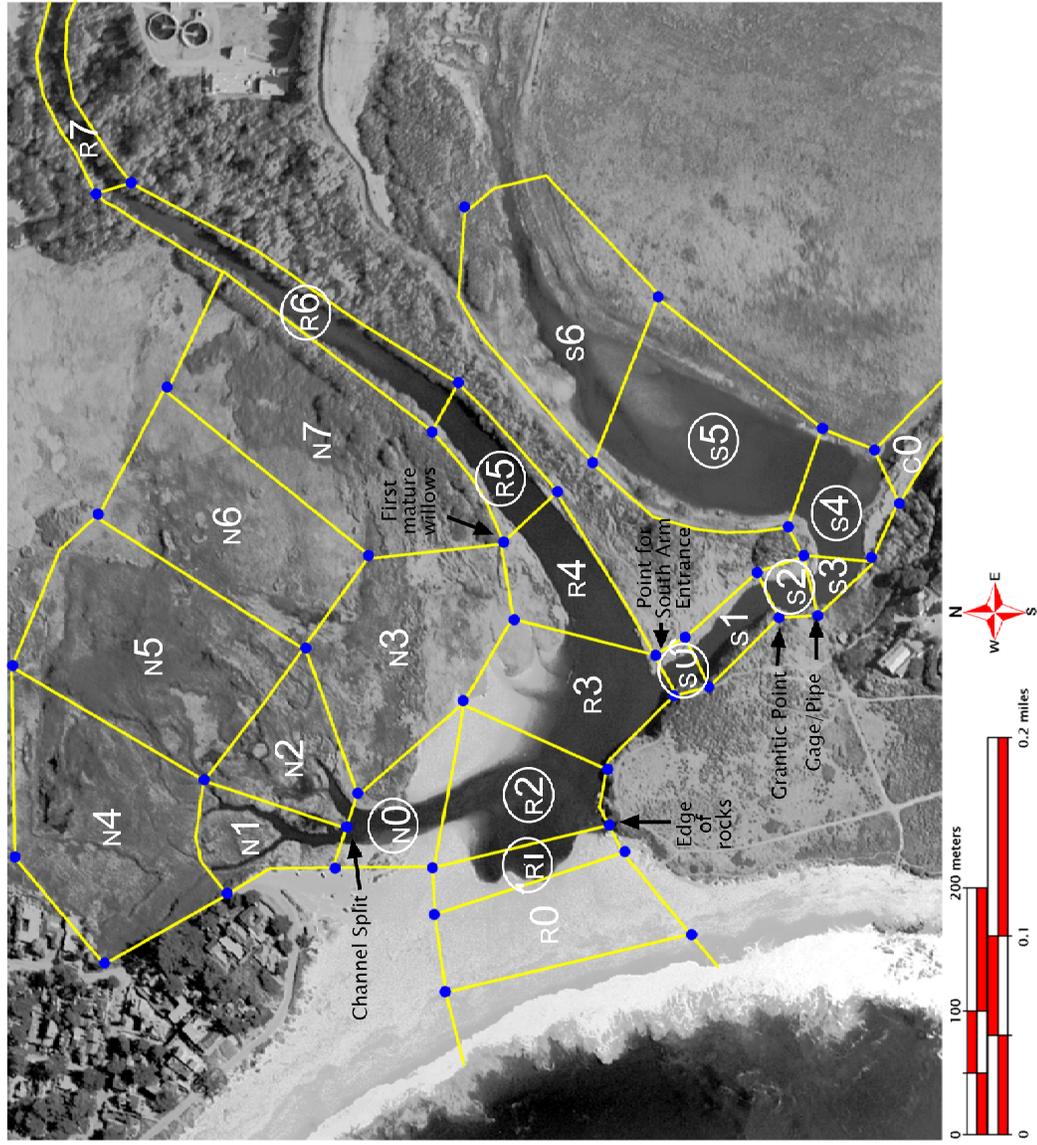


Figure 3.1 Sampling zones for the Carmel Lagoon. Note zones that are circled are the primary sample locations for water quality assessment.

Salinas Lagoon Water Quality Sampling Zones

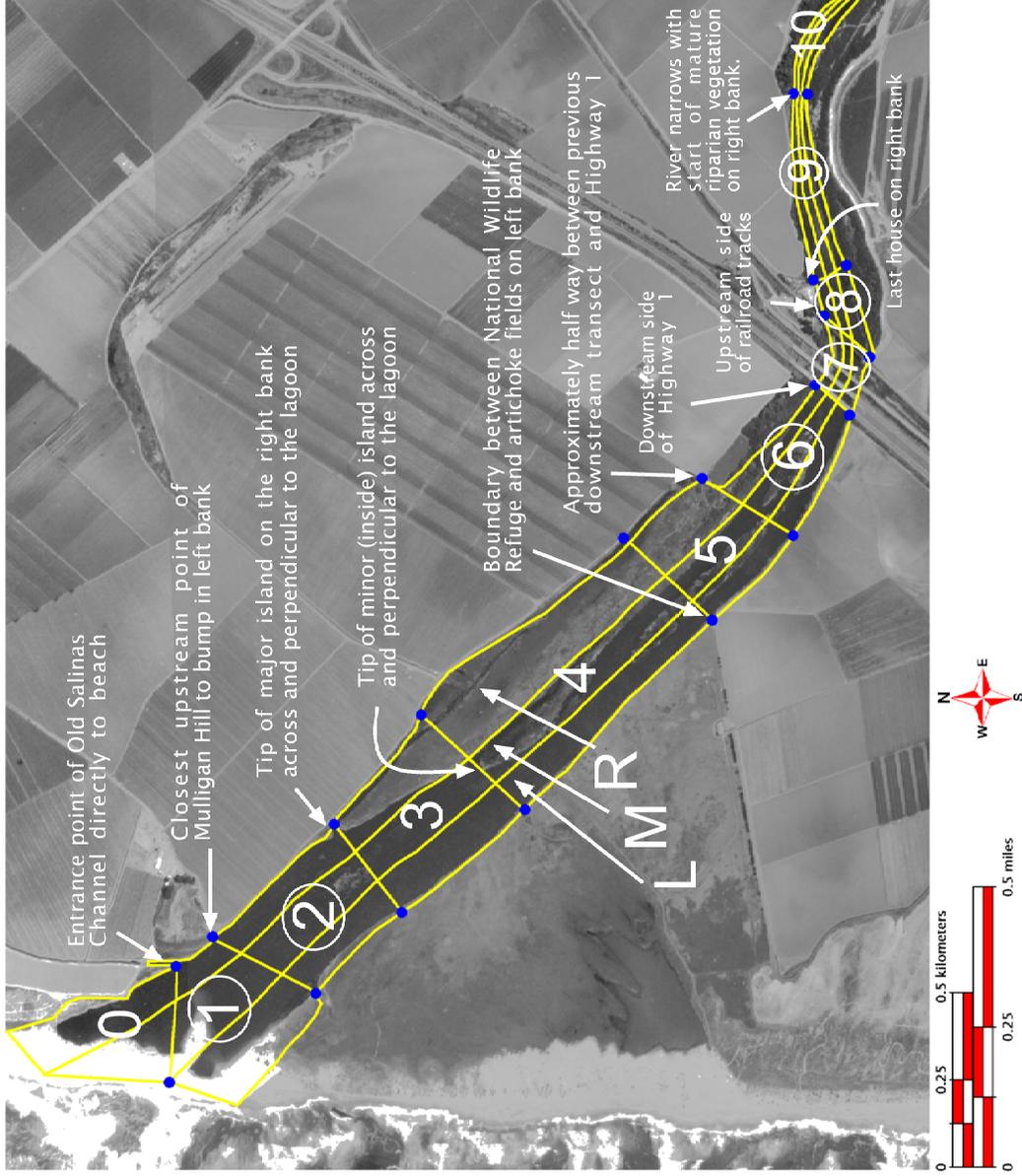


Figure 3.2 Sampling zones for the Salinas Lagoon. Note zones that are circled are the primary sample locations for water quality assessment.

3.2 Access

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 the transportation and of monitoring instruments (Fig. 3.3).



Figure 3.3 One of two tandem kayaks used for water quality monitoring showing the method for collecting water quality information, depth, and bathymetrical data. Photo: Fred Watson 17 Dec. 02

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 \pm 5–6 m with no differential correction needed.

3.4 Bathymetry

A weighted tape measure was used to measure depth in the lagoons. Shallow transects were measured on foot and deeper transects were measured using a tandem kayak with an anchor. 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 distance from the bank was not practical. Instead, a GPS unit was used to measure the distance from the bank and orange markers, placed on both banks, were used for navigation. A minimum of thirteen depth measurements were taken for each transect.

3.5 Bottom Sediment

The d_{50} , or the median particle size, of a lagoon's bottom sediments can be used as an indicator of the type of hydraulic regimes throughout different areas of the lagoon both before and after a breaching event. In a lagoon environment deep sumps and backwater areas are important shelter components for fish and other aquatic organisms during breaching events. Often, a breach can result in violent currents of water exiting the lagoon over a short period of time. If exiting currents are strong enough to scour silt/clay sediments from the bottom of the deep-water areas, this could pose a problem for fish and other aquatic organisms seeking shelter in these refuges.

Also, a change in the benthic d_{50} in the deep sumps could indicate that either significant scouring or deposition had occurred which, overtime would change the volume capacity and overall habitat in the lagoon.

In the Carmel Lagoon, prior to breaching, bottom sediments were collected in the South Arm and in various locations of the main lagoon. Prior to breaching the Salinas Lagoon, benthic sediments samples were only collected in the deep sump under the Highway 1 Bridge. In last year's report, we sampled bottom sediments in several other locations in each lagoon. This year, samples were only repeated in areas that might show significant change.

Sediments were collected from a kayak using a lightweight bottom-sediment sampling dredge with a 36 in² 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 were dried at 70°C for at least 48 hours before a total weight could be measured. After drying, each sample was weighed to the nearest milligram. All samples were wet sieved through 0.063 mm sieve to remove fine particles smaller than 0.063 mm (silt and clay). 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. The new weight indicated the total amount of silt and clay that previously existed in the original sample. Some samples were entirely silt and clay particles and therefore no sample remained.

If a sample still remained, it was sorted through several standard sieves sizes > 0.063 mm. The total amount of each size was weighed and a d_{50} of the original sample was then calculated. The sieve sizes used are shown in Appendices C and D. The d_{50} for each sample is represented on an aerial photograph for each respective lagoon-Figs 4.11 & 5.11.

4 Results – Carmel Lagoon

4.1 Summary and Timeline of the 2002/03 Season

Pre-breach monitoring of all primary sites in the Carmel Lagoon began on the morning of the 13th of December after wave overwash increased the lagoon water elevation to 2.06 m (6.77 ft) (Table 4.1 & Fig. 4.1). Evening monitoring of all sites was also conducted on the 13th of December, although water elevation remained at 2.06 m (6.77 ft).

On the 15th of December, water quality monitoring was conducted at all primary sites approximately 3 hours prior to an initial, yet unsuccessful breaching attempt. Water elevations in the lagoon were 2.71 m (8.88 ft.). As of 09:00 hours on the 16th of December the water elevation had risen to nearly 3.35 m (10.8 ft.) and the lagoon was manually breached at approximately 12:00 hours.

Once the sand bar had successfully breached, flow currents were too severe in the lagoon for kayak-based water quality sampling for the following three days. Therefore, water quality depth profiles were measured from the treatment plant outlet pipe (near the staff gage) in the deeper portion of the South Arm. These events included the 16th, 17th, 18th of December 2002, as well as the 5th of February. Also, a profile was taken from the pipe on the 24th of February 2003 after the sandbar had temporarily closed due to insufficient flows in the Carmel River (Table 4.1).

Another profile was taken from the gage after the sandbar had reformed in early March (March 5th). At this time water elevation in the lagoon was 1.8 m (5.8 ft) and rising.

Table 4.1 Event timeline and weather summary for the Carmel Lagoon

Sand Bar Condition	Events	Weather Condition	
Closed	13 Dec 02 morning	CO,R, B	
Closed	13 Dec 02 evening	CO, R, W,	
Closed	15 Dec 02 afternoon	CL, S W,	
1 st Breach	15 Dec 02 (~21:00)		
2 nd Breach	16 Dec 02 (~12:00)		
Open	16 Dec 02 afternoon	CO, R, W	
Open	17 Dec 02 afternoon	CL, S, B	
Open	18 Dec 02 morning	CL, S, B	
Open	20 Dec 02 morning	CO, R, W	
Open	27 Dec 02 afternoon	CO, R, C	
Open	05 Feb 03 morning	CD, CL,C	
Temporarily Closed	24 Feb 03 afternoon	CO,R,B	
Temporarily Closed	05 Mar 03 afternoon	CL,S,B	
General Weather Conditions			
R = Raining	C = Calm	CL = Clear	H = Hot (extreme)
S = Sunny	W = Windy	PC = Partly Cloudy	CD = Cold (extreme)
L = Lightning	B = Breeze	CO = Cloudy	

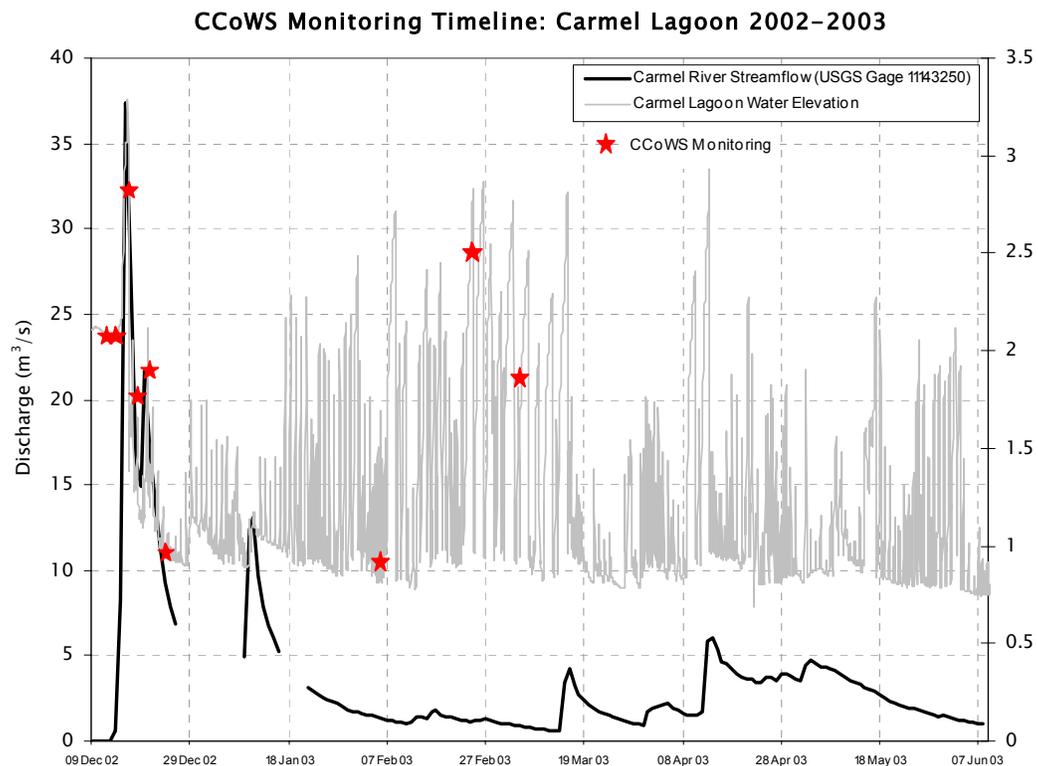


Figure 4.1 Monitoring timeline with respect to lagoon water elevation and streamflow in the Carmel River.

4.2 Carmel River Streamflow and Monterey Bay Oceanographic Data

According to the USGS gage at Via Mallorca Rd. (Fig. 4.4), streamflow in the Carmel River from the previous winter ceased on June 25th 2002⁴. Water elevations in the Carmel Lagoon reached a summer low in mid August of 0.79 m (2.59 ft). Small increases in lagoon water elevation between August and the end of October are likely to be attributed to oceanic inputs (i.e. seepage through sandbar and wave overwash) (Smith, 1990). When the lagoon water elevations are low, simulations suggest that seawater can seep through the sandbar at high tide and/or high wave height (Watson and Casgrande, 2003). In early November (circa 8–9th), a brief but significant storm produced large ocean swells, rainfall, and streamflow in the region. The large ocean waves along with some incoming streamflow filled the lagoon from approximately 1.5 m (5 ft) to an elevation of 2.7 m (8.9 ft) over a five-day period (Figs 4.5 and 4.7). Based on an analysis of lagoon water levels between 1991 and 1994, James (1994) suggested that the maximum lagoon water level attainable due to wave overwash inputs alone is approximately 2.43 m NGVD (8 ft). However, James' analysis also states that the height of the beach berm above datum ultimately controlled the increase in lagoon water elevation from ocean wave inputs.

Throughout the following three weeks, the water elevation in the lagoon slowly subsided and settled at approximately 2.1 m (6.9 ft). We infer that this was mainly due to seepage through the sandbar and some evaporation. With the exception of low flows between November 9th–12th, the lower reaches of the Carmel River remained dry up to the 14th of December 2002, when a succession of storms in mid-December resumed flow in the lower reaches of the river and into the lagoon (Fig. 4.4).

Water elevations rose from 2.06 m (6.7 ft) prior to incoming river water to 2.7m (8.9 ft) on December 15th. At this time, MCPW staff made the decision to breach the sandbar. The channel, approximately 76 m long and 9 m wide, was excavated in the southern end of the sandbar. After a few hours, the channel widened itself to approximately 18 m but had little effect on the lagoon volume. Some water exited the lagoon but large surf (> 4 m) coupled with high tides closed the sandbar later that evening (Figs 4.6 & 4.7). On December 16th,

⁴ Water entering the lagoon may have stopped entering the lagoon a few days earlier, due to porosity of the substrate and the distance from the lagoon.



Figure 4.2 Water exiting the Carmel Lagoon on December 16, 2002. Brown water (center) is runoff from the Carmel River flows and darker water (top and bottom) is residual lagoon water. Photo: Fred Watson, 16 Dec. 02.

morning water elevations in the lagoon reached 3.3 m (10.8 ft). Once the tide levels decreased, the exiting water had formed a new, shorter channel, which eventually drained the lagoon (Fig. 4.2). Approximately four hours later, the lagoon levels dropped to 1.6 m (4.8 ft).

During most years, natural breaching would occur when lagoon water elevation reaches 4–5 m NGVD (12–14 ft) (ENTRIX, 2001). Dettman (1984) estimates that a flow of 5.7 m³/s (200 cfs) is needed to naturally breach the lagoon and that a minimum of 2.1 m³/s (75 cfs) is required to keep it open. Peak flows recorded at the USGS gage at Via Mallorca Rd were approximately 76 m³/s (2,700 cfs) on the 16th of December and were above the 5.7 m³/s (200 cfs) threshold for another week. Due to the volume of water coming into the lagoon and the gage height prior to breaching (9.9 ft), it is likely that the lagoon would have breached naturally either late December 15th or early December 16th, although flooding of the neighboring residential areas would have occurred.

Over the next two months, the mouth of the lagoon remained open. This is indicated in Figure 4.5. High variability shown after December 16th is the result of tidal fluctuations through the open sandbar. The sandbar did re-close briefly on a few occasions in late February and early March as flow in the Carmel River reduced to levels incapable of keeping the sandbar from reforming.

A brief storm in mid March created significant streamflow in the Carmel River. This breached the lagoon after it had re-closed approximately one week earlier. Peak flows generated by the storm at the USGS gage near Carmel indicate that a flow of approximately 7.1 m³/s (249 cfs) had reached the lagoon causing water elevations to rise to 2.8 m (9.2 ft). The lagoon breached later that afternoon.

A series of small storms in mid to late April, as well as early May, kept streamflow in the lower Carmel River and the sandbar open into early June. During this time, the lagoon repeatedly filled and breached itself (Figs 4.3 & 4.5).



Figure 4.3 A psuedo-natural breach of the Carmel Lagoon on March 15, 2003. Psuedo is used because an earlier artificial breaching had already altered the sandbar. (Photo: Paul Huntington, March 15, 2003).

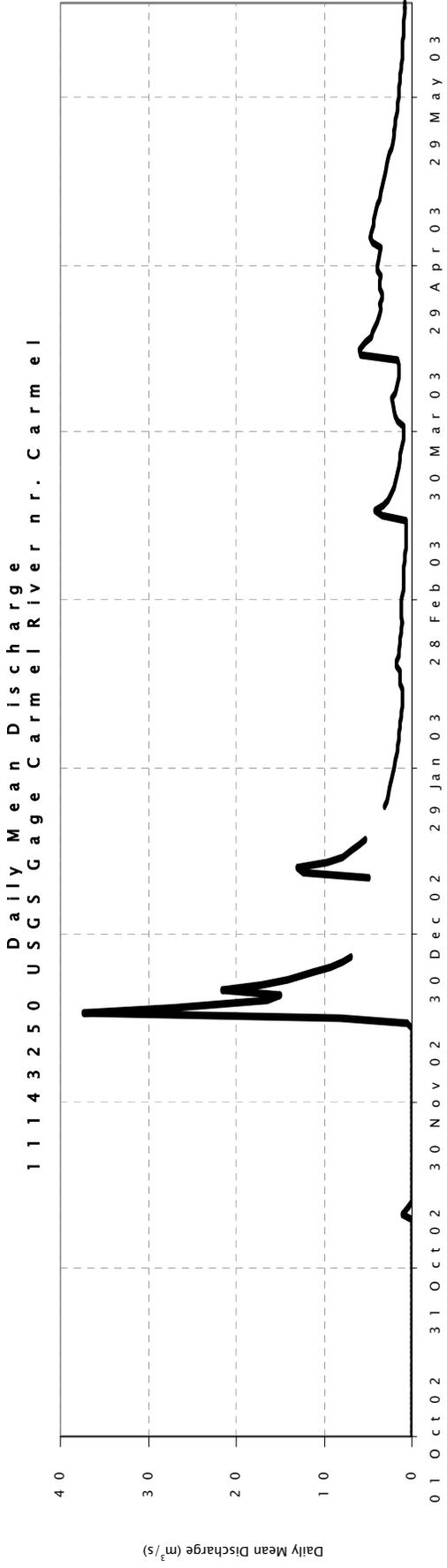


Figure 4.4 Daily mean discharge for the Carmel River USGS station 11143250 nr Carmel at Via Mallorca Road. Note some data are missing.

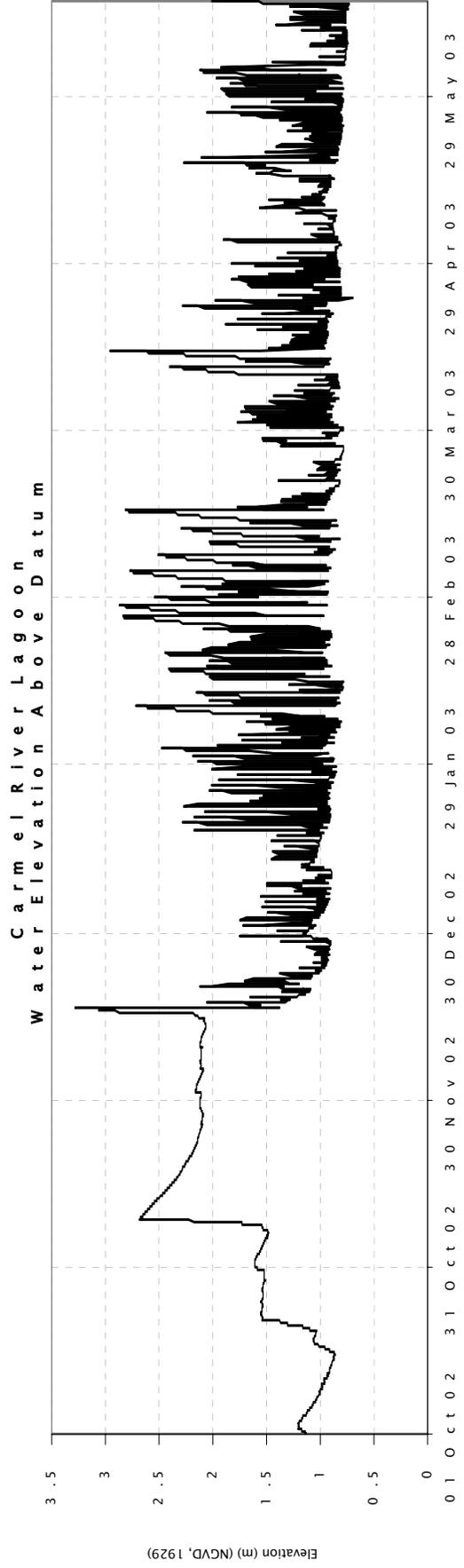


Figure 4.5 Hourly water elevation data for the Carmel Lagoon. Data was collected by the Monterey Peninsula Water Management District.

Tide Levels at NOAA Station 9413450
Monterey Bay, California

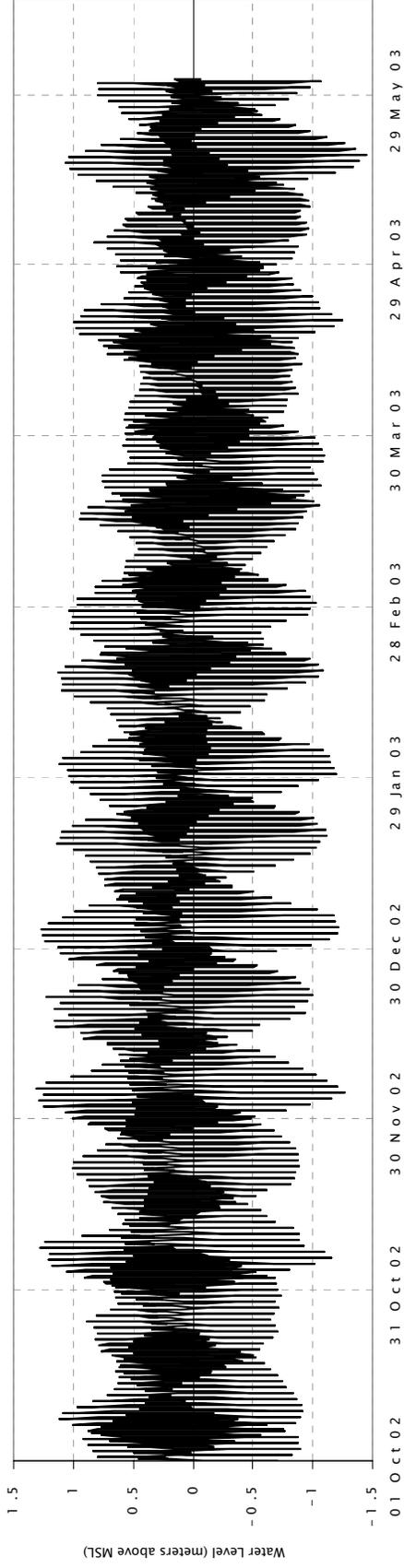


Figure 4.6 Hourly tide levels for Monterey Bay. Data source: NOAA. Verified data not available after May 31st.

Significant Wave Height NOAA Station 46042
Monterey Bay, California

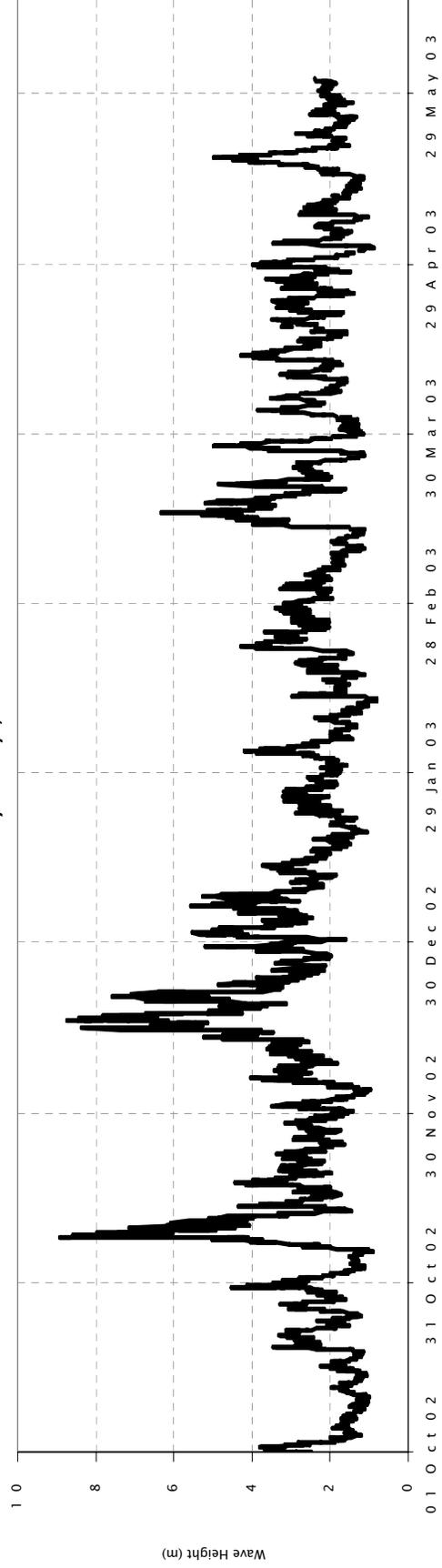


Figure 4.7 Hourly significant wave height for Monterey Bay. Data source: NOAA. Verified data not available after May 31st.

4.3 Central Coast Air Temperatures

Figure 4.8 shows air temperature data for Castroville, California (northwest of Salinas). Air temperature has a strong effect on water temperatures both diurnally and seasonally. Smaller diurnal air temperature differences will have less of an impact on diurnal water temperatures. Conversely, large daily air temperature differences will have a greater effect on diurnal water temperature readings.

Seasonal variation in air temperature and its effects on lagoon water temperatures can be pronounced. Warmer air temperatures associated with summer and early fall will cause water temperatures to increase both at the surface and eventually at depth. However, this will result in stratified profiles where the warmest layers are at the surface and the coolest layers are at the bottom.

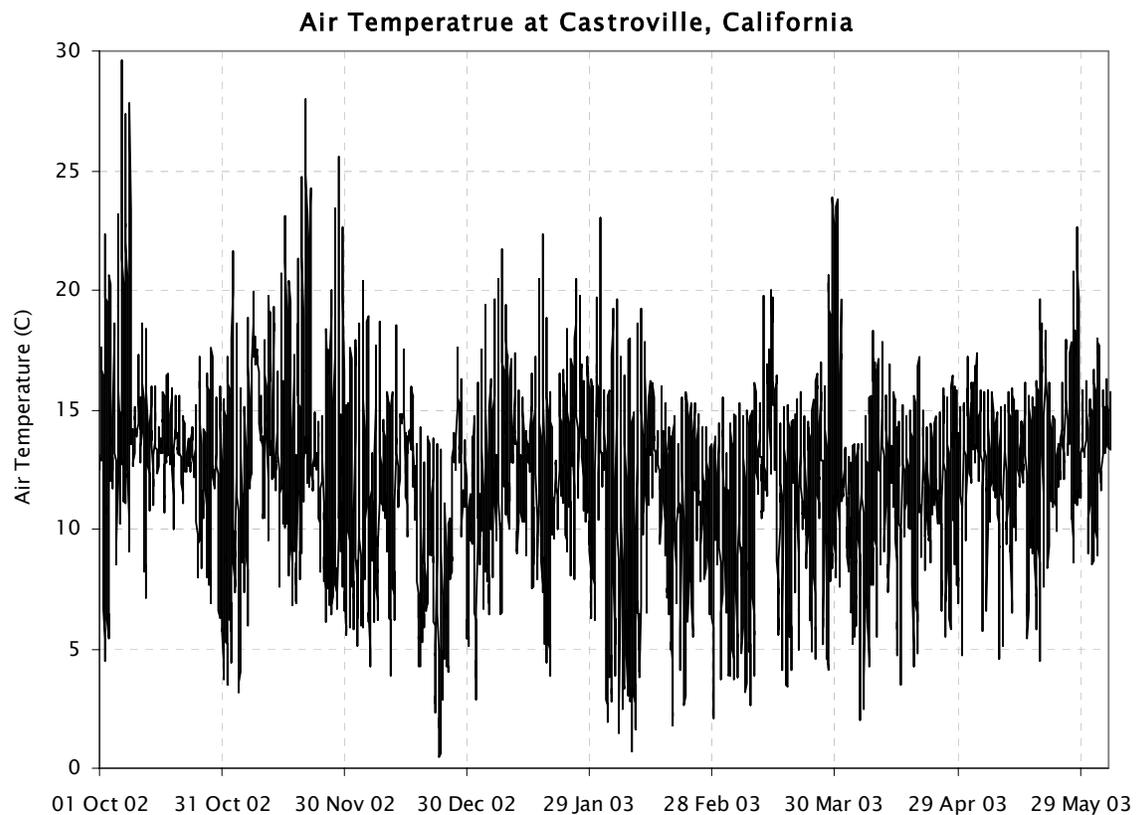


Figure 4.8 Hourly air temperature readings at Castroville, California. Data source: California Irrigation Management Information Systems (CIMIS).

4.4 Bathymetric Data

On December 15th, a bathymetric transect was measured inside the sandbar prior to the breach of the Carmel Lagoon (Fig. 4.9). The intention was to measure several more transects in different areas of the lagoons, however strong winds on two different attempts (December 13th and 14th) resulted in unfavorable conditions for measuring water depths in deeper water.

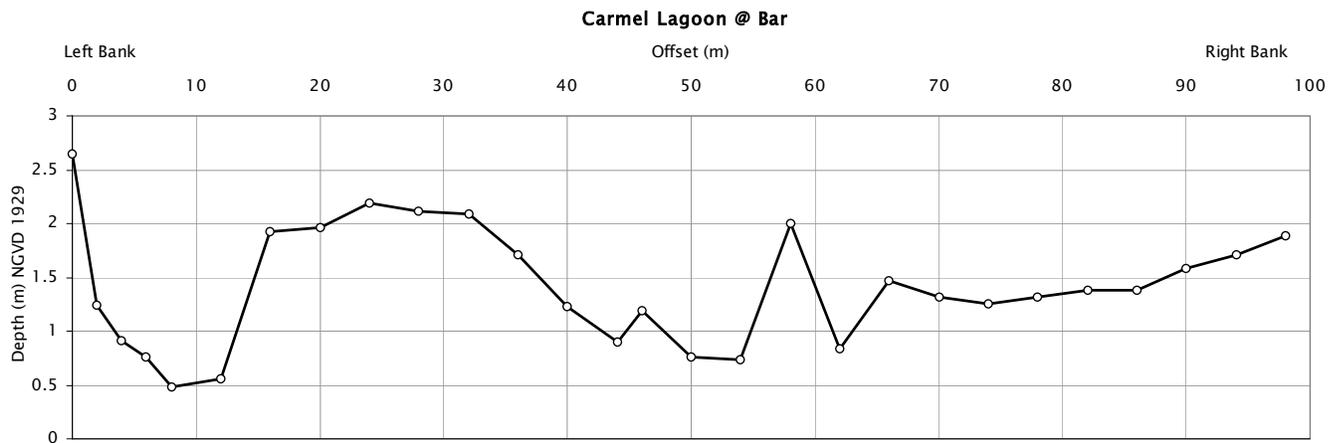


Figure 4.9 This bathymetric transect was taken just inside the bar hours prior to breaching the Carmel Lagoon.

4.5 Bottom Sediment

Six bottom sediment samples were collected on December 15th approximately 7 hours prior to the initial mechanical breaching of the Carmel Lagoon. The median particle size (d_{50}) of each sample is illustrated in Figure 4.11. Detailed size class distribution percentages are shown in Appendix C.

Sediments in the main body of the lagoon consisted of a mixture of large and medium sized sand grains. A sample collected at the entrance to the South Arm, still shallow, had a d_{50} consisting of large sized sand grains. The two samples collected in the South Arm, where water depths are much greater, both consisted of fine materials. Both of the South Arm samples had strong odors associated with them and were black in color, indicating anoxic conditions. Sediments such as these are called *sapropel* (Cole, 1994). Cole defines sapropel as bottom sediments found in environments with extended periods of anoxia and reducing conditions. They are black in color (from ferrous sulfide), watery (lacking a firm structure), and give off a rotten egg-like odor from methane gas releases (Fig. 4.10). Anoxic sediments were found at the bottom of the South Arm in June of 2002 as well (Casagrande et al., 2002). In early December of 2003, fisheries biologist Jeff Hagar, of Hagar Environmental Science, reported that significant portions of the lagoon were anoxic below 2 ft (HES, 2003, in



Figure 4.10 Sapropel (black sediments at top) taken from the bottom of the Salinas Lagoon. Samples similar to this one were collected at the bottom of the South Arm of the Carmel Lagoon. Once exposed to oxygen in either air or water, sapropel will turn brown but retain its watery texture (Cole, 1994). The light-brown sediments (bottom) were on the top of the sample and were the first to be exposed to oxygen. (Photo: Joel Casagrande, 06 Jun 02)

prep). It is likely that oxygen concentrations did not improve between June 2002 and December of 2002, therefore creating conditions (long periods of anoxia) likely to form sapropel.

Bottom sediment samples were not collected after the breach due to the likelihood that no change in bottom particle sizes had occurred. In 2001, the Carmel Lagoon breached at an elevation of 3.25 m (10.7 ft) (Casagrande et al., 2002). In 2002, the lagoon was successfully breached at an elevation of 3.29 m. Because the water elevations were similar, the degree of turbulence and scour would have likely remained the same.

Carmel Lagoon Bottom Sediment d_{50} Pre-breach

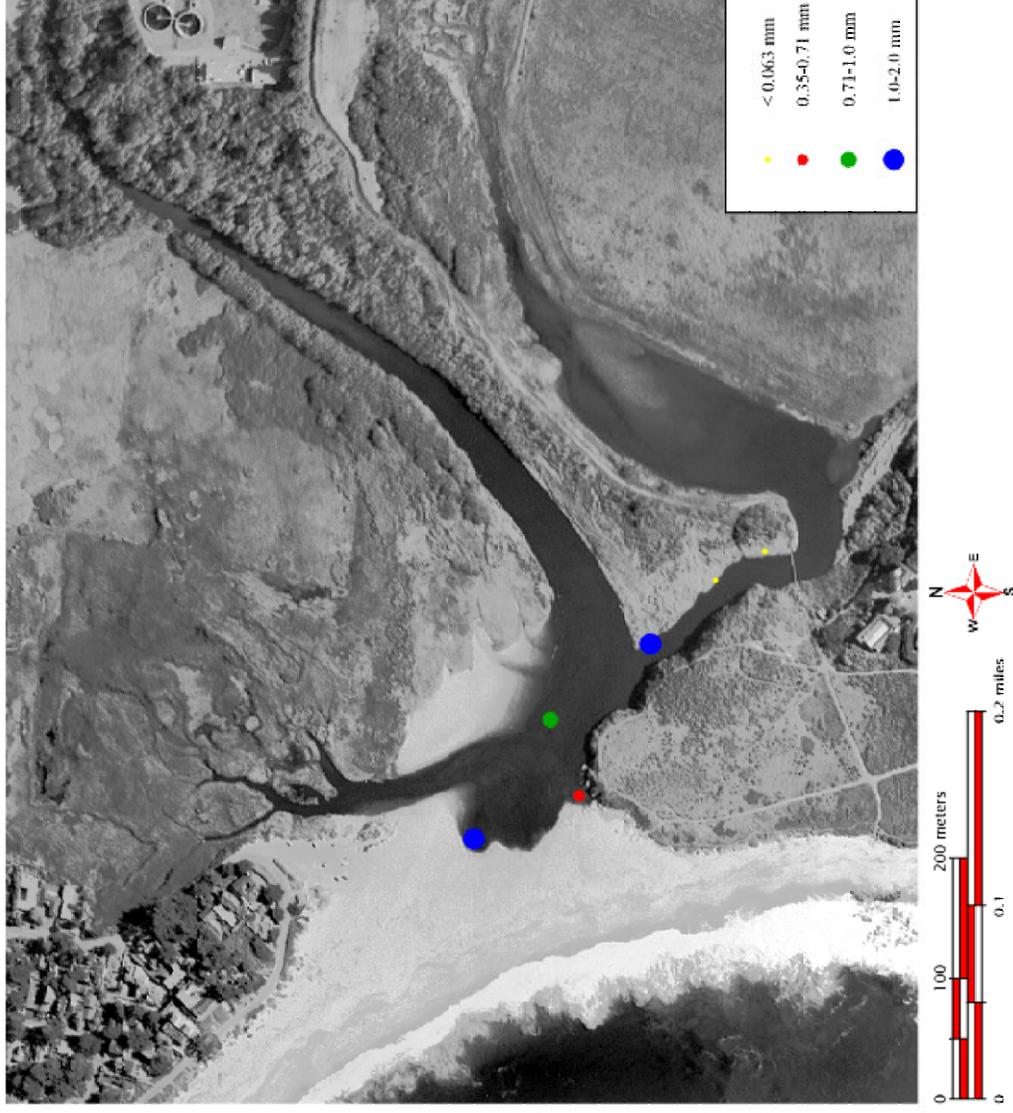


Figure 4.11 This map illustrates the benthic sediment d_{50} in the deep portions of the South Arm as well as the main lagoon during pre-breach conditions.

4.6 Water Quality Pre–Breaching

For this section, refer to Figures 4.12 through 4.14 and Appendix A.

4.6.1 December 13, 2002

Two days prior to breaching of the lagoon (13 Dec 03), lagoon water elevations had reached 2.06 m (6.77 ft) above datum as of 7:30 hours. No streamflow was entering the lagoon at this time. Weather conditions during the previous week were overcast and windy with rain at times.

At all sights, cool water temperatures existed at the surface (12–13°C) and remained isothermal down to 1 meter (Fig. 4.12). Cooler temperatures in the upper meter are attributed to heat loss to the cold night air temperatures. Below 1 m depth, temperatures slightly decreased because of slight heating of surface layer in the morning. Below 2 m, temperatures were higher than at the surface, indicating residual heat from warmer times in the preceding summer and fall. This type of profile is termed a slightly *dichothermal curve*, which is characterized by having the coolest layers of the water column in the middle surrounded by warm layers above and below (Cole, 1994).

Diurnal temperature changes showed moderate increases down to 0.75 m as of 16:45 hours. However, temperatures at the 1–meter level remained cool and did not change with the exception of shallow water sites near the entrance to the North Arm and the upper river. The water elevation did not change and streamflow had yet to reach the lagoon. This indicates daily warming of surface layers, accompanied by wind mixing down to 0.75 m.

Dissolved oxygen (DO) concentrations were moderate at the surface down to 1 m and anoxic, < 1mg/L, in deeper waters (Fig. 4.13). The high values in the upper 1 m are consistent with the levels of wind–forced mixing as stated above. These types of profiles are known as *clinograde oxygen profiles*, where DO is available in the top layers overriding a large anoxic wedge below. Clinograde profiles are the result of a substantial amount of dead and/or dying organic matter in the hypolimnion, or the deep waters (Cole, 94). The organisms feeding on the accumulated dead organic material consume any oxygen present in the hypolimnion through the process of decomposition. With a lack of significant mixing, the effects of oxygen use propagate upwards until reaching the

oxygenated mixed layers near the surface. Often, dense plankton blooms can create a barrier for light passage, thus reducing photosynthesis below. Secchi depth readings were taken both in the morning and evening monitoring runs. These readings indicated that a majority of the solar radiation, or light, was not penetrating below 0.6 m throughout most of the lagoon. In fact, the highest secchi reading measured on this day was 0.73 m at 17:00 hours in the main body of the lagoon, which is fully exposed. This would indicate that the light levels required for rooted aquatic vegetation were not reaching the bottom of the South Arm, and possibly being shaded by plankton blooms near the surface.

Afternoon winds were strong, however they did not induce mixing below 0.75 meters, thus diurnal profile changes in this portion of the lagoon were minimal, except at the surface.

Surface waters were brackish with gradually increasing salt concentrations down to 3-meters (Fig. 4.14). Below the 3-meter depth, concentrations remained between 26 and 27 ppt down to the bottom. No wave overwash was observed during either the morning or evening monitoring events, but the presence of fresh bull kelp in the lagoon indicated that recent ocean overwash had occurred.

Carmel River Lagoon Temperature Depth Profiles

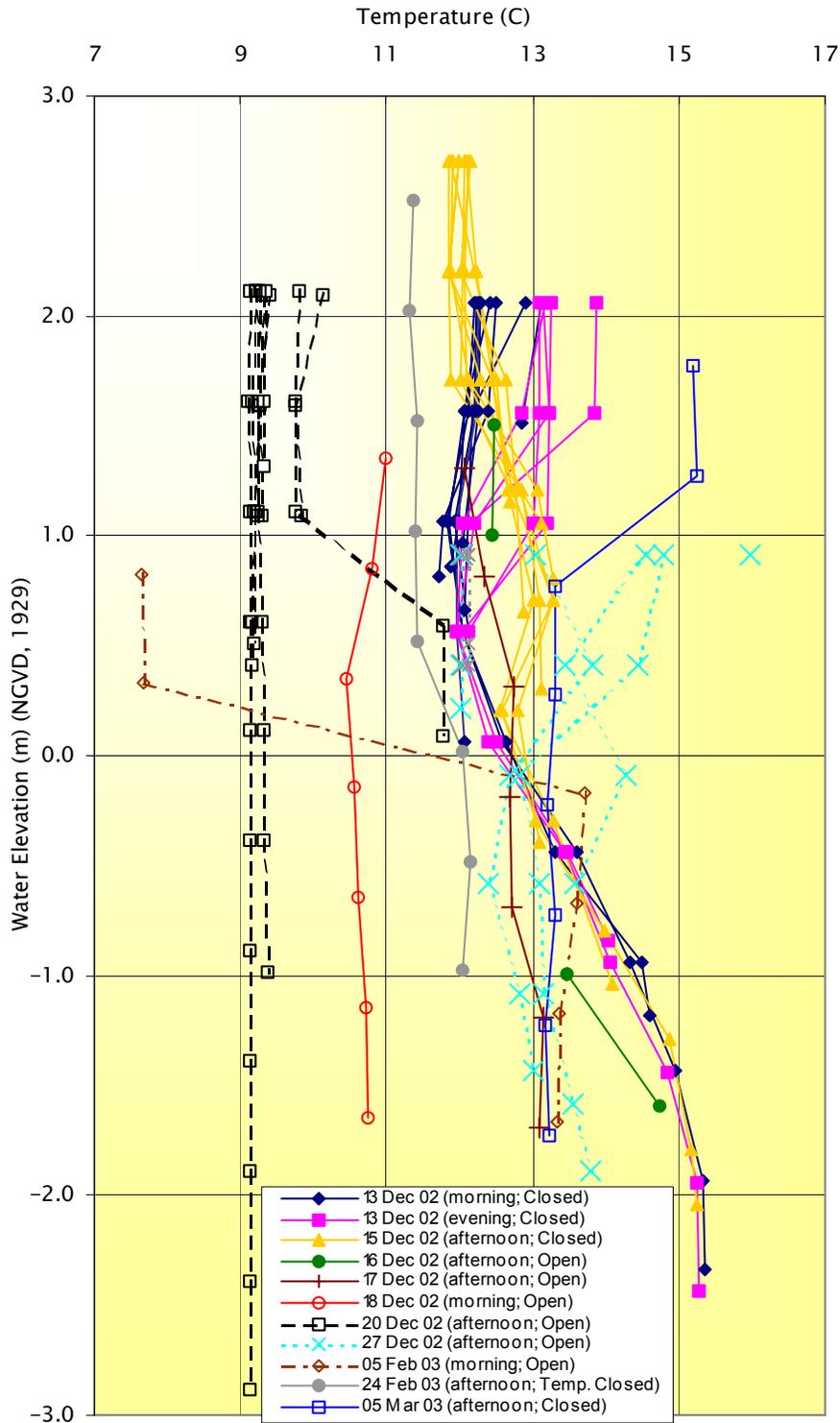


Figure 4.12 Temperature depth profiles for the Carmel Lagoon.

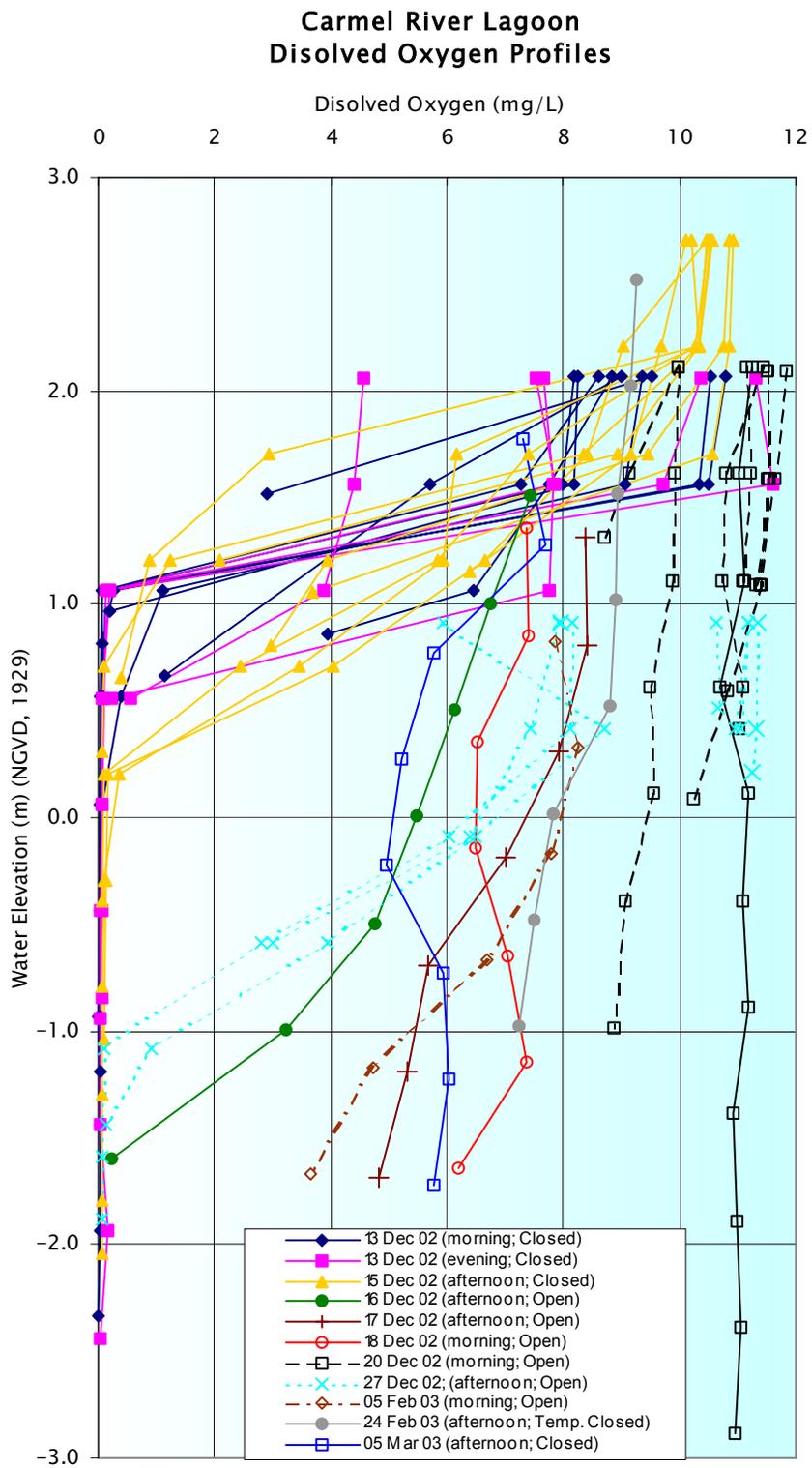


Figure 4.13 Dissolved oxygen depth profiles taken at the Carmel Lagoon

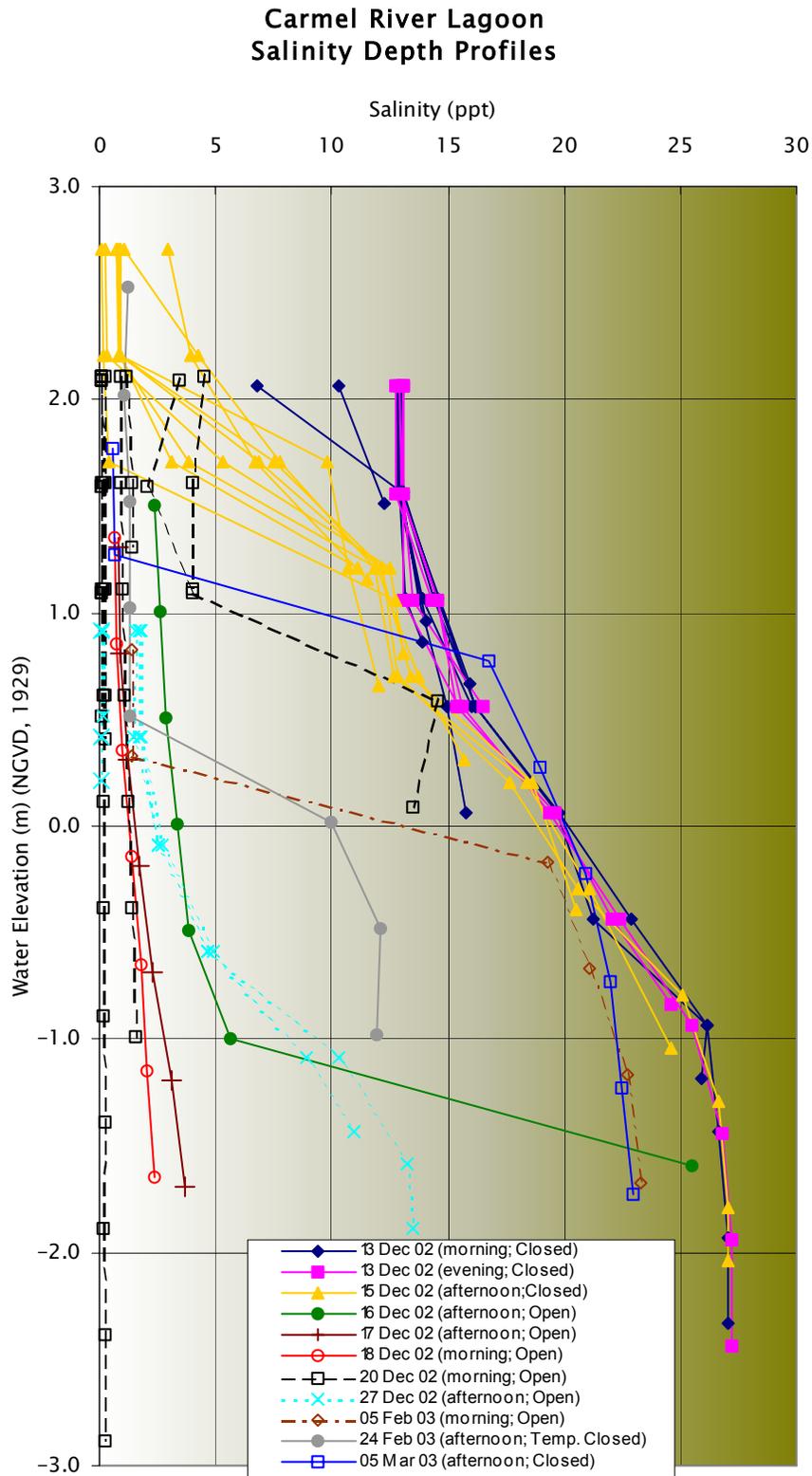


Figure 4.14 Salinity depth profiles taken in the Carmel Lagoon.

4.6.2 December 15, 2002

Streamflow began to enter the lagoon on the 14th of December, which brought the lagoon water elevations up to 2.71 m (8.88 ft). Severe winds gusts were observed throughout most of the afternoon on the 14th and early 15th of December.

Afternoon measurements indicated the upper meter of the water column had cooled as a result of cooler incoming streamflow (Fig. 4.12). The strong winds did produced some mixing in the upper 2 m of the water column but had little or no effect below this point.

Incoming fresh water, along with the severe wind gusts, kept dissolved oxygen levels moderately high in the upper meter of the lagoon. The data also suggest that there was an overall increase in the depth of mixing resulting in a more gradual decrease in DO with depth. Below 2 m, the waters approached anoxic levels (Fig. 4.13).

With incoming streamflow, salinity was significantly lower at the surface. Shallow sites upriver of the lagoon were predominantly fresh. South Arm sites were more gradually stratified to depth (Fig. 4.14).

4.7 Water Quality Post Breach

For this section, also refer to Figures 4.12 through 4.14 and Appendix A.

4.7.1 December 16, 17, 18, 2002

A series of depth profiles were taken from the gage in the South Arm of the lagoon on the 16th, 17th, and 18th of December (Table 4.1). At the gage the water depth is almost the deepest found in the lagoon (approximately 0.5 m short of the deepest). However, this site is easily accessible by foot and it provides an efficient indication of the overall change in water column chemistry.

In general, post-breach conditions reflected a several day transition from a stratified brackish and saline state to a completely fresh, cool, oxygenated state throughout the lagoon.

The lagoon was breached for a second time in less than 18 hours at approximately noon on the 16th after water elevations reached 3.25 m (10.7 ft). A depth profile from the gage was taken approximately 2.5 hours later when the stage was 1.51 m (4.95 ft). Temperatures at the surface in the South Arm were similar to those measured just prior to breaching. Mid-profile data is absent due to instrument error. Overall, temperatures appeared to have been well mixed, with slightly warmer temperatures at bottom. DO was still showing a slightly clinogadic-like curve, but mixing did not appear to have been as significant as those measured last year immediately after the breach (Casagrande et al., 2002). Anoxic conditions still existed at the bottom. Saline water occurred only on the bottom. The upper meters were slightly brackish (mid) to primarily fresh (top).

On the afternoon of the 17th, significant streamflows (35 m³/s) from the previous night began to have a greater effect on the water quality in the lagoon. Temperatures were cooler, DO had increased throughout with no anoxic conditions and the entire water column was relatively fresh (< 4 ppt).

The following morning, temperatures were uniform from top to bottom due to continued mixing of incoming river water. DO decreased slightly at the surface but increased moderately at depth and salinity levels were slightly lower throughout the profile, especially at the bottom.

4.7.2 December 20, 2002

A full monitoring run of all sites was conducted in the afternoon of the 20th of December. Weather conditions were overcast, raining with mild winds.

At most sites, temperatures were cool throughout and uniform from top to bottom, indicating that significant mixing had occurred and possibly was still occurring. Cold incoming streamflow had completely mixed the water column creating a cold, well-oxygenated and fresh water lagoon. Light penetration conditions due to increased suspended sediment did not favor high autotrophic production, which was indicated by low Secchi disk readings—0.20 m in the main body of the lagoon and 0.13 m throughout the South Arm. Therefore, the well-oxygenated water was more a result of well-mixed conditions.

Saline water was detected only at the bottom of the breach corridor and at the entrance to the North Arm due to the mixing of sea and river water while the sandbar was breached. In addition, temperatures were slightly higher at depth in these locations due to the presence of warmer seawater.

4.7.3 December 27, 2002

Eleven days after breaching, streamflow had subsided to 6.10 m³/s (219 cfs) and the lagoon had begun to re-stratify resulting in fresh river water overlaying seawater that had been washed in by tide and waves. This same trend of a relatively quick transition to a stratified system was observed three days after breaching during last years monitoring (Casagrande et al., 2002). The most pronounced re-stratification occurred in the South Arm.

Temperature profiles re-stratified back to the pre-breach dichothermal form of warmer layers both above and below the coolest layer (Fig. 4.12). The surface layers were warmed from solar radiation. The warm layers at the bottom of the sump in the South Arm are due to warmer, density stratified seawater. Inflowing cool river water kept surface temperatures in the main body of the lagoon and up-river sites a few degrees cooler than sites in the South Arm. The flowing river water and wind exposure also kept DO concentrations in the main lagoon

and breaching corridor slightly higher than those in the South Arm area. In the South Arm, DO profiles had also returned to the clinograde form that was established prior to breaching. The bottom layers of the lagoon were anoxic with moderate oxygen concentrations in the mid-layers and the highest found at the surface. The reduction of DO in the sump of the South Arm, since the previous monitoring a week earlier, may be attributed to many factors, including the reduction of mixing due to lower incoming streamflows, a series of cloudy days prior to this sampling and an increase from previous weeks in bottom decomposition, or more likely, a combination of all three.

The reduction of fresh water streamflow into the lagoon while the sandbar was still open, allowed brackish water to settle in the bottom of the South Arm. During periods of high streamflow, the incoming river water appears to be able to flush, or squeeze, out any seawater that entered during high tide. As the streamflow intensity decreases, so does its capability of flushing out the seawater in the bottom of the lagoon.

4.7.4 February 5, 2003

On February 5th 2003, an early morning profile (7:30 hours) was taken at the gage in the South Arm. Extreme cold air temperatures (Fig. 4.8) during the previous evening reduced surface temperatures significantly (Fig. 4.12). A strong thermocline existed between the 0.5 and 1 m depth. Temperatures below 1 m were warmer and isothermal; indicative of temperatures that are residual from warmer river flow and sea water in the preceding weeks.

DO concentrations were moderate (8mg/L) at the surface to moderate to poor (3.5 mg/L) in the middle layers. The absence of anoxic conditions at the bottom also suggests that significant mixing of the water column had occurred. However, the deepest point in the lagoon is a few meters to the north of the gage and therefore a truly lagoon "bottom" measurement was not measured on this day.

Salinity was low at the surface layers in the South Arm and saline below 1 m. Again, low streamflows entering the lagoon were not enough to completely flush out seawater that reached the bottom of the South Arm.

4.7.5 February 24, 2003

On February 24th, 2003, late afternoon measurements were taken at the gage in the South Arm. This monitoring run was made due to alerts that the lagoon would be breached after it had closed earlier in the week. Water elevations reached approximately 2.5 m (8.2 ft) and streamflow entering the lagoon was slow (1.13 m³/s). Temperatures from top to bottom were cool (11.4–12°C) and relatively uniform (Fig. 4.12).

Afternoon readings of dissolved oxygen in the South Arm had slightly increased at all depths (Fig. 4.13) from measurement taken on the 5th of February, but especially at the surface and bottom layers. In the days prior to this monitoring, the weather was clear, warm and slightly breezy in the afternoon. These conditions could have increased algal and plant production, thus increasing the amount of oxygen in the water column. This is supported by the very high secchi depth readings of 2.45 m.

The amount of freshwater had increased in the lagoon as a result of the temporary closing of the sandbar, which trapped incoming streamflow. Below 1 m, brackish water extended to the bottom unlike previous weeks, where salinity was much higher at depth (Fig. 4.14). The closing of the sandbar allowed the freshwater to mix down into the water column, thus diluting the salinity concentrations at depth. An additional factor in the explanation of the reduction in salinity concentrations maybe the result of sandbar formation occurring at low tide. This would leave the least amount of seawater in the lagoon, primarily at the bottom of the South Arm. With incoming streamflow, the freshwater lens would grow on top of the smaller seawater wedge at the bottom.

4.7.6 March 5, 2003

On March 5th, 2003, a profile was taken from the gage during the late afternoon. An advisory warning was sent stating that the sandbar had reformed once again and that lagoon levels would rise at a projected rate of 0.1 feet per hour due to the minimal incoming streamflow still entering the lagoon. The water elevation in the lagoon was 1.8 m (5.8 ft) and rising.

Afternoon weather conditions were clear and warm with a slight breeze. The previous week had similar weather conditions, which led to an increase in overall temperature readings throughout the water column. The surface layers (0–0.5m) were the warmest followed by a mild thermocline, which then led to isothermal temperatures to depth (Fig. 4.12). A secchi disk reading from the South Arm measured 1.4 m.

This generally uniform temperature profile is typical of the equinoxes, and is a transitional state between the negative clinograde conditions of winter and the positive clinograde conditions of summer.

Dissolved Oxygen was stratified into a negative heterograde oxygen profile (Cole, 1994). This type of profile is characterized by the lowest layers of DO concentration occurring in the mid-layers bordered by layers of higher concentrations of DO on both top and bottom. Profiles of this type are difficult to explain. Cole (1994) states that well defined layers of the metalimnion, or the rapid change zone, contain substantial concentrations of “non-migrating” animals (phytoplankton) that are respiring, thus using up oxygen. Secchi depth readings (1.4 m) support this.

Freshwater existed in the top 0.5 m. This was followed by a moderate halocline. Again, the deepest part of the lagoon was not measured where it is presumed that slightly higher salinity concentrations existed.

4.8 Water Quality Post Closure

As of June 23rd, the sandbar at the mouth of the Carmel Lagoon/River had not closed for the season; therefore an assessment of the post-closure water quality was not completed within the timeframe of this report.

5 Results – Salinas Lagoon

5.1 Summary and Timeline of the 2001/02 Season

Pre-breach water quality monitoring in the Salinas Lagoon began on the morning of the December 17, 2002 (Table 5.1 & Fig. 5.1). In the days prior to this monitoring, significant wave overwash was observed entering the lagoon and raised the lagoon water elevation to 2.02 m (6.63 ft.).

Two attempts were made to breach the lagoon. The first attempt was during the evening of the 17th of December. The second and final attempt was made on the 18th of December at approximately 14:00 hours.

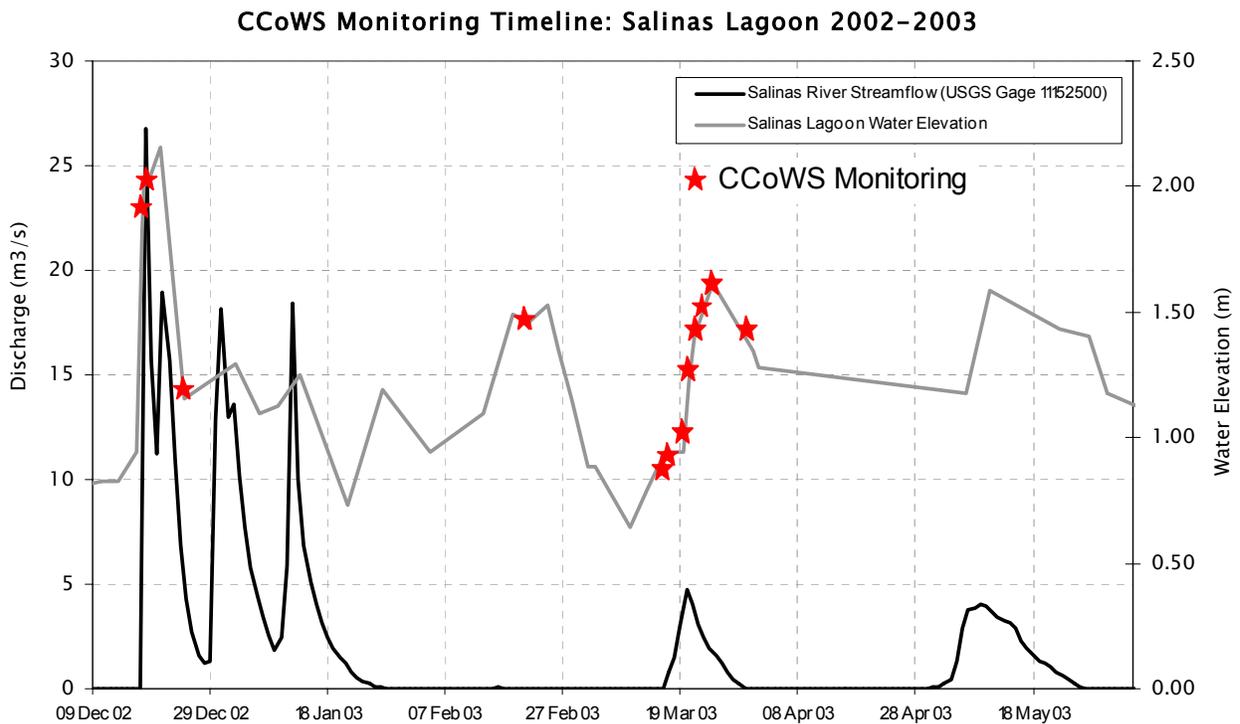
Post breach water quality conditions in the lagoon were monitored during the afternoon of December 20th, although water elevations in the lagoon were still at 2.2 m (7.1 ft) due to a high tide. After a peak flow of 37 m³/s (1310 cfs) on December 18th 2002, daily mean streamflow was still 10.2 m³/s (360 cfs) on December 18th at Spreckels with a second peak on the way. Another set of profiles was measured after the second peak on December 24th. This time water elevations in the lagoon were much lower: 1.2 m (3.8 ft).

No profiles were measured in the lagoon during January of 2003. Through the first half of February the lagoon remained open until February 18th, due primarily to tidal fluxes.

Post closure water quality measurements at all primary sites were measured during the morning and evening on February 24th. In mid March, a late winter storm produced moderate streamflow in the Salinas Watershed and into the lagoon; although a breach of the lagoon did not occur. Several profiles were taken from the Del Monte Bridge with the anticipation of either a late winter breach, or an entire freshwater conversion of a primarily saline lagoon.

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

Sand Bar Condition	Events	Weather Condition	
Closed	17 Dec 02 morning	PC, R, B	
1 st Breach	17 Dec 02 (~ 16:00)		
2 nd Breach	18 Dec 02 (~ 13:25)		
Open	20 Dec 02 afternoon	CO, R, W	
Open	24 Dec 02 afternoon	CO, B	
Closed	21 Feb 03 morning	CL, C, S	
Closed	21 Feb 03 afternoon	CL, W, S	
Closed	March Rain Event – See Table 5.2		
General Weather Conditions			
R = Raining	C = Calm	CL = Clear	H = Hot (extreme)
S = Sunny	W = Windy	PC = Partly Cloudy	CD = Cold (extreme)
L = Lightning	B = Breeze	CO = Cloudy	

**Figure 5.1** Monitoring timeline for the Salinas Lagoon with respect to lagoon water elevation and streamflow in the Salinas River.

5.2 Salinas River Streamflow and Oceanic Data (Monterey Bay)

Streamflow in the lower Salinas River was intermittent throughout the summer. Water released from the Nacimiento and San Antonio Dams had reached the USGS gage at Spreckels in September but soon ceased by October. The lower river through most of October, November and early December was dry. Lagoon elevation was 0.73 m (2.4 ft) on November 1st (Fig. 5.4).

In mid-November, large ocean swells caused significant wave overwash, which increased the lagoon water elevation to 1.77 m (5.8 ft). Peak tides were recorded between November 9th–12th and in early December (Fig. 5.5) and peak wave heights were recorded between the 9th–12th of November (Fig. 5.6).

Over the next two weeks the lagoon was slowly drained down through the outlet gate to the Old Salinas River Channel to an elevation of 0.76 m (2.5 ft). In mid-December a significant storm produced large ocean swells. Observations were made of large waves overtopping the sandbars, especially at high tide on the 17th of December (Figs 5.5 & 5.6). The increase in wave overwash raised the lagoon elevation to 2.01 m (6.6 ft) on December 17th. Streamflow was not entering the lagoon at this time, although a substantial amount of runoff was on its way. Due to the increased water elevations in the lagoon, the staff from the Monterey County Water Resources Agency (MCWRA) reviewed the circumstances and decided to breach the lagoon (MCWRA, pers. comm., 2002). The channel was excavated by the early evening and flows began exiting the lagoon (Fig. 5.2). However, high surf coupled with a high tide had caused the sandbar to reform and allowed water levels in the lagoon to rise even further.

On December 18th the first significant streamflow entered the lagoon. Daily mean streamflow for the Salinas River at Spreckels was 26.7 m³/s (944 cfs). Water elevations reached 2.2 m (7.1 ft) as of 12:00 hours and streamflows at the USGS Speckels gage peaked at 36 m³/s (1,270 cfs). At this time it was determined by staff from the MCWRA that a second manual breach of the lagoon was necessary with the anticipation of further incoming streamflow. This attempt was successful.



Figure 5.2 Excavation of the breach corridor at the Salinas Lagoon 17th December 2002.
Photo: Fred Watson 17 Dec. 02

The lagoon remained open through mid-February and finally closed on February 18th. Streamflow entering the lagoon from the Salinas River ceased on January 26th. Although low flows at the Spreckels gage continued, it is likely that they did not reach the lagoon.

A late winter storm in mid-March resumed moderate flows to the lower Salinas River (Fig. 5.3). However, water elevation in the lagoon prior to the addition of the incoming river water was low enough to accommodate the river water without requiring a manual breach. As a result, water elevation in the lagoon reached 1.65 m (5.4 ft) on March 24th. The increased elevations were quickly drained down through the Old Salinas Channel.

A similar series of storms in late April and early May, briefly returned streamflow in the lower Salinas River and lagoon (Fig. 5.3). Again, water elevations in the lagoon rose to approximately 1.5 meters above datum and no breaching of the sandbar occurred.

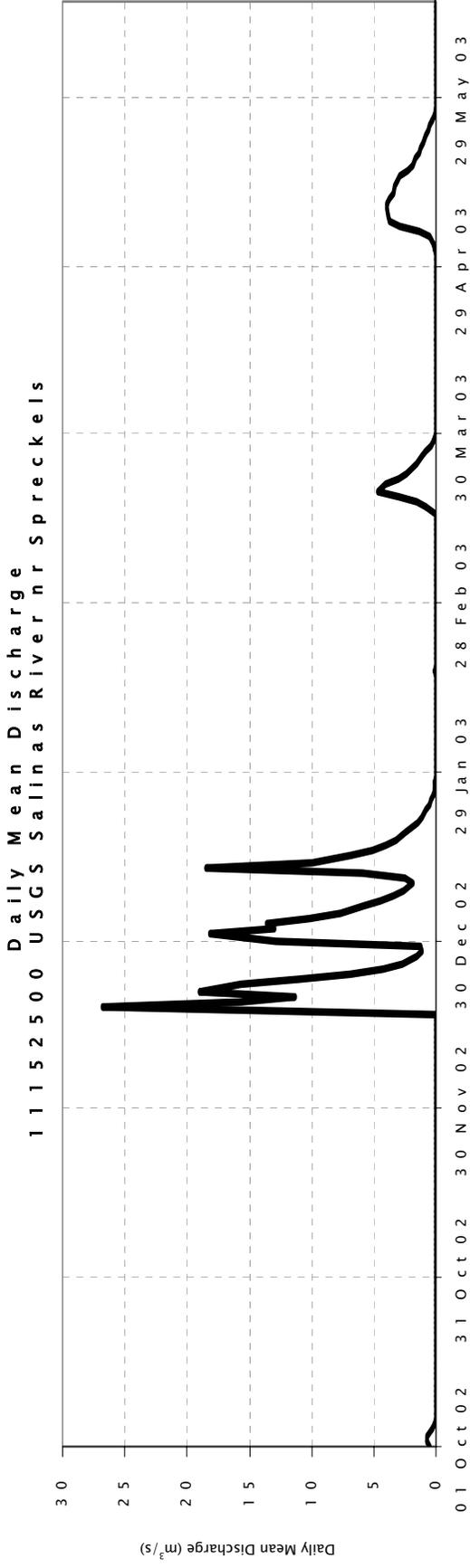


Figure 5.3 Daily mean discharge for the Salinas River USGS station 11152500 near Spreckels.

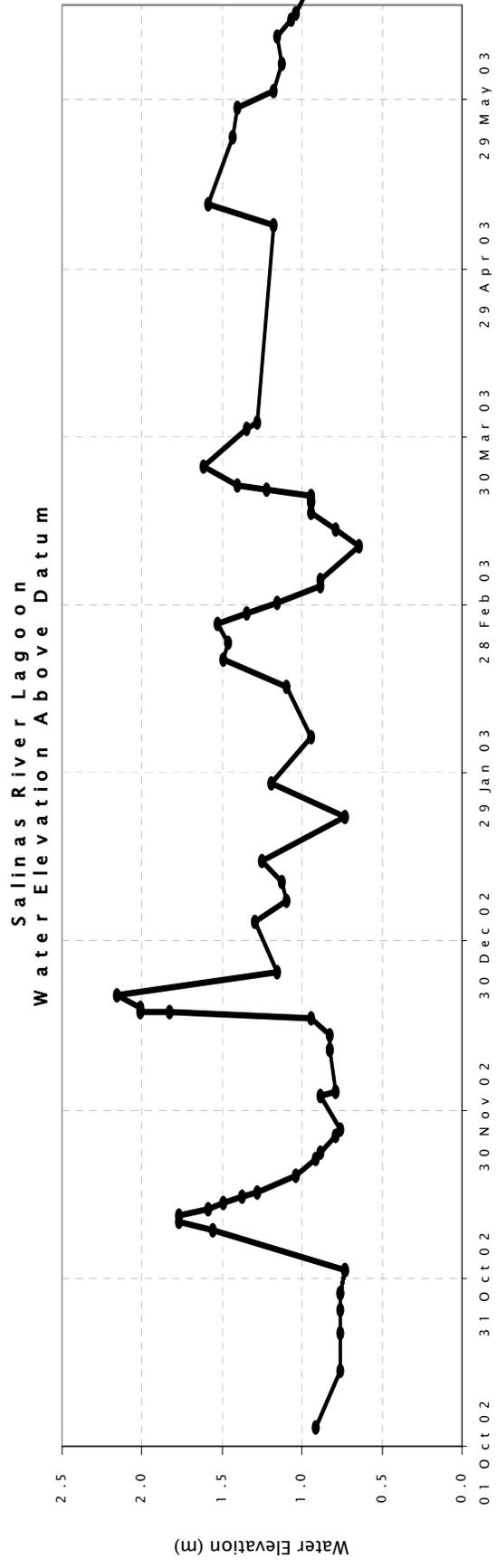


Figure 5.4 Salinas Lagoon water elevation. Data was collected by the Monterey County Water Resources Agency and COWS.

Tide Levels at NOAA Station 9413450
Monterey Bay, California

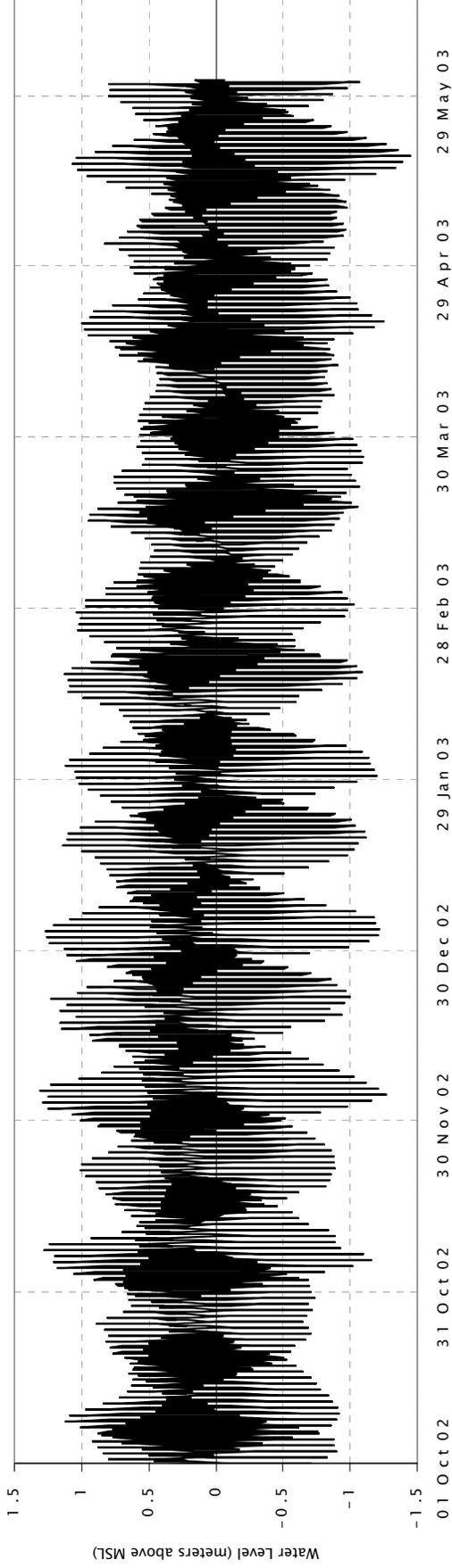


Figure 5.5 Hourly tide levels for Monterey Bay. Data source: NOAA. Verified data not available after May 31st.

Significant Wave Height NOAA Station 46042
Monterey Bay, California

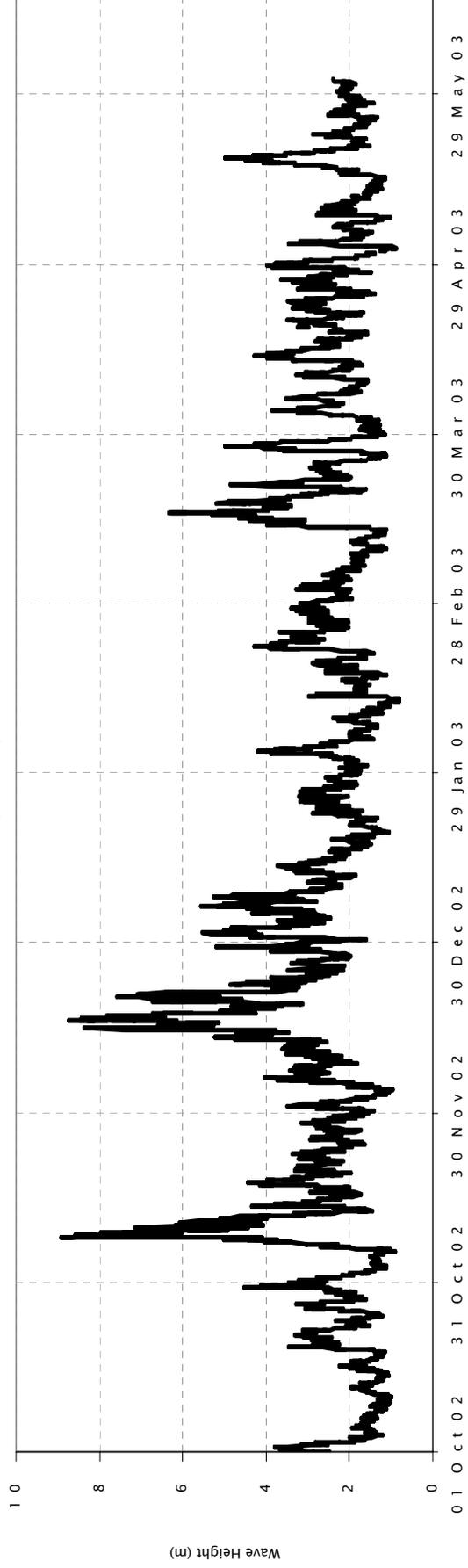


Figure 5.6 Hourly significant wave height for Monterey Bay. Data source: NOAA. Verified data not available after May 31st.

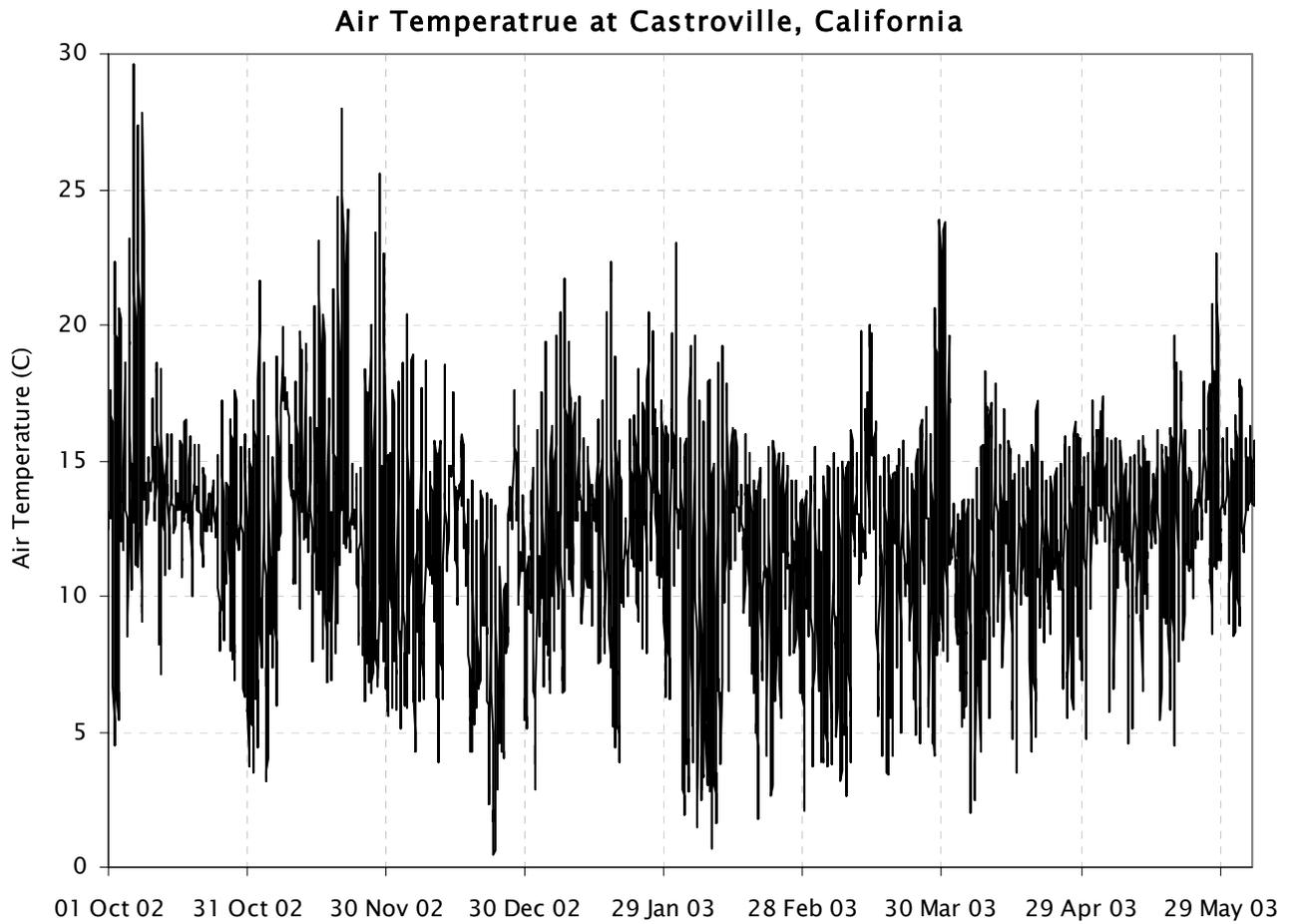


Figure 5.7 Hourly air temperature readings at Castroville, California. Data source: California Irrigation Management Information Systems (CIMIS).

5.3 Bathymetric Data

Six bathymetric transects were measured on December 18th 2002 in the Salinas Lagoon (Fig. 5.8). At this time the water elevation in the lagoon was approximately 2 m. The location of each transect is shown in Figure 5.9.

Starting closest to the ocean, Transect A has two main, well-defined channels with the thalweg at center and a third and much smaller and shallower channel along the left bank. In general, the channel is moderately deep with a maximum depth below surface of 2.35 m (-0.35 m NVVD).

Transect B was 150 m upstream from Transect A. Here the lagoon is broad and depths are moderate. Thalweg maximum depth was 2.35 m (-0.35 m NVVD) below surface. Like Transect A, there was a smaller channel along the right bank. During these measurements, high water submerged the top of the left bank. This explains the difference in bank elevation from left to right.

Transect C was measured near the midpoint of the large island (Fig. 5.9). Generally, this reach of the lagoon is broad and shallow with the exception of a smaller yet deeper channel between the island and the right bank. Note that on the right bank high water elevations during the measurement had flooded dense vegetation that made further measurements difficult.

Upstream at Transect D, the thalweg is much deeper, reaching 3.6 m (-1.6 NGVD). The left bank is steep and lined with riprap to prevent erosion of the bridge structure. Transect E, the deepest part of the lagoon at 4.6 m (-2.6 NGVD), is located just downstream of the railroad bridge, which runs parallel and upstream of Highway 1. The deep thalweg is most likely the result scouring around the trestle supports during large flood events such as the El Niño of 1995 and the floods of 1998.

Furthest upstream, Transect F was measured approximately 200 m upstream of the railroad bridge. In this reach the channel is much narrower with a well-defined thalweg along the right bank.

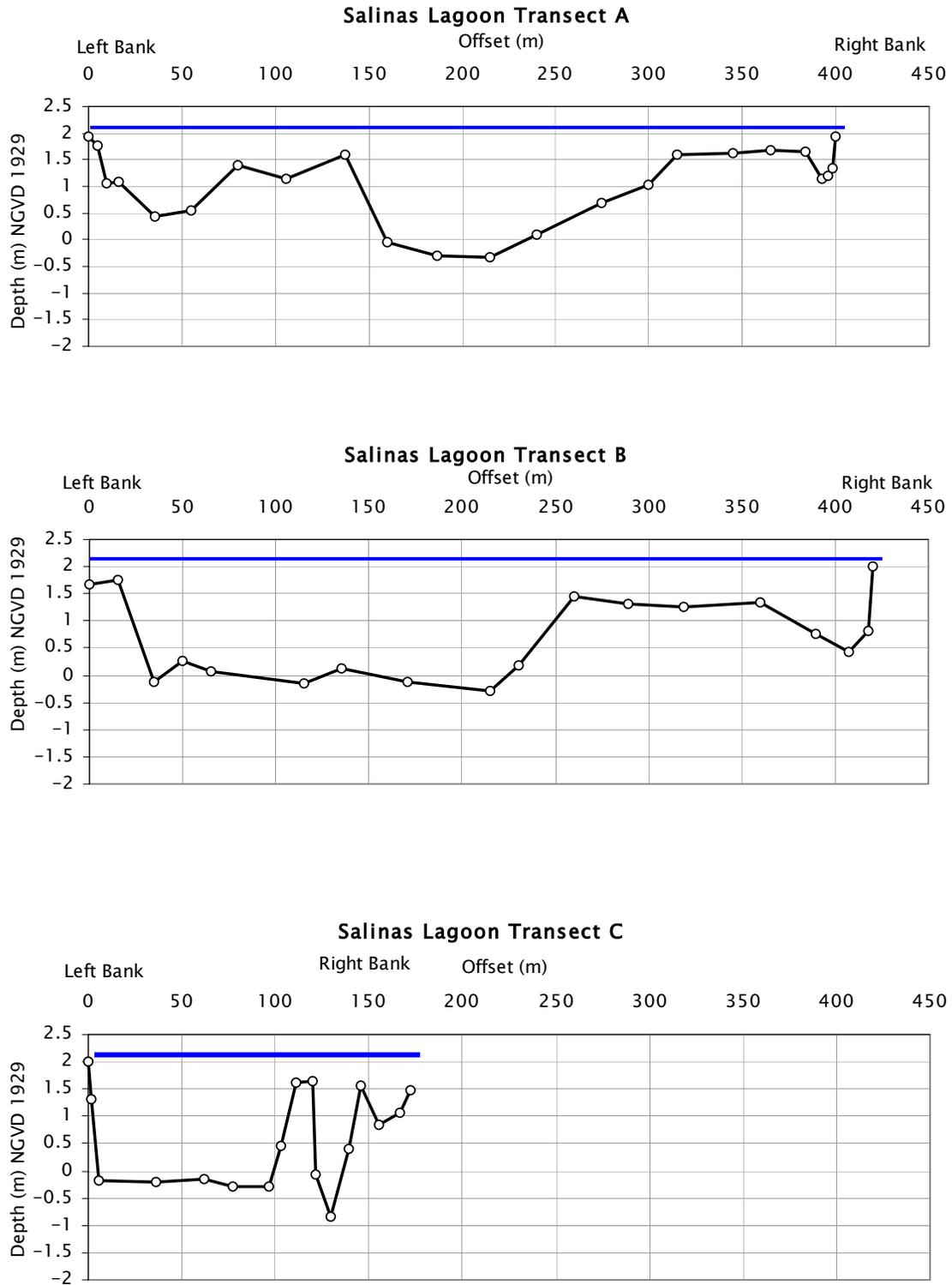


Figure 5.8 Channel cross sections for the Salinas Lagoon measured on December 17th 2002. This year's high water mark is represented with a blue horizontal line on each cross section.

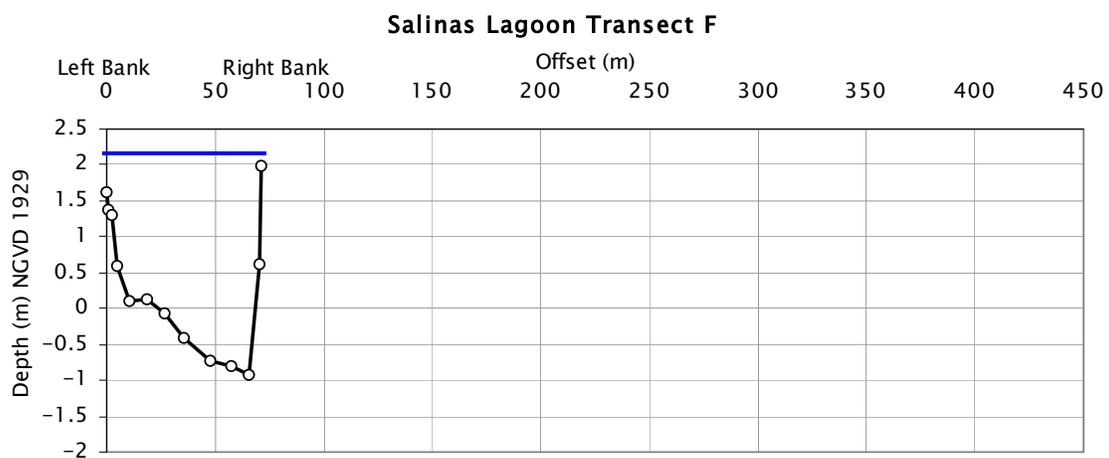
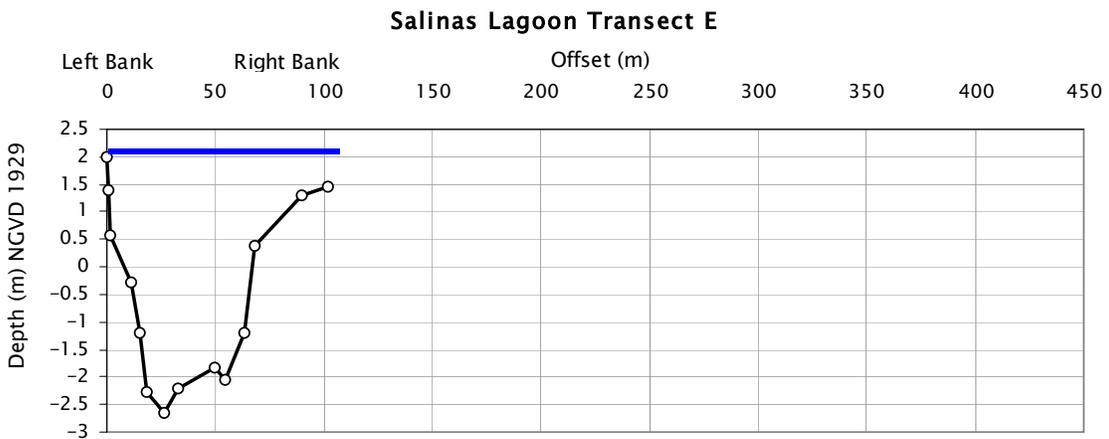
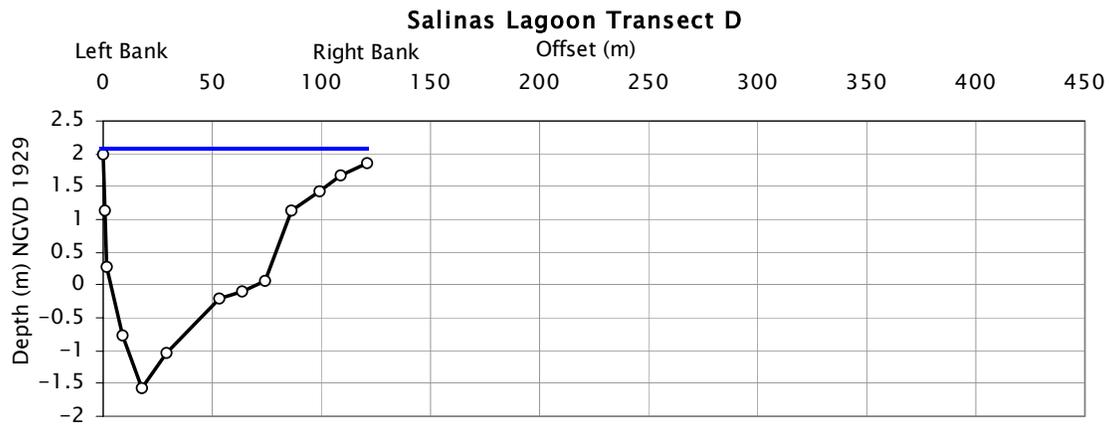


Figure 5.8 Continued Channel cross-sections for the Salinas Lagoon measured on December 17th 2002.

Salinas River Lagoon

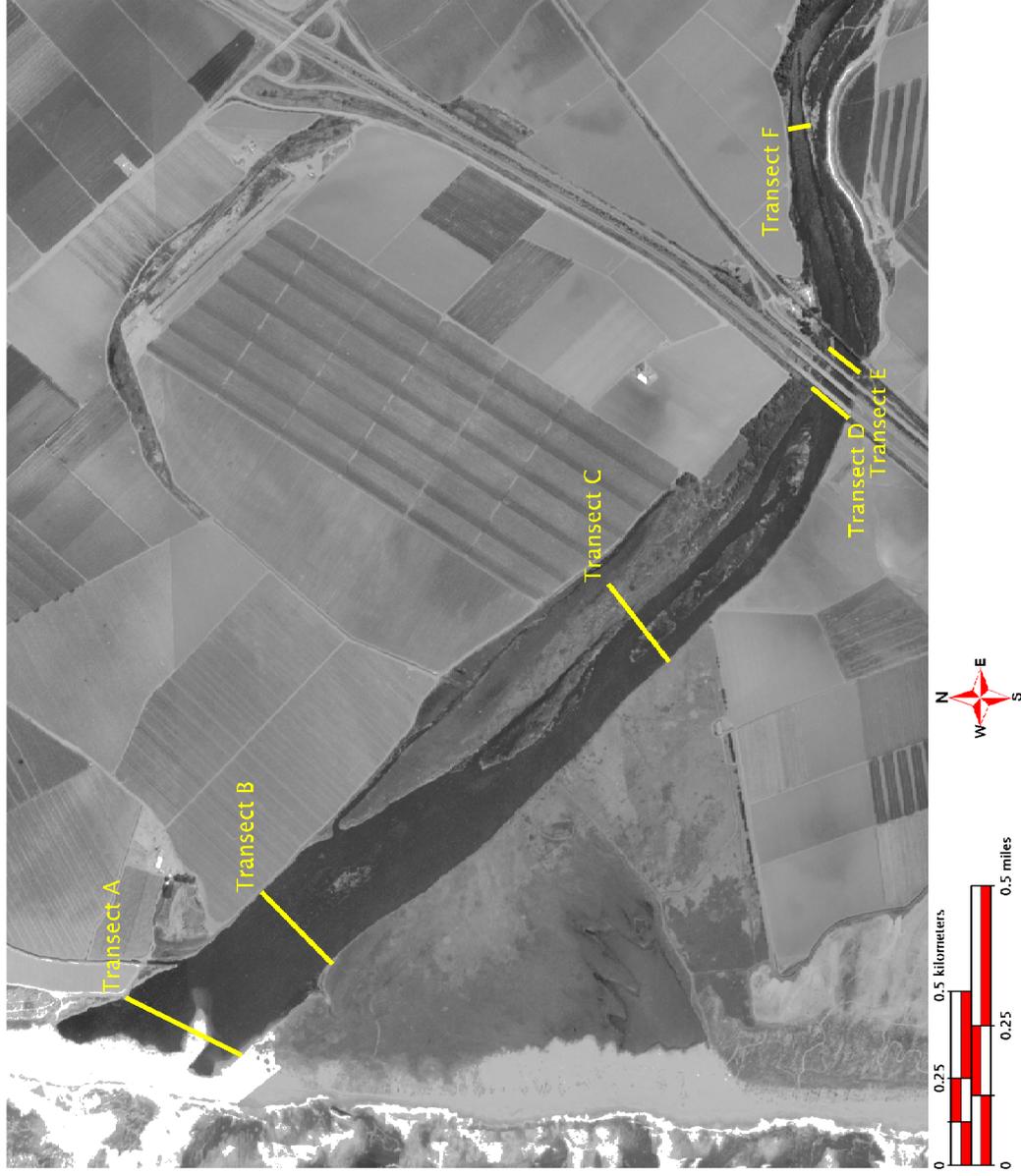


Figure 5.9 Bathymetric transect locations for the Salinas Lagoon.

5.4 Bottom Sediment

Bottom sediments were measured in the Salinas Lagoon approximately 24 hours before the lagoon was successfully breached (Fig. 5.10). Three samples were collected in three different locations in the deep sump. The deep sump was targeted because of its depth and the presence of fine accumulated sediments measured during the previous year's sampling (Casagrande et al., 2002). By measuring the bottom sediments in the deepwater both before and after the breach of the sandbar, one could infer whether or not the hydraulic response to the breach was violent enough to displace, or wash out, fish seeking refuge in these shelter environments based on the presence or absence of fine sediments.

All three samples had d_{50} , or median particle sizes, < 0.063 mm (Fig 5.11 and Appendix D). In comparison with samples collected in June 2002 (Casagrande et al., 2002), there was no change in bottom sediment d_{50} . The samples were anoxic, black and had a gelatinous texture, indicative of sapropel (Fig. 4.10). Other bottom samples were collected in March and June of 2003 (post breach) and also had a $d_{50} < 0.063$ mm (Kozlowski et al., 2003). It is likely that large flood events, ≥ 25 year flood (i.e. the 1995 flood), would be required to scour adhesive sediments at 4–5 m depth. Annual peak flows in the lower Salinas River the past two water years have been small, with recurrence intervals less than 1.3 years (Fig. 5.12).

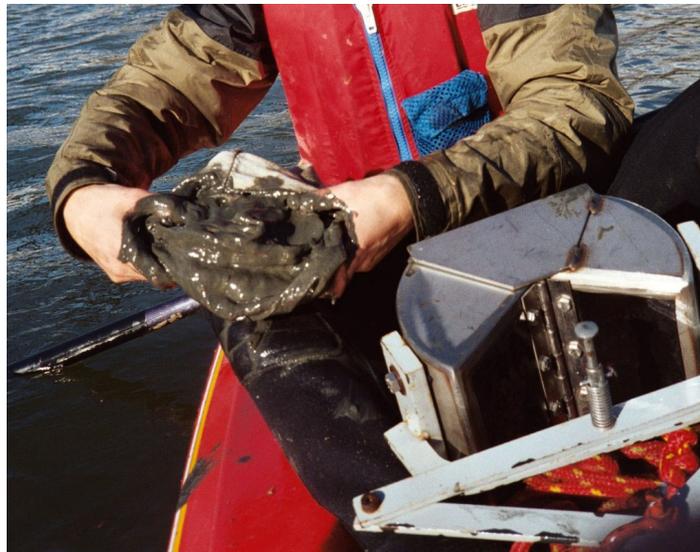


Figure 5.10 Sampling bottom sediments in the Salinas Lagoon with a bottom sampling dredge. (Photo: Thor Anderson, 17 Dec 02)

Salinas Lagoon Bottom Sediment d_{50} Pre-breach



Figure 5.1.1 This map illustrates the bottom sediment d_{50} for deep sump in the Salinas Lagoon during pre-breach conditions. The blue circle shown at the lower end of the figure highlights the locations of three bottom sediment samples collected.

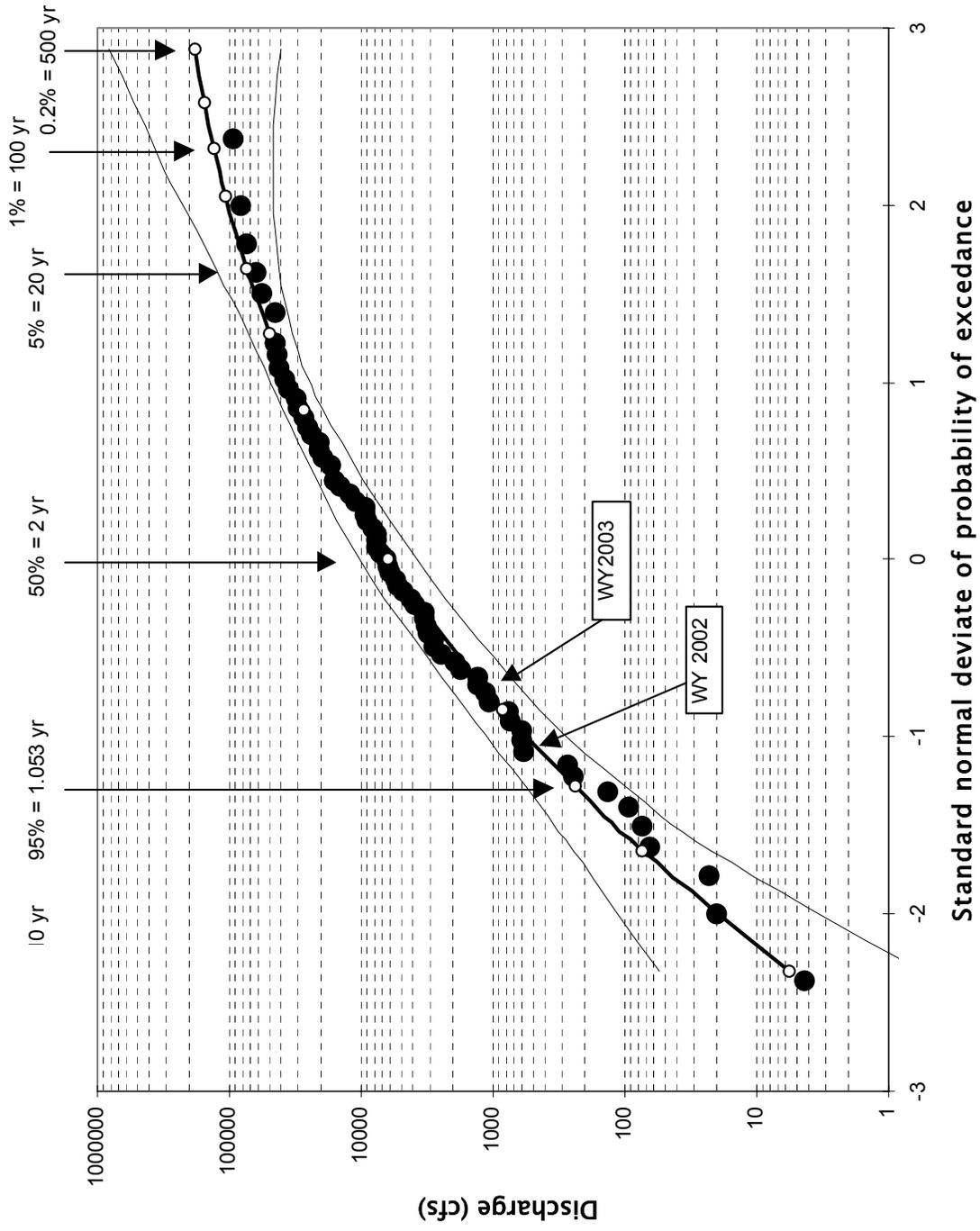


Figure 5.12 Annual peak flood frequency for the Salinas River at Spreckels.

5.5 Water Quality Pre-Breach

For this section, refer to Figures 5.13 through 5.15 and Appendix B

5.5.1 December 17, 2002

Pre-breach water quality monitoring in the Salinas Lagoon was conducted on December 17, 2002 at approximately 10:00 hours. Storm conditions persisted throughout the previous week, with high gusty winds and a substantial amount of rain. High ocean waves caused significant wave overwash into the lagoon. Waves were observed breaking over the sandbar from as far south as the saline pond and as far north as Monterey Dunes Colony residential area. Water elevation in the lagoon had risen to 2 meters (6.6 ft) (Fig. 5.4) connecting the South Pond with the main lagoon. No streamflow was entering at this time, although the Salinas and Arroyo Seco Rivers were flowing significantly further upstream.

Late morning water temperatures were cool throughout. Near the sandbar, gusty winds created a well-mixed isothermal water column. At the deep sites near the Twin Bridges, water profiles were relatively well mixed with slightly warmer waters at depth that were residual from warmer summer and fall months (Fig 5.13). Surface layers had lost heat to the cooler air during the evening hours (Fig. 5.7).

Dissolved oxygen (DO) concentrations were generally low to moderate, with the lowest near the midpoint between the bar and the Twin Bridges. In this shallow mid section, the water was dark green and a substantial amount of organic debris was observed. While actual secchi disk readings were not taken, estimates made using a dark blue and yellow kayak paddle, indicated that secchi depth was approximately 0.15 meters at 11:00 hours. The presence of green water suggests that a large algal bloom was present, which is also supported by the low estimates of secchi depth. Near the sandbar, well mixed conditions also created homogenized oxygen concentrations through the profile. Here too, there was a substantial amount of organic debris. Sites near the sandbar are slightly deeper and there is less contact with emergent vegetation. At the deep-water sites near the Twin Bridges, oxygen concentrations were moderate at the surface and poor at depth—but not anoxic.

The lagoon was brackish at upstream sites and saline downstream of the Twin Bridges due to a large amount of wave overwash. Any leftover freshwater from summer and fall that had existed in the lagoon prior to the large input of wave overwash would have been at the surface due density driven stratification (Casagrande et al., 2002). The outlet gate to the Old Salinas River Channel is designed to allow the surface layers of the lagoon to drain into the channel and these layers are usually the most fresh. With little or no incoming freshwater over a long period of time and a significant amount of seawater coming in, the lagoon turned into a more saline system.

Profiles near the sandbar had uniform concentrations (28.5 ppt) to depth (Fig 5.15). Further upstream in the mid-section of the lagoon, concentrations decreased slightly—although they were still uniform. Near the Twin Bridges and upstream, the lagoon was brackish (13–14 ppt) in the upper half meter followed by a strong halocline, which reached 25 ppt at depth.

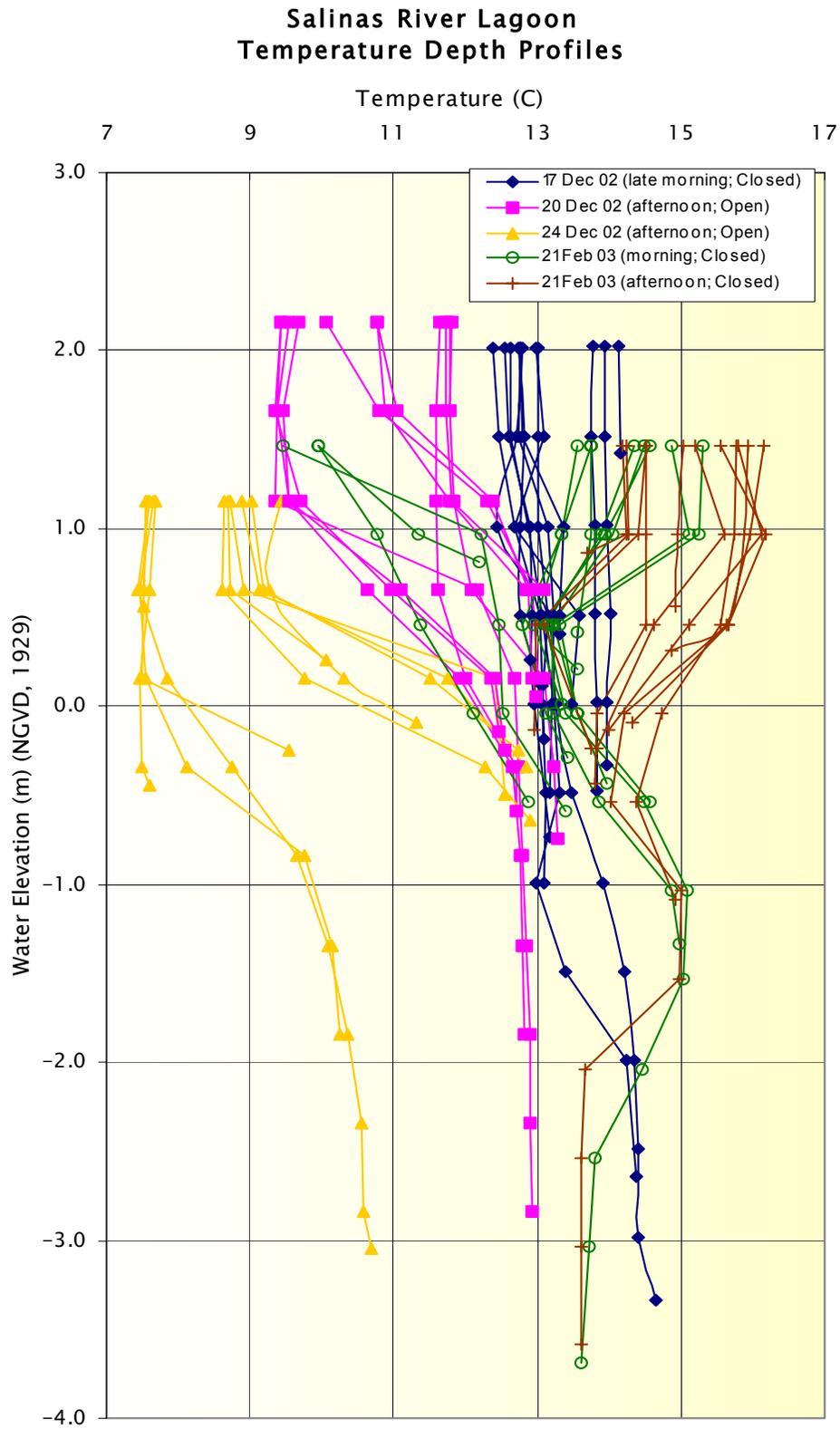


Figure 5.13 Temperature depth profiles from the Salinas Lagoon for all monitoring sessions.

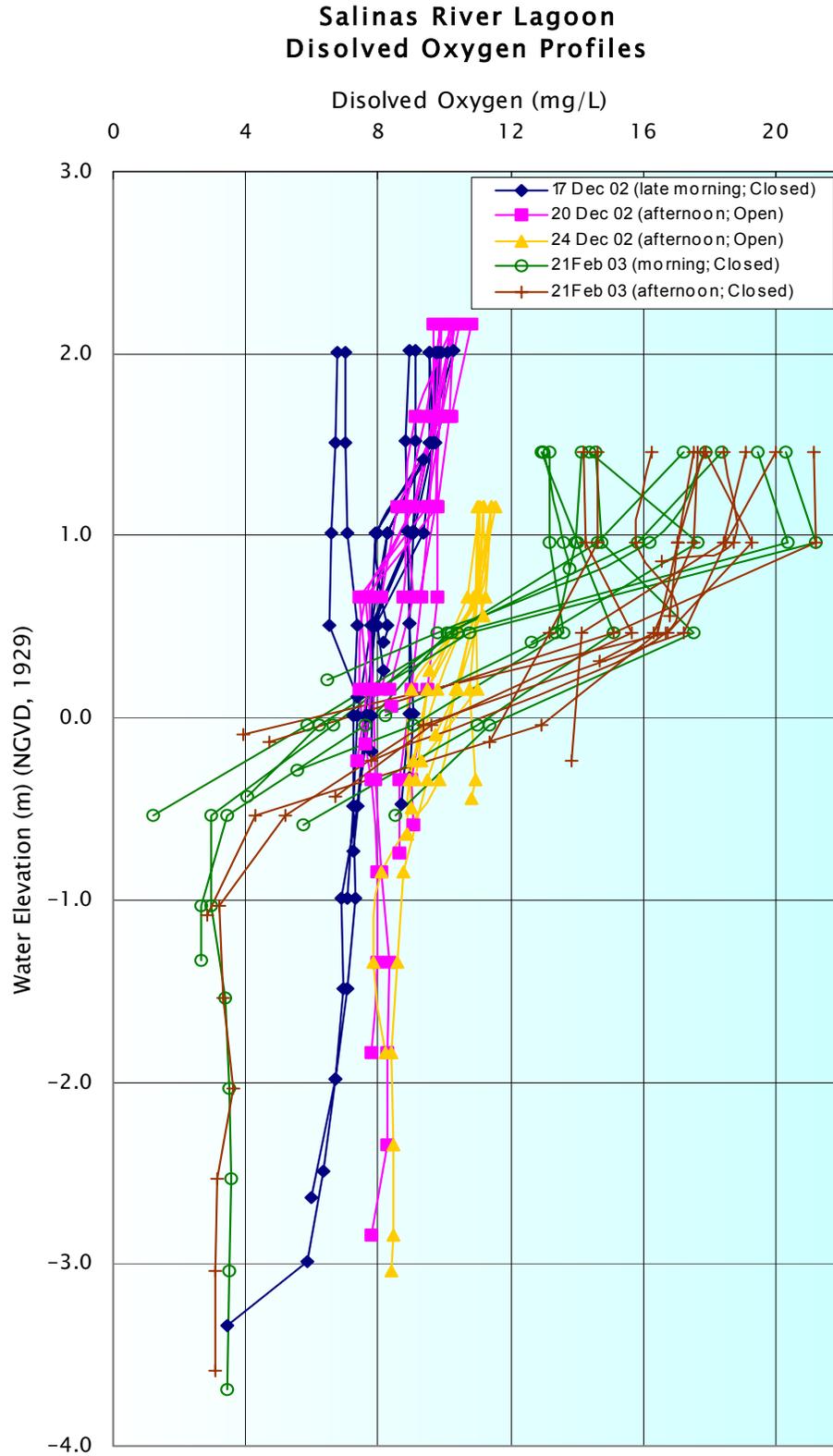


Figure 5.14 Dissolved oxygen depth profiles from the Salinas Lagoon for all monitoring sessions.

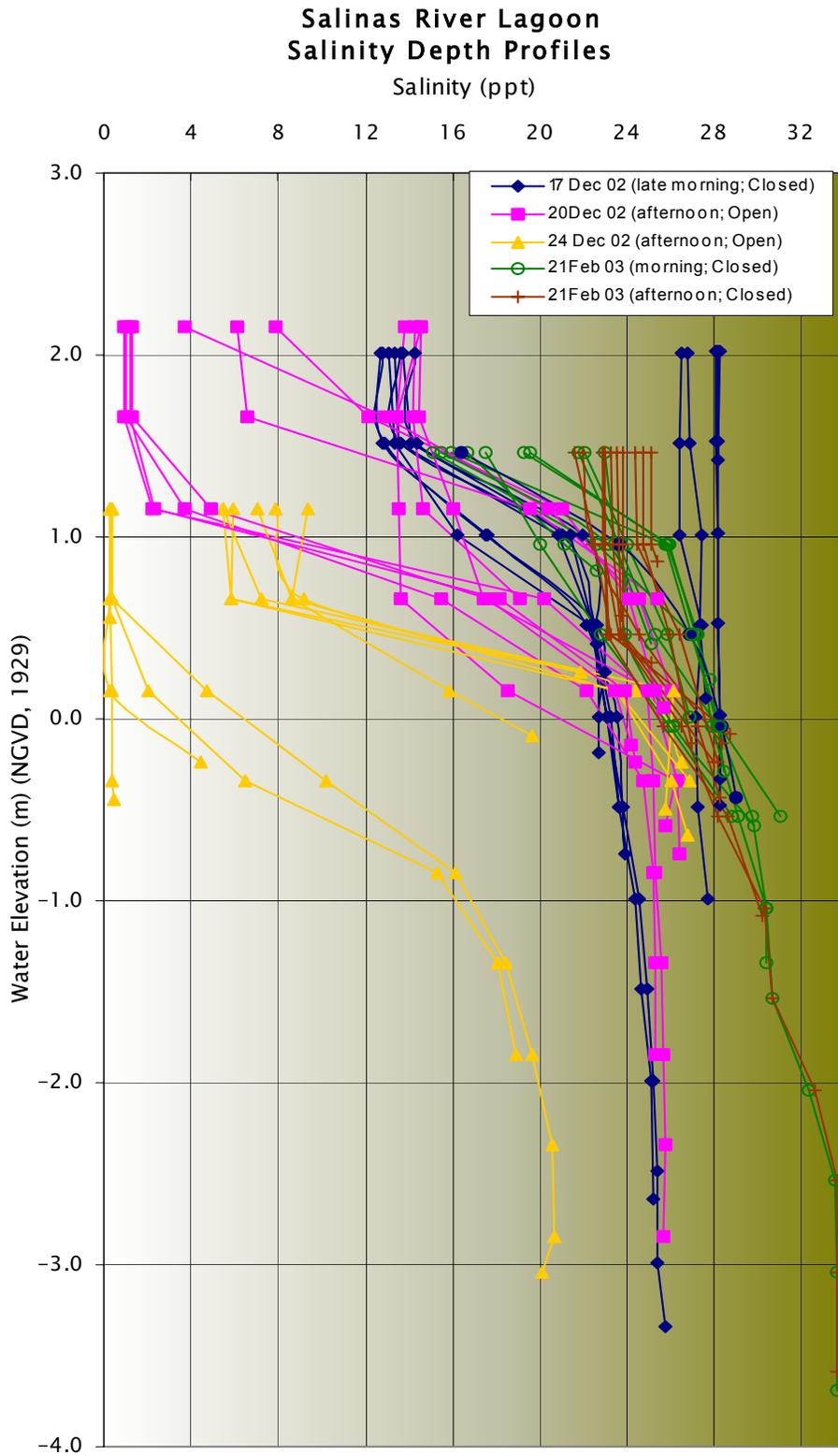


Figure 5.15 Salinity depth profiles from the Salinas Lagoon for all monitoring sessions.

5.6 Water Quality Post Breach

For this section, also refer to Figures 5.13 through 5.15 and Appendix B.

5.6.1 December 20, 2002

After an initial attempt at breaching on the 17th that re-closed at high tide, the Salinas Lagoon was completely breached during the late afternoon of December 18th. Streamflow began entering the lagoon early on the 18th. Water elevation in the lagoon was 2.2 m (7.1 ft) at 13:00 hours. On December 20th, a full monitoring run was conducted in the Salinas Lagoon. Daily mean streamflow at the USGS Spreckels gage was 11.35 m³/s (398 cfs) (Fig. 5.3).

Temperature data indicated that the incoming river water was influencing the surface waters, especially the upper meter, of the lagoon. Temperatures were also cooler than pre-breach temperatures, which was also prior to any incoming river water (Fig. 5.13). Surface temperatures in the upper meter were coolest upstream of the Twin Bridges sites and further downstream, surface waters warmed slightly due to the mixing of incoming ocean water.

Dissolved oxygen concentrations were good and nearly uniform from top to bottom (Fig. 5.14). Surface concentrations were slightly higher at all sites presumably a result of incoming freshwater and intense wind mixing.

Sites at the Twin Bridges area and further upstream had a meter-thick layer of freshwater overriding a strong halocline that reached 25 ppt below 2 m depth (Fig. 5.15). Mid-lagoon sites had slightly brackish water in the upper meter with more saline waters at depth. Near the bar, salinity concentrations were even more brackish at the surface due to the influx of ocean water through the breach corridor. However, at depth, concentrations increased only slightly. Fresh river water was approximately a meter thick, indicated by the upper lagoon profiles. This meter thick current kept salinity concentrations near the mouth moderately brackish by constantly mixing with any incoming seawater.

5.6.2 December 24, 2002

Weather prior to this sampling event had been cold, windy, overcast and rainy at times. Daily mean streamflow had decreased to 7.3 m³/s (258 cfs) (Fig. 5.3). In general, the lagoon showed signs of increasing river influence, with freshening, cooling conditions.

Cool temperatures were observed throughout the lagoon. Since the last monitoring, surface temperatures had decreased a few degrees at all sites. Near the mouth, the site closest to the breach corridor was a degree warmer at the surface presumably due to slightly warmer seawater that was flowing in and out with the waves. Sites near the Twin Bridges and further upstream had the coldest temperatures. Sites at mid-lagoon and near the bar were a few degrees warmer suggesting that seawater mixing was occurring here as well.

Dissolved oxygen concentration profiles were very similar to those measured on the 20th of December, with only slight increases measured in the top meter (Fig. 5.14). This may be explained by further mixing due to stronger winds and a continued river input.

Salinity profiles in the deep-water areas also showed evidence of further mixing and input of fresh river water since the previous sampling (Fig. 5.15). Salinity concentrations in the entire water column had decreased and surface concentrations were < 1 ppt. Further upstream, profiles measured were primarily fresh river water. Downstream near the middle of the lagoon waters were brackish in the upper half meter followed by a strong halocline to depth.

5.7 Water Quality Post Closure

5.7.1 February 21, 2003

The Salinas Lagoon closed on February 18th. Streamflow in the lower Salinas River ceased on the 3rd of February, but probably stopped entering the lagoon several days prior to that. All sites were monitored during both the morning and late afternoon. Morning weather conditions were clear, calm and sunny. The afternoon weather conditions were still clear and sunny but with intense winds that started around noon. Water elevation in the lagoon was 1.46 m (4.8 ft) throughout the day.

Morning surface temperatures were mild at the mid and upper lagoon sites and cold (< 10 °C) near the bar. Temperature profiles in the deep-water sites were slightly stratified with slightly cooler temperatures at the 1–1.5 m depths. At 2.5 m, the temperatures increased slightly followed by cooler temperatures near the bottom. In the afternoon, profiles near the sandbar were significantly warmer at the surface. The deeper water profiles had warmer temperatures than previous monitoring at the 1–2 m depths due to an increase in wind velocities and warmer air temperatures. However, temperatures below 2.5 m showed little change.

Profiles of dissolved oxygen were clinogradic in the deeper areas of the lagoon – with rich oxygen concentrations near the surface followed by a metalimnion that ended with several meters of poorly oxygenated water below. However, no anoxic levels existed at the bottom. Diurnal changes were small and occurred only in the upper 1.5 m of the water column (Fig. 5.14). Surface concentrations of dissolved oxygen were higher further upstream than those measured near the bar.

At this time, any remnant freshwater that existed in the lagoon had left via the Old Salinas Channel or was mixed into the larger volume of trapped saline water. Profiles measured throughout the lagoon indicated that the lagoon was predominantly saline or brackish from top to bottom. Afternoon measurements indicated that the surface waters increased in salinity from measurements taken in the morning. The surface layers were exposed to greater mixing with the

increase in wind velocities in the afternoon, thus raising the surface concentrations slightly and lowering concentrations at bottom of mixing layer.

5.7.2 March Rain Event (March 16, 18, 19, 20, 21, 22 & 24, 31, 2003)

For this section, refer to Figures 5.16 through 5.18.

In years with normal runoff, the sandbar at the river's mouth reforms after the river's flow and ocean wave height subsides in late spring. The remaining minimal flows, although too weak to keep the mouth open, provide the lagoon with a critical source of freshwater for the remainder of the year; additionally summer agricultural return water from the Blanco Drain adds a small amount of fresh water. As a result, in spring and summer the lagoon is usually heavily stratified with a thick freshwater layer in the upper meters overriding a smaller saline layer at depth (Casagrande et. al., 2002). The freshwater layers provide important habitat for native fish species including hitch, Sacramento sucker, Sacramento pikeminnow, and Sacramento blackfish (Habitat Restoration Group et al., 1992).

This year the sandbar reformed in mid February and the lagoon was primarily a saline environment. After January 20th freshwater inputs to the lagoon were minimal and any fresh water that existed in the lagoon at this time was allowed to escape to the ocean. By February 5th the lagoon was almost entirely saline. Measurements taken on 21st of February (after the lagoon closed) confirmed that the lagoon was an entirely saline or brackish environment (Fig. 5.15). Once the lagoon closed, the staff at MCWRA reopened the slide gates to the Old Salinas Channel.

However, on March 13th, much of coastal California experienced a late winter storm that produced significant runoff in the Salinas Watershed. Peak streamflow measured at the Spreckels gage during this event was 4.9 m³/s (172 cfs) at 13:30 hours on the 20th of March and remained at or near that level for a period of a few days.

This section describes intense monitoring and assessment of the rate of change from a predominantly saline lagoon environment to a more freshwater environment with the addition of freshwater from the Salinas River. Profiles were taken on several days – all are listed along with their respective weather conditions in Table 5.2.

The legend in Figure 5.18 shows the real-time streamflow at the USGS Spreckels gage as well as the presence of strong winds. Changes in lagoon water elevations indicated that river water began entering the lagoon on the 19th.

Temperature readings in the upper meters of the water column varied depending on the time of day and the amount of river water entering the lagoon. Profiles measured on March 18th at 10:45 hours (calm) and 16:45 hours (windy) suggest that strong winds and the turbulence associated with them significantly mixed the upper two meters of the water column as they warmed during the day. However, all profiles indicated that temperatures remained constant near the bottom suggesting that mixing did not occur to this depth. The days prior to the March 31st profile were clear and warm with a slight breeze. Temperatures increased significantly at all depths down to 3 meters due to the recent increase in solar heating. Temperatures at the bottom still showed no change.

Table 5.2 This table lists dates and weather conditions for all surface-to-depth profiles taken immediately following the March rain event. All profiles were taken from the upstream side of the Del Monte Road Bridge, approximately 50 m from the southern end of the Bridge.

Sand Bar Condition	Events	Weather Condition
Closed	16 Mar 03 12:00	CL, S, B
Closed	18 Mar 03 10:45	CL, S, B
Closed	18 Mar 03 13:45	CL, S, W
Closed	18 Mar 03 16:45	CL, S, W
Closed	19 Mar 03 09:35	CL, S, B
Closed	20 Mar 03 10:00	CL, S, B
Closed	21 Mar 03 10:00	CL, S, B
Closed	22 Mar 03 12:20	CL, S, W
Closed	24 Mar 03 14:45	CL, S, W
Closed	31 Mar 03 12:50	PC, S, B
General Weather Conditions		
R = Raining	C = Calm	CL = Clear
S = Sunny	W = Windy	PC = Partly Cloudy
L = Lightning	B = Breeze	CO = Cloudy
		H = Hot (extreme)
		CD = Cold (extreme)

Salinas Lagoon Temperature Depth Profiles March Rain Event: Post Closure

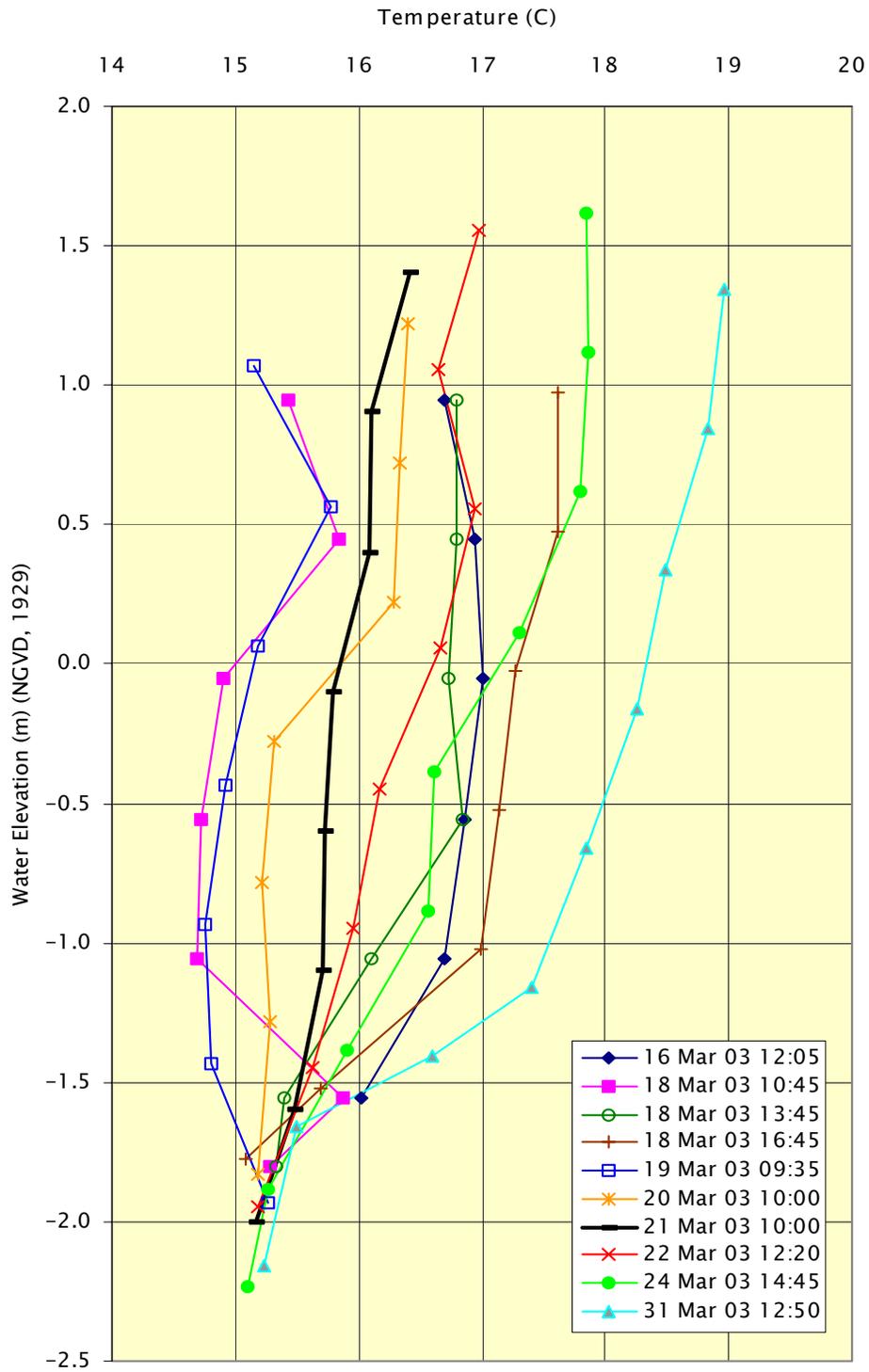


Figure 5.16 Temperature profiles collected during the rising hydrograph following the mid March rain event.

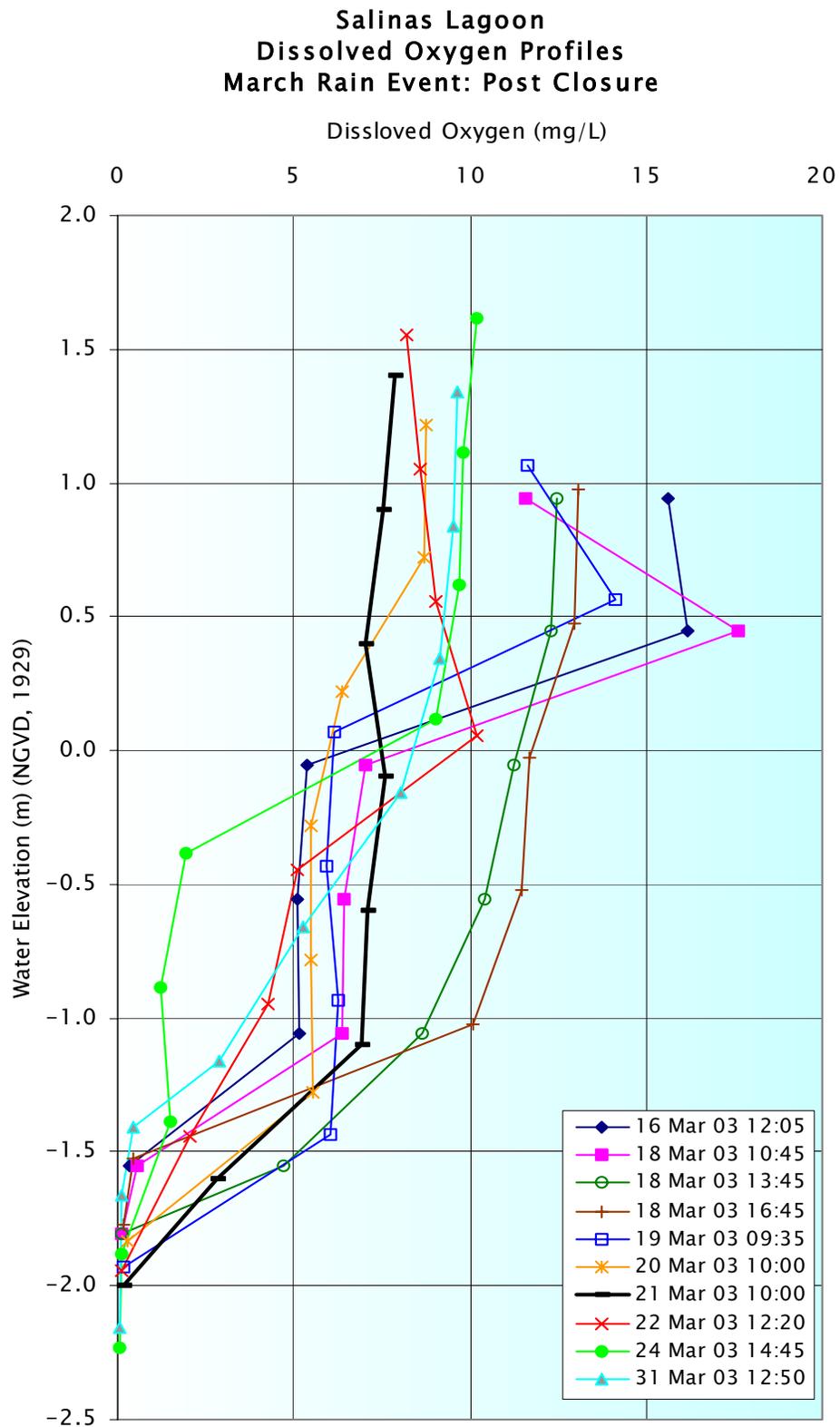


Figure 5.17 Dissolved oxygen profiles collected during the rising hydrograph following the mid March rain event.

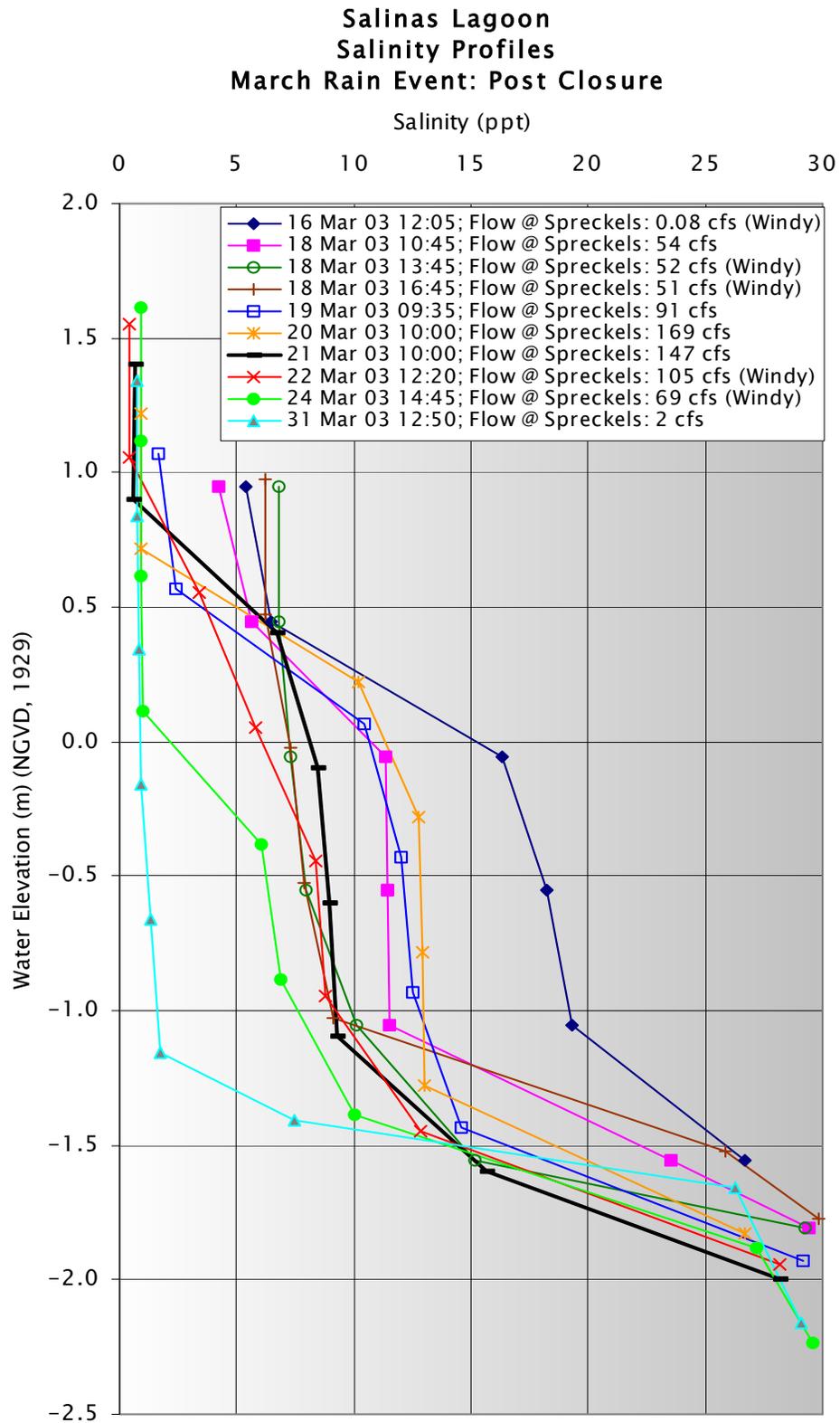


Figure 5.18 Salinity profiles collected during the rising hydrograph following the mid March rain event.

At the surface (March 16th & 18th), calm stratified conditions with no incoming streamflow seemed to have created preferred conditions for photosynthetic production. The presence of anoxic conditions at depth in all profiles also indicates that mixing did not occur to depth. A secchi disk reading at 10:45 hours on the 18th was only 0.35 m and reached a peak of 0.5 m at 13:35 hours. A profile taken at 16:45 hours also indicated that afternoon wind mixing diluted the higher surface DO down to approximately 2 m depth. The arrival of turbid river water caused a reduction in light penetration. Secchi disk readings after this date did not exceed 0.20 m. On March 31st DO concentrations showed moderate increases below 1 m as well as increased secchi disk readings of 0.5 m.

On days where photosynthesis is high, the highest concentration of dissolved oxygen is at the 0.5 m depth with slightly lower concentrations at the very surface. This is most likely because the high dissolved oxygen is causing supersaturation of oxygen, which is able to de-gas (volatilize) at the surface but can only move away from deeper layers by turbulent diffusion – a slower process.

On March 16th the lagoon surface was still brackish, although salt concentrations decreased significantly since February 21 (Figs 5.15 & 5.18). As river water started to enter the lagoon (March 19th), the lagoon volume began to gradually increase. The first changes in salinity concentration occurred at the surface as the freshwater layer slowly grew (March 19th). As streamflow inputs increased the freshwater layer began to expand to deeper depths (March 21st). Finally, after nearly two weeks of incoming streamflow, the lagoon was predominantly fresh except for the deepest layers at the bottom (March 31st). This is generally thought to be good for freshwater fish species (i.e. Sacramento suckers) that use the deeper, yet less productive waters of the lagoon during the spring and summer months.

6 Habitat Relations

6.1 Schematic Diagrams

The spatial dynamics of physical water quality parameters between 2002 & 2003 for both lagoons are summarized in Figures 6.1 to 6.4. These diagrams provide a schematic illustration of the various habitats within each lagoon just prior to breaching, after breaching and just after the sandbars had reformed.

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 pre-breach and post-closure diagrams, the sand bar is drawn at full height. The post-breach diagram shows a lowered sand bar, allowing for a clear passage to the ocean.

The Salinas Lagoon is a more linear feature, with no off line habitats. The main deep-water habitat, the sump beneath the bridges (shown), is in the direct line of streamflow. As with the Carmel Lagoon, tall riparian trees line the lagoon along the inland portions, but the 2700 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 bottom 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. Lagoon average secchi depth is depicted with a thin red line.

Based on the above parameters, water depth, presence of cover, secchi depth and difficulty of predator access (illustrated using symbols for birds and pinnipeds), local habitat optimality for steelhead smolts is indicated. Fish icons are used to indicate the locations of preferred habitats where steelhead smolts are most likely to occur based on the present data. 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 HES (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 10 ppt, and cover is provided either by deep water, vegetation, or shallow secchi depth all of which provides cover from avian predators. These numbers are meant to be broad indications of habitat suitability, approximating the values reported by Pennell and Barton (1996), Alley (1997), and Dettman (1984). In cases where such 'suitable' habitats do not exist, no smolt symbols are placed in the diagram(s).

Three stages of lagoon dynamics are illustrated: *Pre-breach*, *Post-breach*, and *Post-closure* of the lagoons. An additional diagram is included illustrating the conversion of a saline lagoon to a more fresh lagoon following a March runoff event. For both lagoons, the *Pre-breach* conditions were drawn from surveys conducted hours prior to breaching (Carmel: December 15th; Salinas: December 17th). *Post-breach* conditions for the Carmel Lagoon were drawn from monitoring conducted on December 20th and *Post-breach* for the Salinas Lagoon was drawn from monitoring done on December 24th. *Post-closure* of the Salinas Lagoon was drawn from the monitoring conducted on February 21st.

Seasonal dynamics of southern Monterey Bay lagoons, 2002-2003
 1: Pre-breach conditions

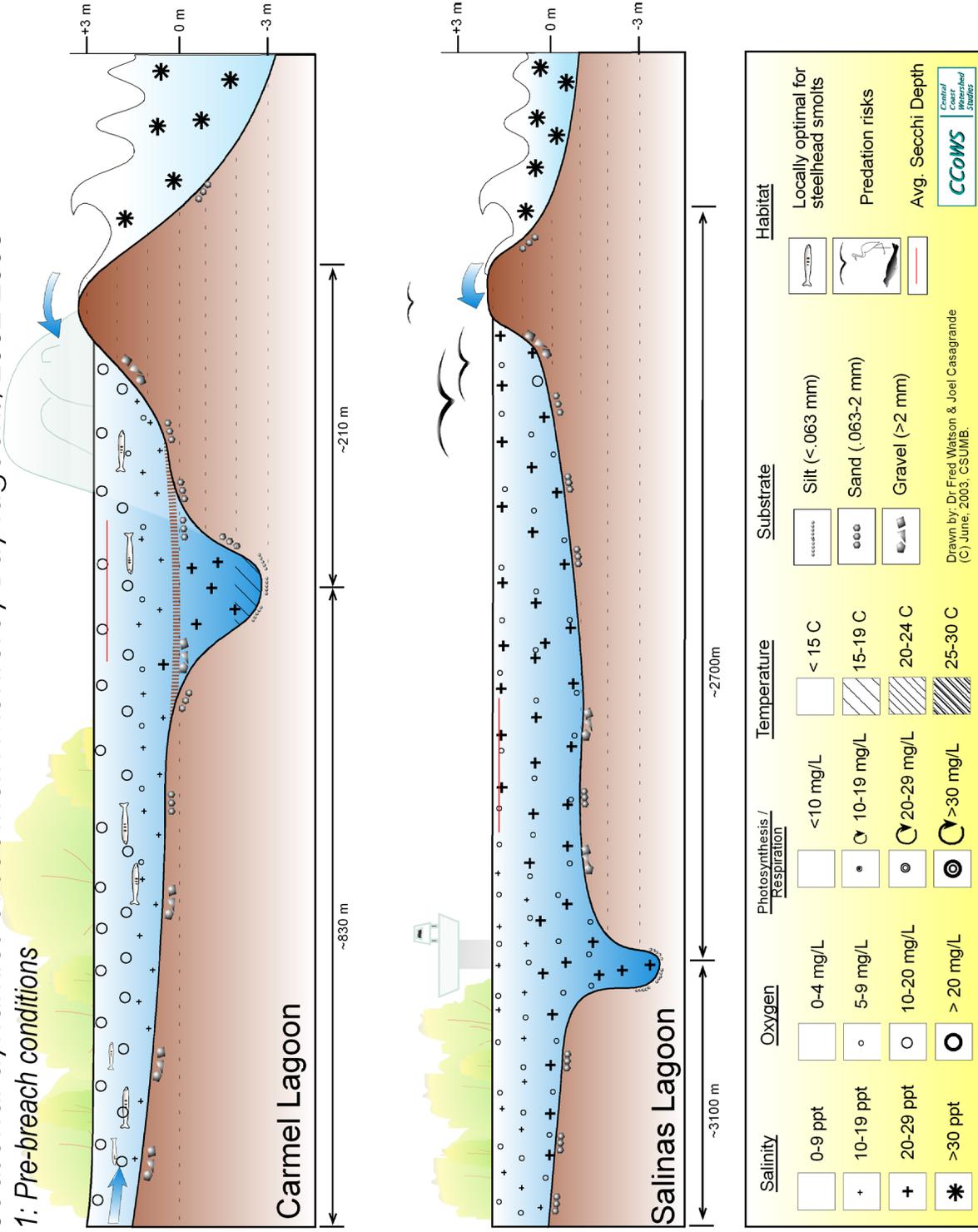


Figure 6.1 Pre-breach conditions of the Carmel and Salinas Lagoons, 2002–2003. Note that secchi depth was only measured in certain areas of the lagoons.

Seasonal dynamics of southern Monterey Bay lagoons, 2002-2003
 2: Post-breach conditions

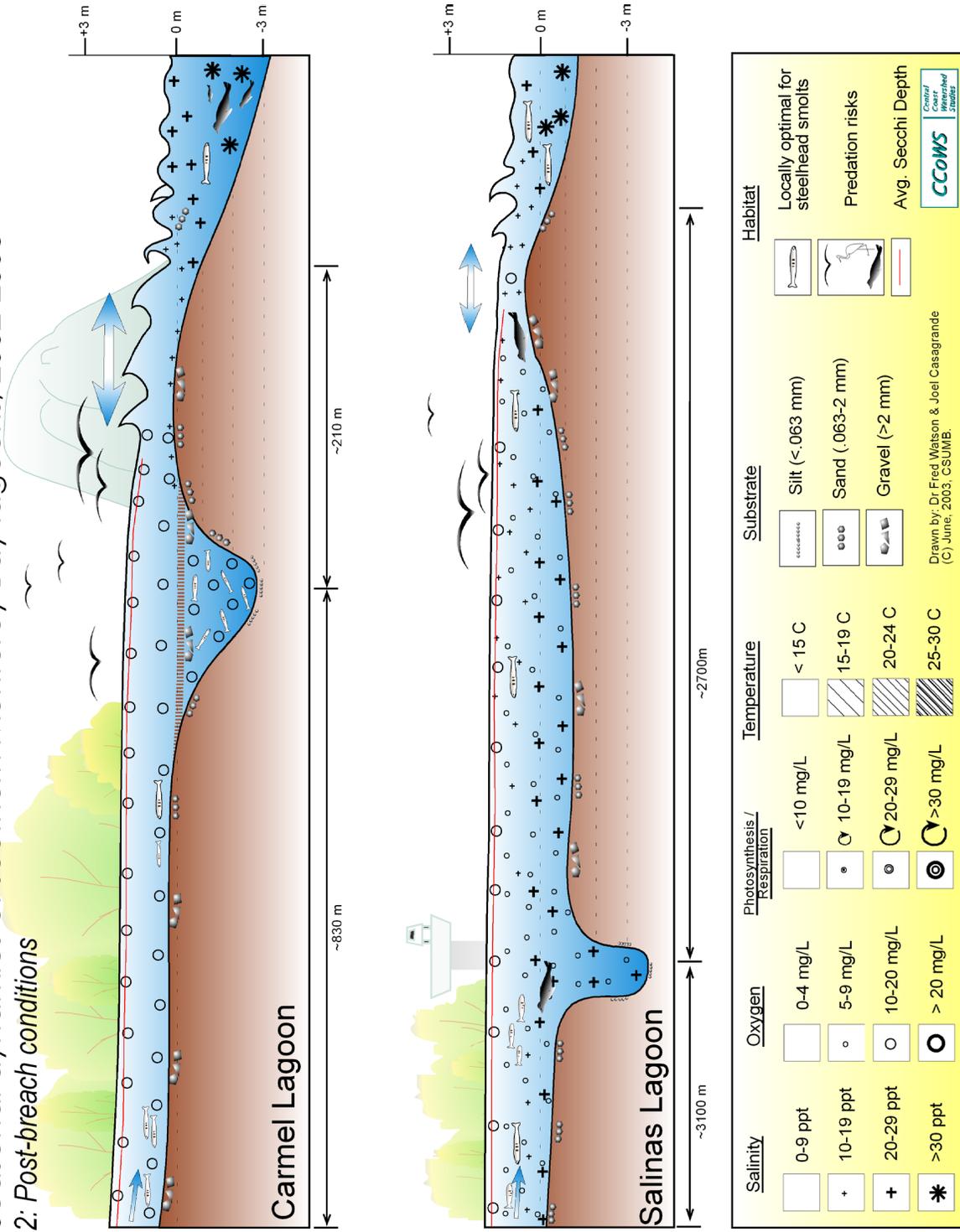


Figure 6.2 Post breach conditions of the Carmel and Salinas Lagoons, 2002-2003.

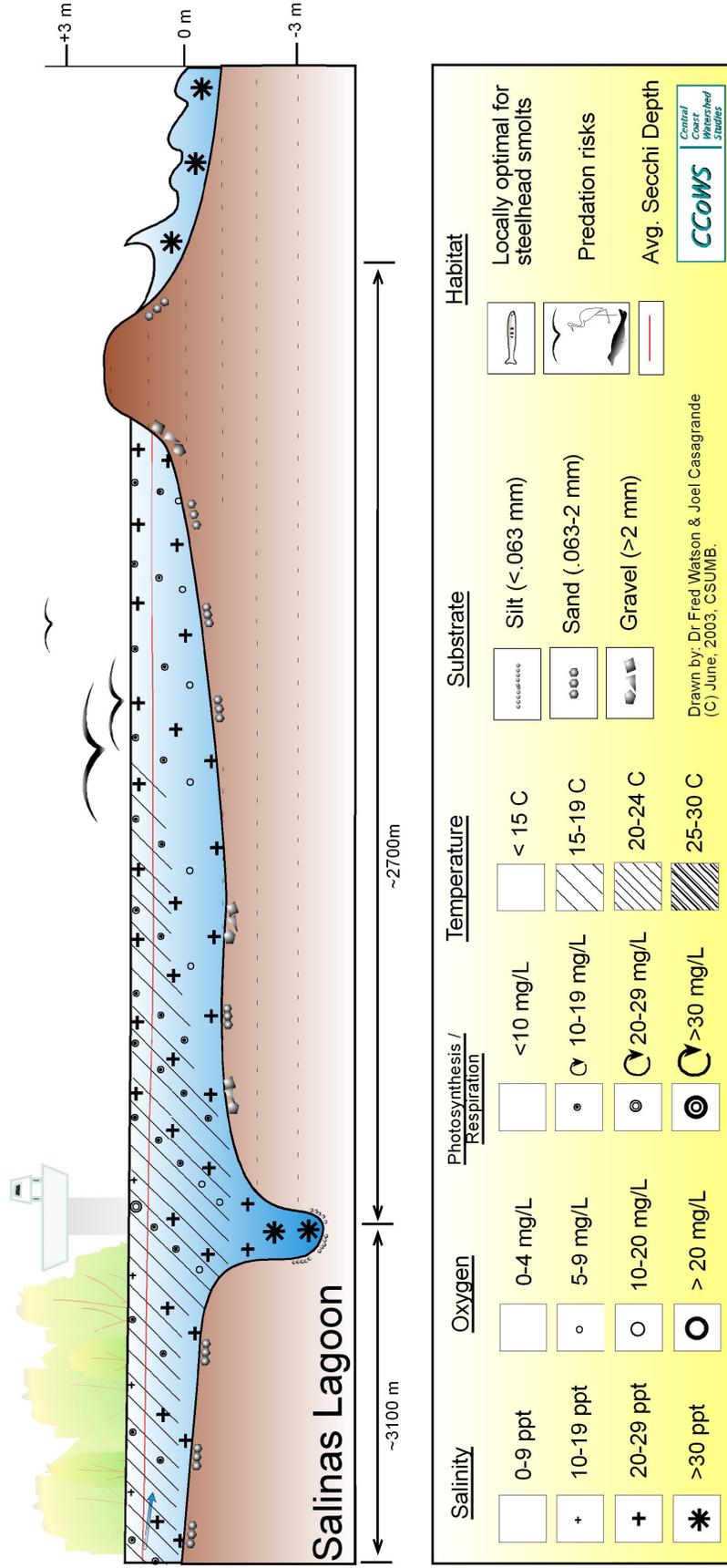
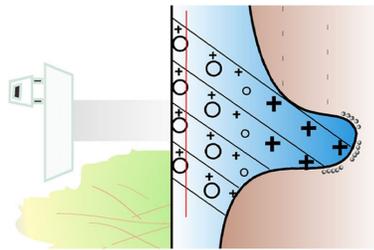


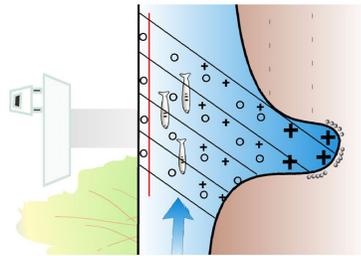
Figure 6.3 Post closure conditions for the Salinas Lagoon, 2002–2003. As of June 23rd, the Carmel Lagoon had not closed; therefore a post-closure schematic was not constructed for the Carmel Lagoon.

Seasonal dynamics of southern Monterey Bay lagoons, 2002-2003 4: Post Closure Salinas Lagoon March Runoff Event

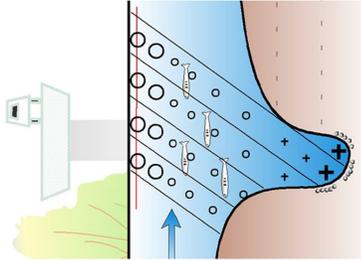
March 16, 2003
(no incoming streamflow)



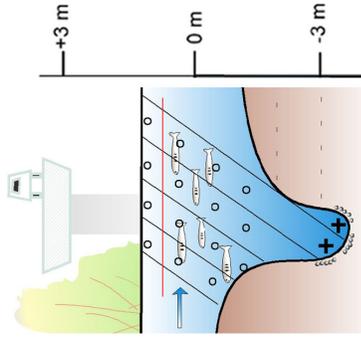
March 20, 2003
(4.8 m³/s; 169 cfs @ Spreckels)



March 24, 2003
(2 m³/s; 69 cfs @ Spreckels)



March 31, 2003
(0.05 m³/s; 2 cfs @ Spreckels)



Salinity	Oxygen	Photosynthesis/ Respiration	Temperature	Substrate	Habitat
<input type="checkbox"/> 0-9 ppt	<input type="checkbox"/> 0-4 mg/L	<input type="checkbox"/> none	<input type="checkbox"/> < 15 C	<input type="checkbox"/> Silt (<.063 mm)	<input type="checkbox"/> Locally optimal for steelhead smolts
<input type="checkbox"/> + 10-19 ppt	<input type="checkbox"/> o 5-9 mg/L	<input type="checkbox"/> o 10 mg/L	<input type="checkbox"/> 15-19 C	<input type="checkbox"/> Sand (.063-2 mm)	<input type="checkbox"/> Predation risks
<input type="checkbox"/> + 20-29 ppt	<input type="checkbox"/> O 10-20 mg/L	<input type="checkbox"/> O 20 mg/L	<input type="checkbox"/> 20-24 C	<input type="checkbox"/> Gravel (>2 mm)	<input type="checkbox"/> Avg. Secchi Depth
<input type="checkbox"/> * >30 ppt	<input type="checkbox"/> O > 20 mg/L	<input type="checkbox"/> O 30 mg/L	<input type="checkbox"/> 25-30 C		

Drawn by: Dr. Fred Watson & Joel Casagrande
(C) June, 2003, CSUMB.

Figure 6.4 Water quality conditions and change in the Salinas River Lagoon during a brief March runoff event.

6.2 Habitat Inferences

Pre-breach

Just prior to breaching the Carmel Lagoon, water quality conditions that were locally optimal for steelhead smolt survival existed only in the upper 1.5 m of the water column. However, this suitable habitat was relatively new. Monitoring of the lagoon a few days prior revealed that much of the lagoon was anoxic below 0.5 m and salinity was 13 ppt at the surface. In addition, measurements collected by Hagar Environmental Science throughout the lagoon (HES, 2003 in prep). In the Salinas Lagoon, pre-breach conditions were not suitable for smolt habitat. The lagoon was saline (> 20 ppt at the surface), yet was well oxygenated. Fresher conditions may have existed further upstream near the Blanco Drain outflow, but this area was not surveyed. Both lagoons had experienced significant wave overwash in previous months causing the salinity to increase to near seawater levels.

Once streamflow began entering the Carmel Lagoon, water quality and the amount of available smolt habitat improved significantly. Mixing with cool, incoming streamflow increased dissolved oxygen at depth and decreased temperatures throughout. The incoming river water also diluted the salinity.

Post-breach

The Salinas Lagoon was breached just hours after streamflow began entering the lagoon therefore the high water period was very brief. For both lagoons, water quality was measured within days of their respective breaching. In the Carmel Lagoon, fresh, cool, and well-oxygenated conditions were found throughout. Optimum smolt habitat existed throughout the lagoon, but especially in the South Arm. Smith (1990) stated that both growth and survival of steelhead in lagoons located in Santa Cruz County, were better when the lagoons were open to full tidal mixing or unstratified freshwater conditions. In the South Arm, juvenile steelhead are able to take advantage of the tidal mixing while staying out of the faster and more fatiguing river currents. HES (2002) showed that steelhead smolts captured and marked in the central portion of the Carmel Lagoon prior to breaching were re-captured in the South Arm after the breaching of the sandbar.

In the Salinas Lagoon, salinity concentrations in the bottom half of the water column remained above 20 ppt, thus excluding much of the deep-water refuge. The upper 1.5 m of the water column was cool, fresh, and well oxygenated, ultimately the best habitat available for any smolts that may have been in the lagoon.

During the past three years of monitoring post-breach conditions in both the Carmel and Salinas Lagoons, it is evident from salinity profiles that the Salinas Lagoon does not mix from top to bottom during average and below average runoff years. This suggests that complete mixing of the deeper waters in the Salinas Lagoon must require larger volumes and velocities of incoming streamflow to completely mix. Other factors may include the longitudinal distance between the lagoon's deepest sump and the ocean, as well as the beach slope. In the Salinas, the deep sump under the Twin Bridges is approximately 2700 m from the ocean and therefore this distance may be enough to prevent significant mixing at depth during a breach event. At the Carmel Lagoon the beach is relatively steep, formed by larger and steeper near-shore waves common in Carmel Bay. Conversely, the beach at the Salinas Lagoon is broad and shallow and waves generally break further off shore. A steeper beach will result in a faster and more violent exit of the accumulated lagoon water. Because of this, the Salinas Lagoon drains much slower and with less power than the Carmel Lagoon. It is possible that the turbulence associated with a more powerful exit of water could cause well-mixed conditions from top to bottom.

Post-closure

The available habitat in the Salinas Lagoon decreased as incoming streamflows diminished. When the lagoon closed in mid-February, the salinity concentrations had reached 20 ppt at the surface downstream of the Twin Bridges, although temperature and dissolved oxygen concentrations were adequate throughout. In March, a series of storms added freshwater to the lagoon resulting in an increase in habitat availability. By the end of the month, fresh streamflow had pushed much of the salt out of the lagoon, which broke up the stratified water column caused by density differences. Had these storms not produced significant runoff into the Salinas Lagoon, it is possible that the lagoon could have remained brackish or heavily stratified, with only a small freshwater lens at

the surface. If the water column remains stratified by water density, it becomes more difficult to mix (Smith, 1990). This can result in the maintenance of warm, anoxic conditions in deeper, stable layers.

As of June 19th, the Carmel Lagoon had not closed. Since breaching, the streamflow entering the lagoon has ultimately subsided with a few brief periods of increased streamflow – See Fig. 4.4. The open sandbar allowed tidal waters to move in and out of the lagoon, thus allowing the salinity to fluctuate as well. Mixing associated with incoming river water decreases as the flows subsided, but windy conditions, common along the coast, generally keep dissolved oxygen concentrations within tolerable levels. If the sandbar closes before the streamflow stops entering the lagoon, summer conditions should be similar to conditions found in the 2002 summer (Casagrande et al., 2002). These conditions were relatively cool, well oxygenated and fresh except for the very bottom of the deeper South Arm. However, if the streamflow entering the lagoon ceases and high tides, larger ocean waves, or human disturbances keep the sandbar open throughout most of the summer, this could lead to a fluctuating saline lagoon with very little habitat for steelhead smolts.

7 Lagoon Database

A Microsoft Access database was constructed for all known published water quality data for the Carmel and Salinas River Lagoons. Figure 7.1 is an example of the data entry form, which consists of a series of connected sub-forms. Each form corresponds to an individual table within a relational database structure. Figure 7.2 the relationship between the tables. The database is a working product. Its structure will be improved from time to time.

7.1 Database Structure

The main data entry form shown in Figure 7.1 consists of five sub-forms. The first sub-form (the gray area in Fig. 7.1) contains only the lagoon names and their respective codes, or abbreviations. The next sub-form is for General Data (light green). Here, all general information about the actual monitoring event is noted. These data include:

- Field Leader (Who collected the data)
- Pub Code (The source publication for the data; e.g. Casagrande et al., 2002)
- Date Time (The date and time of the visit)
- Stage (m)
- Breach Open? (Was the sandbar open?)
- Out Gate Open? (Salinas Lagoon Only - was the outlet gate open or not?)
- Notes (Any general observations)
- Air Temp (°C)
- Inflow (m³/s) (Nearest gaged flow for that visit time)
- Wind Speed (m/s)
- Weather Code (e.g. W, PC = W, windy PC, partly cloudy)
- Fish Notes (Fish species observations)

Microsoft Access - [frmLagoons]

File Edit View Insert Format Records Tools Window Help

MS Sans Serif 8 B I U

LagoonCode: SAL LagoonName: Salinas Lagoon

General lagoon data for each visit

FieldLeader: Joel Casagrande Notes: Lagoon closed on Feb 18th. Dead beaver found 100 m ds of Twin Bridges

PubCode: CASAG3

DateTime: 21-Feb-2003 4:12:00 PM AirTemp (C):

Stage (m): 1.46 Inflow (m3/day): WeatherCode: CL S.W

BreachOpen: OutGateOpen: Wind (m/s): FishNotes:

Record: 31 of 42

Sites in this lagoon

Depth profiles taken at different times at this site

GeneralDateTime: 21-Feb-2003 9:31:00 AM

ProfileDateTime: 21-Feb-2003 10:45:00 AM

DepthFr	Elevat	WaterTe	Salinity	DO_mg/L
0	1.46	14.49	19.59	18.35
0.5	0.96	14.04	25.88	15.86
1	0.46	13.19	27.22	10.1
1.5	-0.04	13.22	27.89	7.62
2	-0.54	13.86	29.12	3.42
2.5	-1.04	14.88	30.37	2.68
2.8	-1.34	14.98	30.4	2.68

Record: 7 of 8

Record: 21 of 33

Record: 2 of 2

Form View

Figure 7.1 The data entry form for the CCoWS Lagoon Water Quality Database.

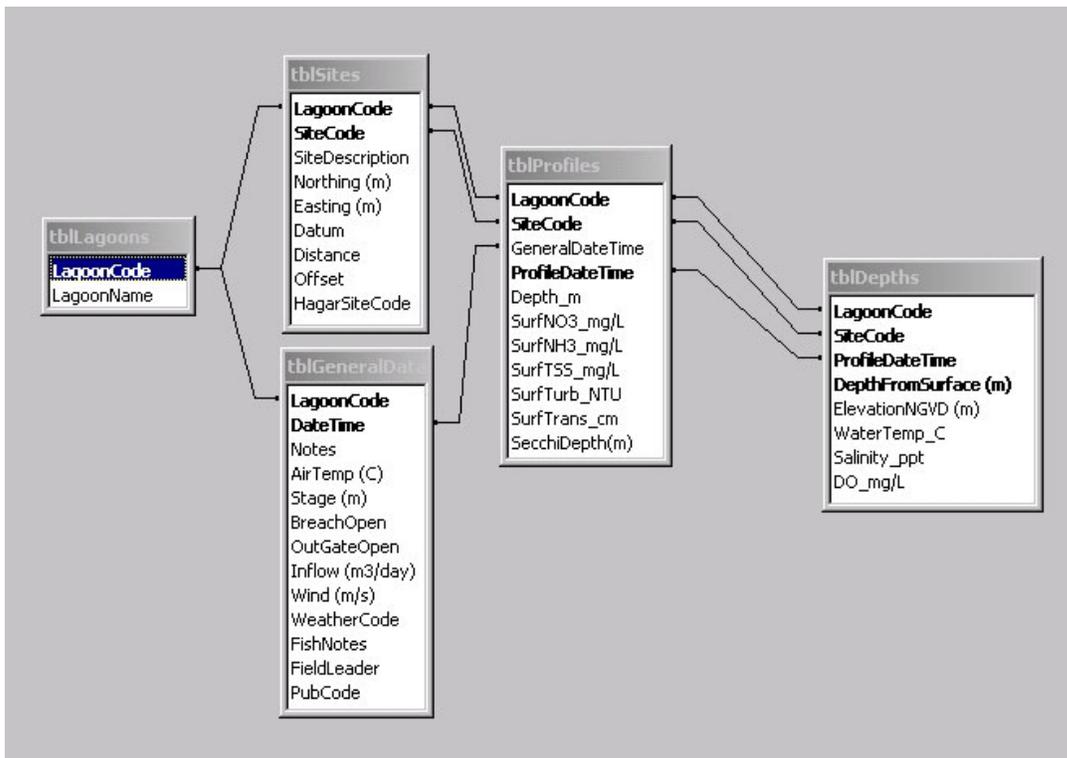


Figure 7.2 Database relationship structure.

Following the General Data sub-form is the Sites sub-form (purple). This is where the general location of a particular surface to depth profile was measured. General locations or zones (Figs 3.1 & 3.2) were created due to the difficulty of returning to an exact location under windy human propelled conditions. Each lagoon was divided into zones of similar habitat type (Figs 3.1 & 3.2). The center point of the zones were determined using GIS and were imported into the database. Anytime a profile was taken within the boundaries of a given zone the site for that zone is selected during data entry. Profile data collected in other studies were only placed in a particular zone if GPS coordinates or a general description could reveal the location of the measurement. When a profile location was unknown, the site code was listed as "UNK" or unknown. Each lagoon has a "UNK" site code for this purpose. The zone codes, a brief description, and the GPS coordinates and datum are shown in the Sites sub-form. The zone codes can also be translated using Figures 3.1 & 3.2.

After the Sites sub-form is the Profiles sub-form. All profile specific data should be entered here. These data include:

- Lagoon Code (linked from Lagoon sub-form)
- Site Code (linked from Site sub-form)
- General Date Time (linked from General Data sub-form)
- Profile Date Time (this would be the actual time when the profile was measured)
- Depth (m) (this is the total depth of the profile in meters at a profile)
- Surf NO₃_mg/L (if a Nitrate concentration was measured at a profile)
- Surf NH₃_mg/L (if an Ammonia concentration was measured at a profile)
- Surf PO₄_mg/L (if a Phosphate concentration was measured at a profile)
- Surf TSS_mg/L (if a Total Suspended Sediment concentration was measured at a profile)
- Surf SSC_mg/L (if a suspended sediment concentration was measured at a profile)
- Surf Turb (if a surface turbidity measurement was taken at a profile)
- Surf Trans (if a transparency measurement was taken at a profile)
- Secchi Depth (m) (secchi disk readings)

The final section is the Depths sub-form. All profile water quality data are entered here. In Figure 7.1, this area is shown in a spreadsheet-like display. Only the following data are noted here:

- Depth (m)
- Elevation (m) NGVD, 1929
- Water Temperature (°C)
- Salinity (ppt)
- Dissolved Oxygen (mg/L)

The database is intended to be a general reference to make it easier to monitor long term changes over time, and to examine spatial patterns such as longitudinal shifts in the halocline.

8 Conclusions

Preamble

The objective of this study was to collect, assess and interpret water quality conditions in the Carmel and Salinas Lagoons surrounding the 2002–03 season breaching events. This was done primarily to evaluate whether or not manual, or artificial, breaching of the lagoons is in any way adversely affecting water quality and ultimately steelhead habitat in the lagoons.

Based on seasonal water quality measurements over the past three years (all normal or average runoff), a seasonal pattern, or cycle, for lagoon water quality dynamics is becoming more clearly understood for the Carmel and Salinas Lagoons. Once the sandbar closes, the lagoons eventually accumulate large volumes of fresh, oxygenated, and relatively cool waters from the receding streamflow.

As summer progresses, stratified conditions begin to form. The bottom–most waters are usually saline, warm and anoxic. By this time, freshwater inputs have ended (except for minimal groundwater exchange) allowing lagoon volumes to begin their dry season decrease due to evaporation and sandbar seepage. In the late summer and fall, when lagoon volumes are usually at their lowest, Pacific Ocean wave heights increase and often result in significant amounts of wave overwash, as well as sandbar seepage, into the lagoons; thus increasing salinity and lagoon volume. By late fall and early winter the lagoons are often brackish and oxygen limited (except for surface waters). The bottoms layers are mostly anoxic and salinity is usually near seawater levels.

After the first severe storm, winter runoff in the Salinas and Carmel Rivers adds freshwater to the lagoons, resulting in a fresher, more oxygenated, and higher volume system. Cooler air temperatures and cooler streamflow associated with winter cause lagoon water temperatures to decrease. The sandbars are usually artificially breached during the first major runoff event that enters, or is predicted to enter, into the lagoon. For a brief period after the sandbar is breached, water temperatures remain cold, adequately oxygenated, and salinity concentrations fluctuate with the tides. These conditions persist as long as fresh

streamflow continues to enter the lagoon and keep the sandbar open. Usually, the sandbars form by the end of spring or early summer and the entire cycle starts again.

There is no well-established baseline against which to compare the effects of artificial breaching events. This is for two reasons: a) the historic conditions are undocumented; and b) major natural breaches have not been monitored.

Historically, prior to substantial groundwater extraction and water storage in reservoirs upstream of the lagoons, the seasonal runoff duration in the Salinas and Carmel rivers was longer and the ensuing dry season was shorter; especially in the Salinas River (See Watson, et al., 2003 for a discussion of hydrologic changes to the Salinas River). One could infer that the dry season water quality and volume would not have been as degraded in historic times.

Conclusion

During the present study, both the Carmel and Salinas Lagoons were artificially breached in order to minimize the risk of flooding of adjacent lands. Both lagoons required at least two separate attempts to successfully induce lagoon drainage to the ocean. The aim of the present work was to analyze changes in water quality surrounding manual breaching of the Salinas and Carmel lagoons in the 2002–3 winter. Before making conclusions regarding this analysis, we briefly note two questions that were beyond the scope of this work.

1. Was a natural breach impending at the time manual breaching was conducted? For both lagoons, the likely answer for the 2002–3 season is 'yes', since the daily stream flow volumes upstream of the lagoons were significantly larger than the lagoon volume itself. A more detailed analysis is beyond the present scope.

2. Would a natural breach have had similar effects to the manual breaches? This remains unknown, chiefly because the extent of lagoon drainage under natural conditions has not been well documented in historic times.

The conclusions below relate to water quality effects only, in isolation from the above considerations.

Aside from the simple fact that breaching results in a reduction of lagoon surface water volume, no negative impacts of the artificial breaching were evident during the present study. Conversely, there may be some evidence to suggest that the breaching of the sandbars may actually have benefited water quality in both lagoons. As observed in the Carmel Lagoon in December 2001, the 2002 artificial breaching of this lagoon caused the water column to completely mix from top to bottom replacing trapped anoxic, saline waters with oxygen-rich fresh water. Mixing also occurred in the Salinas Lagoon although to not as great an extent as in the Carmel Lagoon. It is hypothesized that the Salinas Lagoon would require larger runoff volumes to completely mix the water column.

9 Further work

Understanding of Central Coast lagoons is incomplete. The following is a list of recommended future work that would provide further information for the future management of the Carmel and Salinas lagoons, as well as other Central Coast lagoons.

- More work further up the Salinas Lagoon (i.e. to the Blanco Drain and above). The entire Salinas Lagoon system can extend approximately 8.3 km (5 river miles) up to the Blanco Drain and sometimes as far as 12.5 km (7.5 river miles) to the Blanco Road Bridge. Prior to breaching, water backed up in the lagoon can reach both of these locations. When salinities are high in the “lower” lagoon (area currently studied), fresher water may exist further upstream. A detailed assessment of the longitudinal salinity gradient would be valuable. Figure 9.1 is a preliminary illustration of how this may be achieved. Construction of monthly or even bi-monthly diagrams such as Fig. 9.1 for each parameter (i.e. temperature, dissolved oxygen, and salinity) throughout the entire lagoon system would lead to a better understanding of the habitat availability prior to and following a breaching event,
- Sampling and comparison of benthic and pelagic invertebrate abundance/biomass during different lagoon stages (i.e. pre-breach, post-breach and dry summer conditions). This should also be done spatially, especially in longitudinal gradient,
- Monitoring different breaching tactics (i.e. a southern breach vs. northern breach etc.)
- Add bottom sediment sizes to the database,
- Develop a systematic method for measuring abundance of live and dead photosynthetic biomass in the lagoons. This would lead to a better understanding of dissolved oxygen fluctuations,
- and a predictive simulation modeling of different breaching strategies.

Salinity Gradient, Salinas Lagoon, 2002-2003 Pre-breach (December 17, 2002)

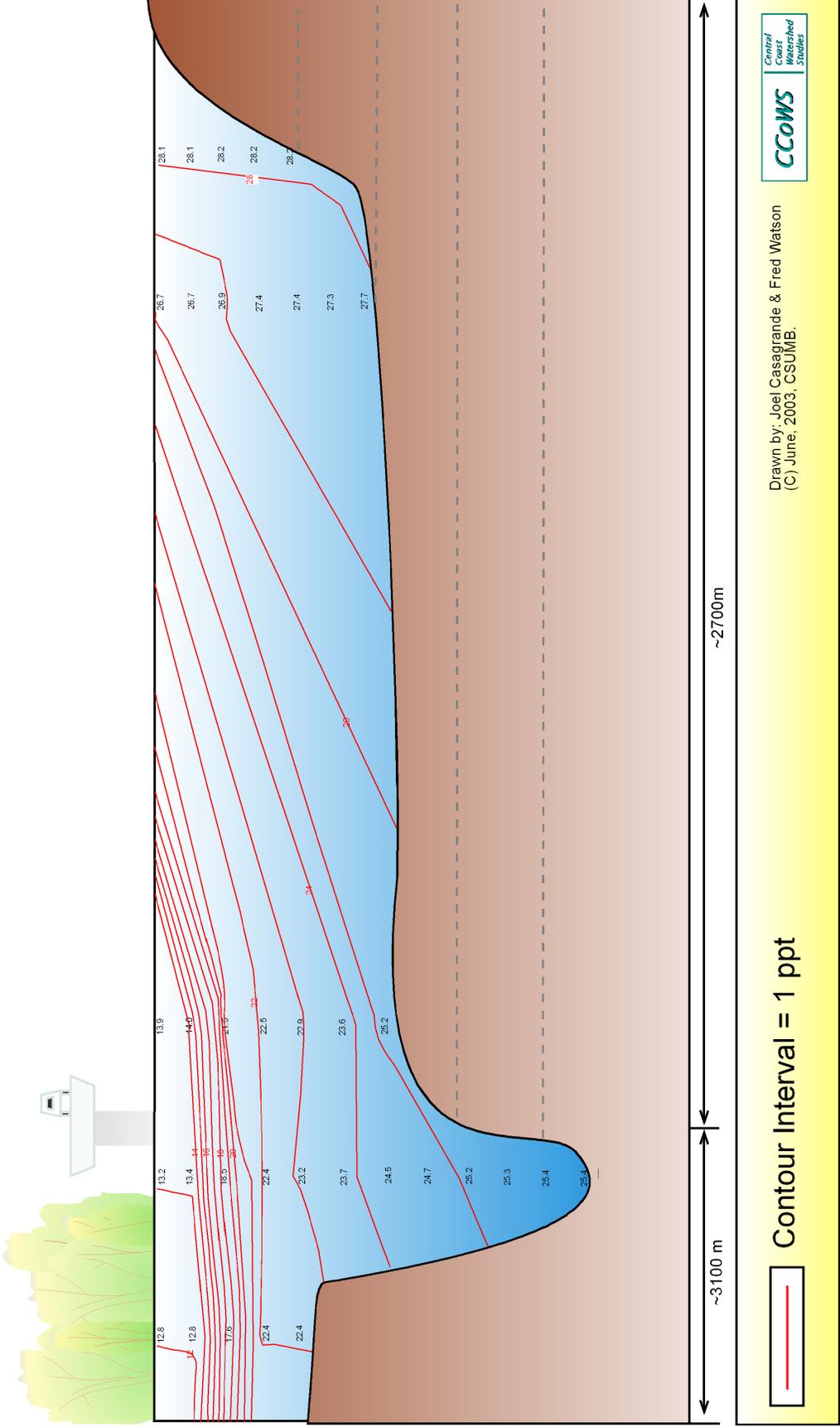


Figure 9.1 Longitudinal salinity gradient in the Salinas River Lagoon prior to breaching.

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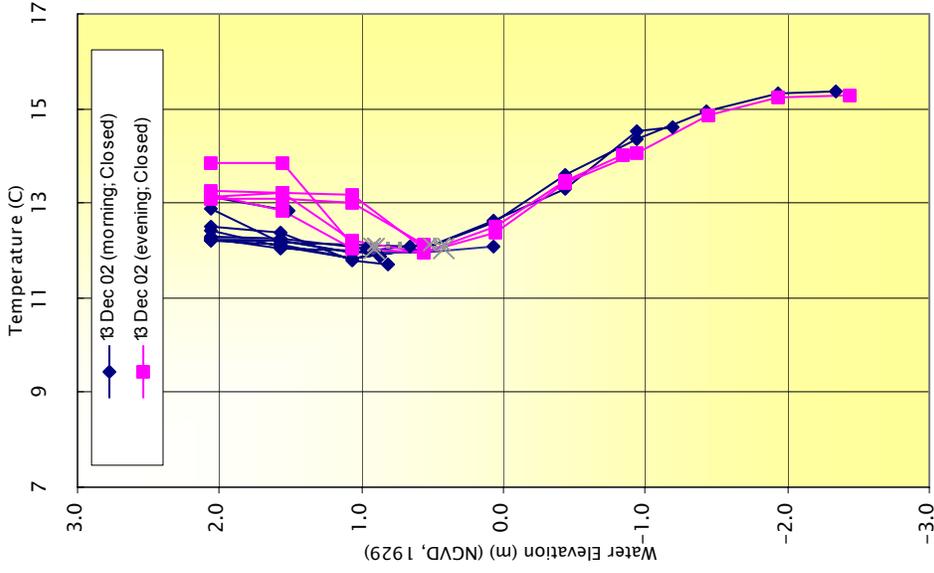
11 Appendix

11.1 Appendix A: Carmel Lagoon Events

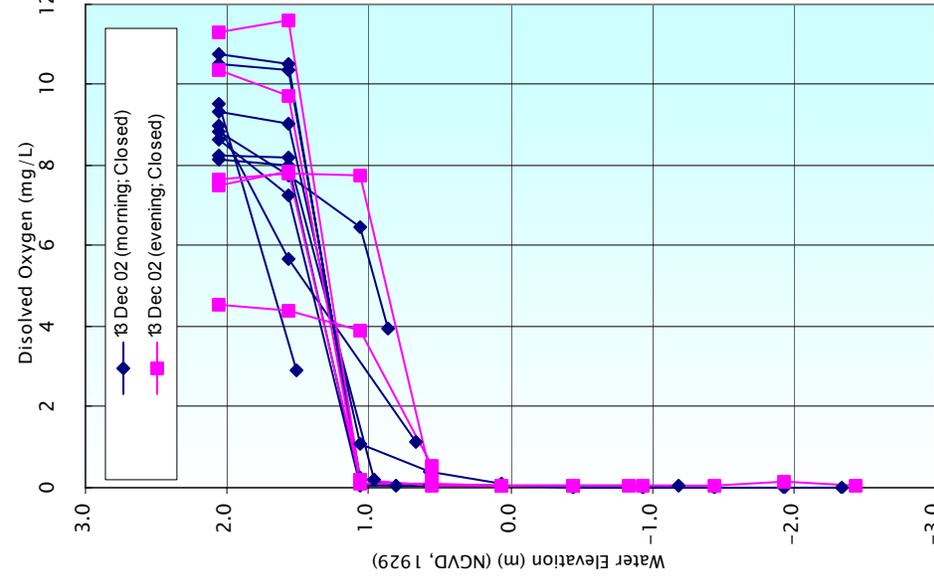
The following figures illustrate, separately, temperature, dissolved oxygen and salinity at several locations in the Carmel Lagoon during each monitoring event.

December 13, 2002

Carmel River Lagoon
Temperature Depth Profiles
December 13, 2002



Carmel River Lagoon
Dissolved Oxygen Profiles
December 13, 2002



Carmel River Lagoon
Salinity Depth Profiles
December 13, 2002

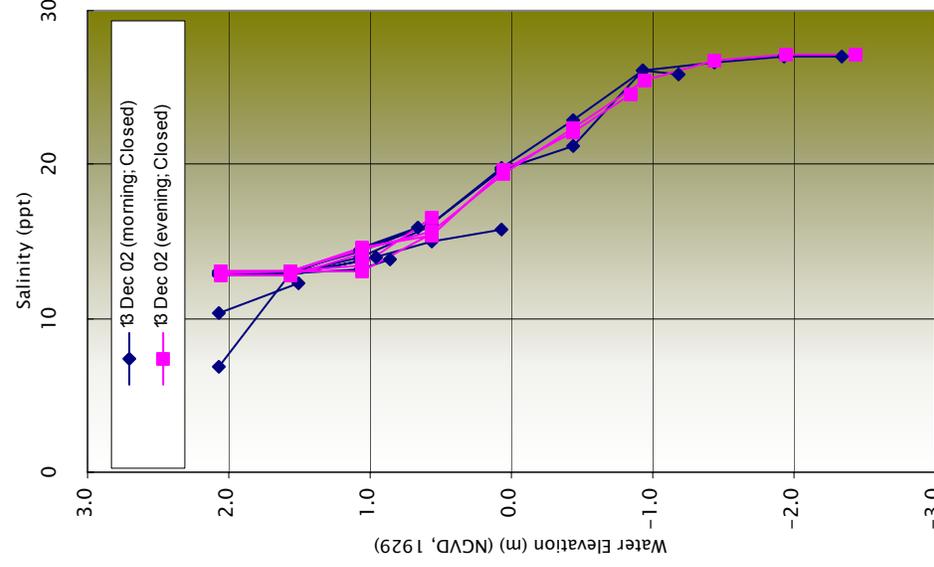


Figure 11.1 Temperature, dissolved oxygen and salinity surface to depth profiles for December 13, 2002, Carmel Lagoon.

December 15, 2002

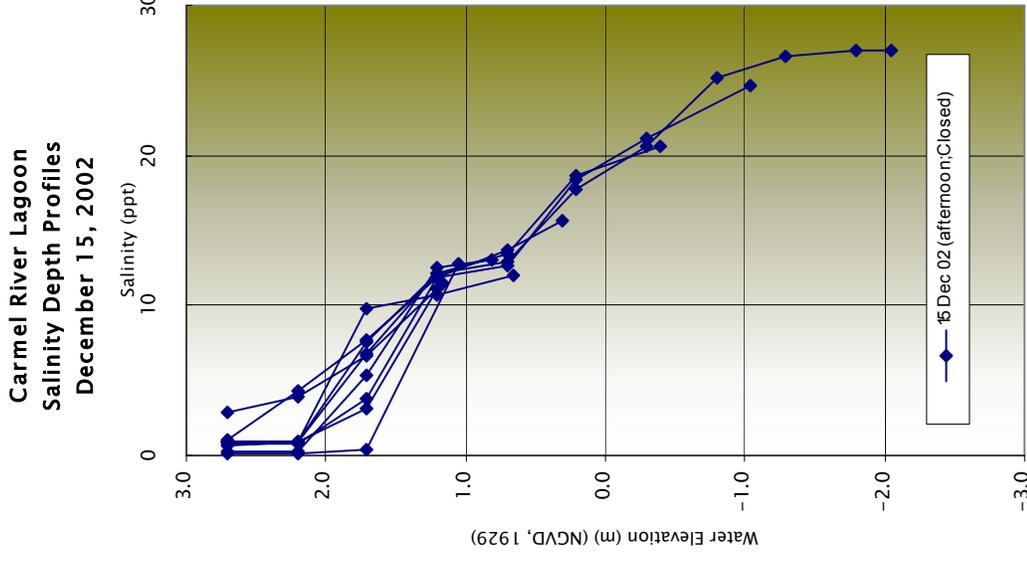
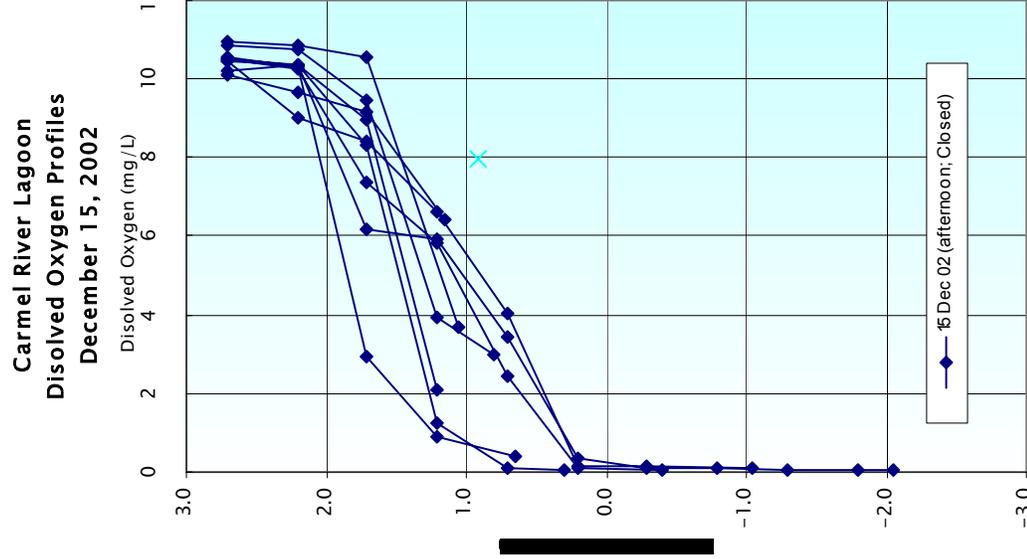
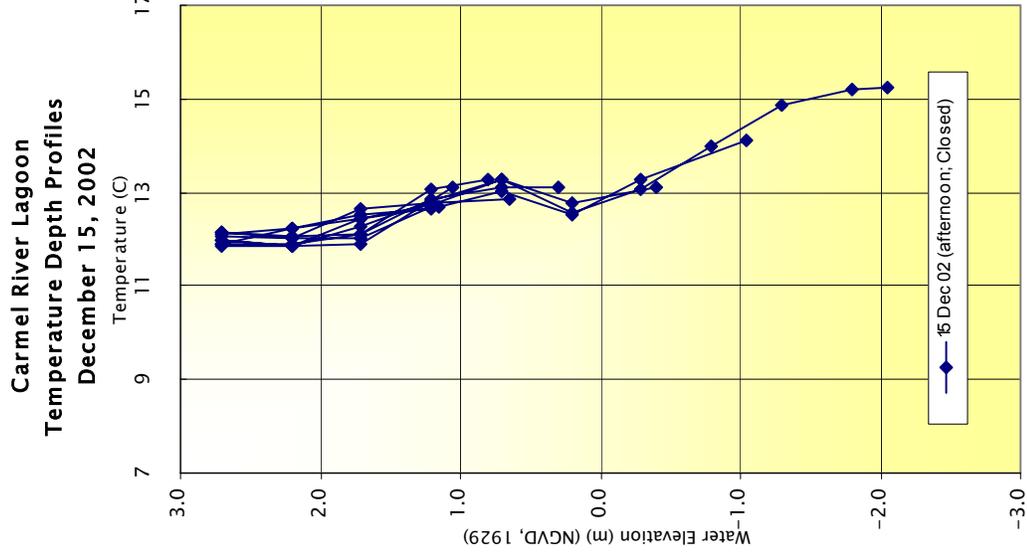
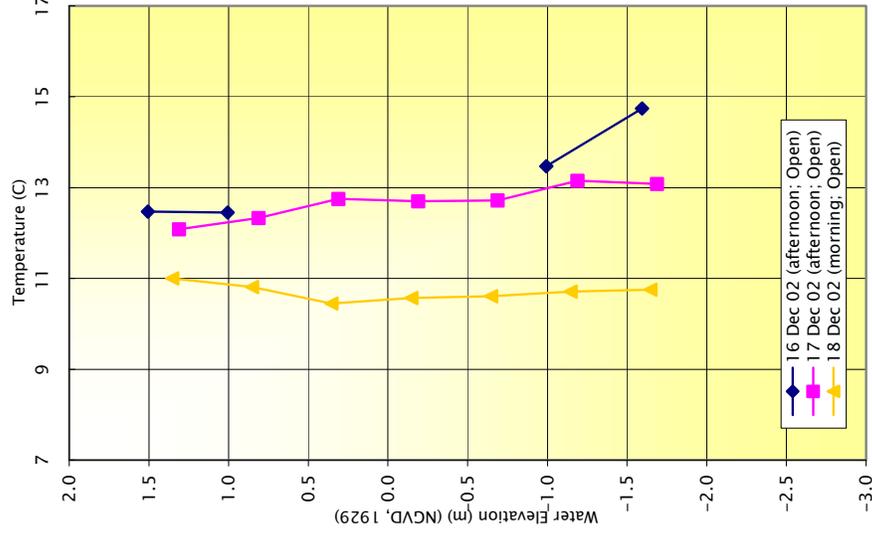


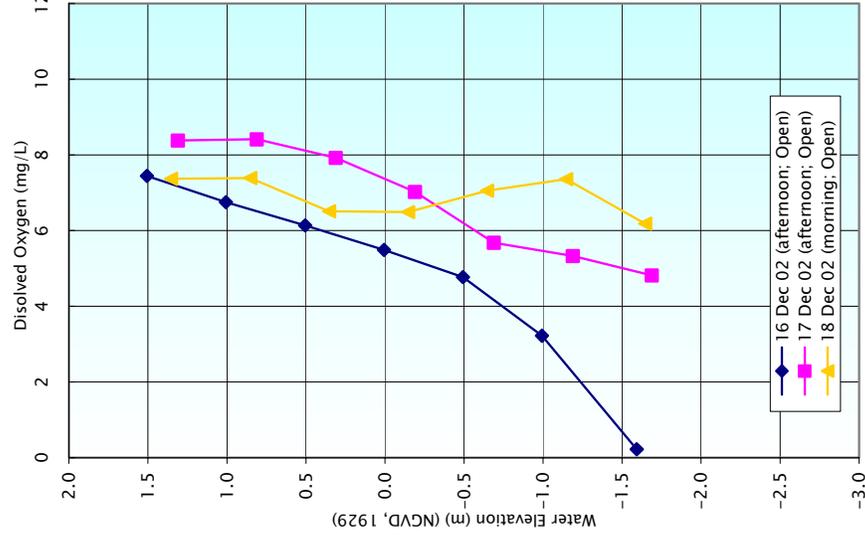
Figure 11.2 Temperature, dissolved oxygen and salinity surface to depth profiles for December 15, 2002, Carmel Lagoon.

December 16, 17, & 18, 2002

Carmel River Lagoon
Temperature Depth Profiles
December 16, 17, & 18, 2002



Carmel River Lagoon
Dissolved Oxygen Profiles
December 16, 17, & 18, 2002



Carmel River Lagoon
Salinity Depth Profiles
December 16, 17, & 18, 2002

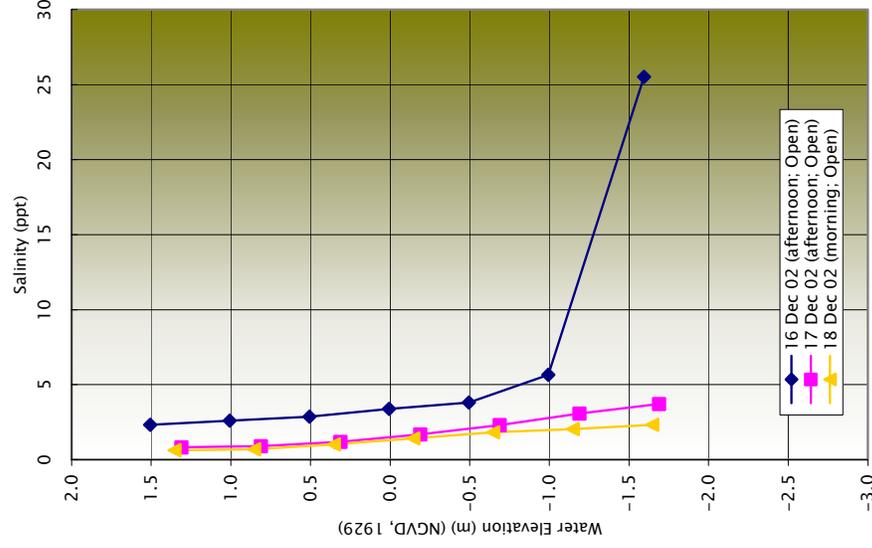
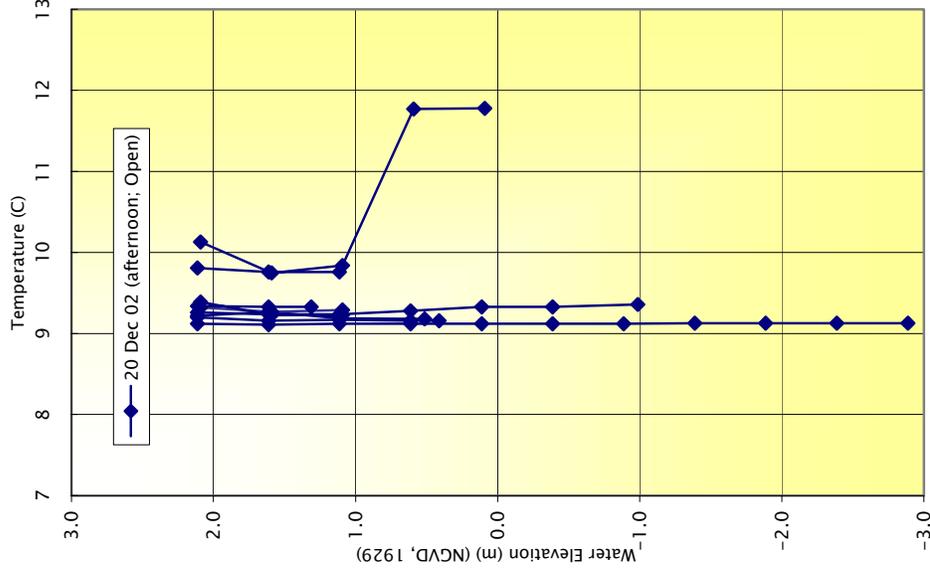


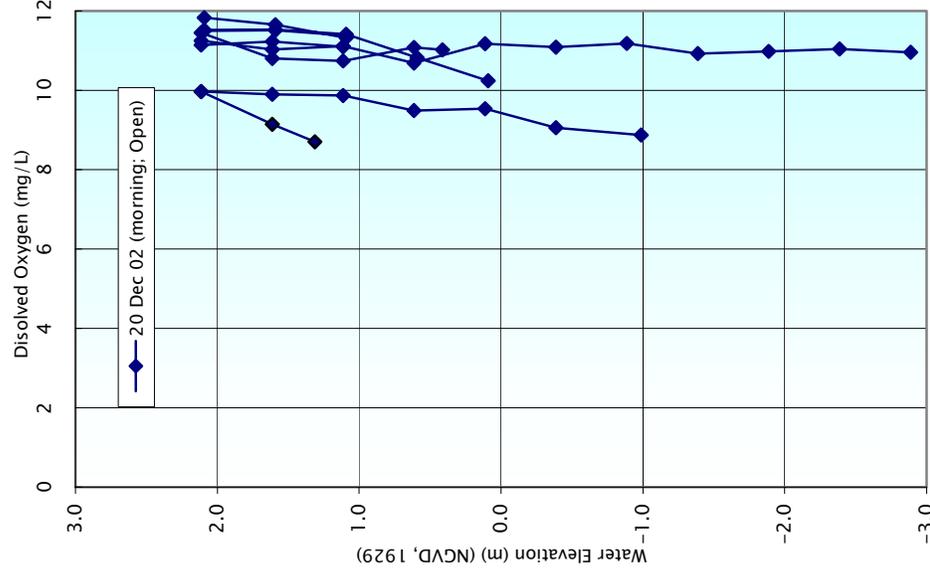
Figure 11.3 Temperature, dissolved oxygen and salinity surface to depth profiles for December 16, 17, & 18, 2002, Carmel Lagoon.

December 20, 2002

Carmel River Lagoon
Temperature Depth Profiles
December 20, 2002



Carmel River Lagoon
Dissolved Oxygen Profiles
December 20, 2002



Carmel River Lagoon
Salinity Depth Profiles
December 20, 2002

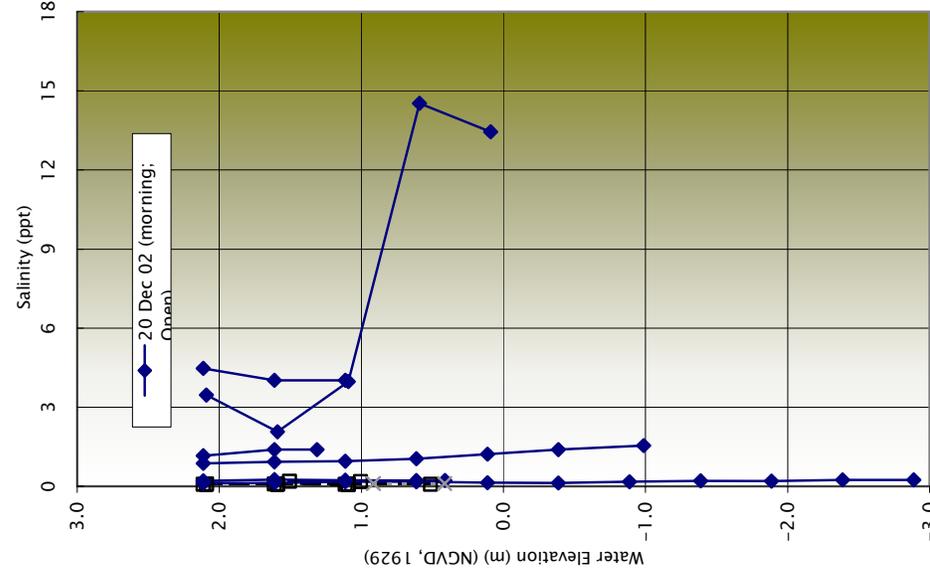


Figure 11.4 Temperature, dissolved oxygen and salinity surface to depth profiles for December 20, 2002, Carmel Lagoon.

February 5 & 24, 2003

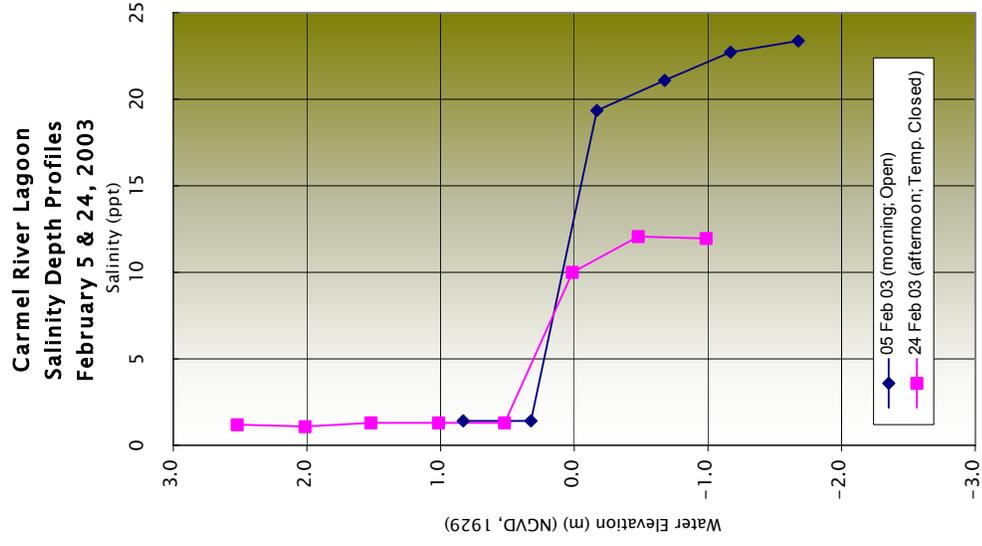
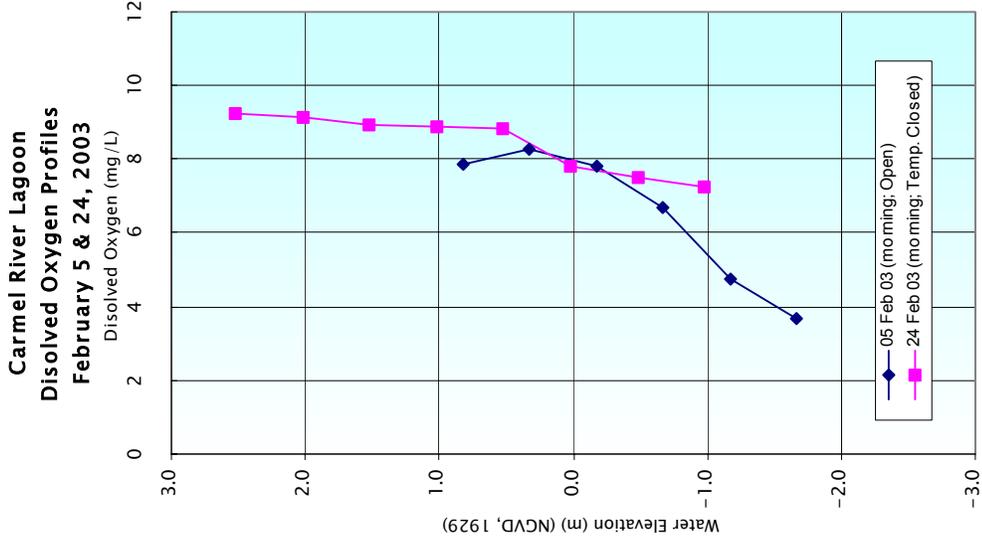
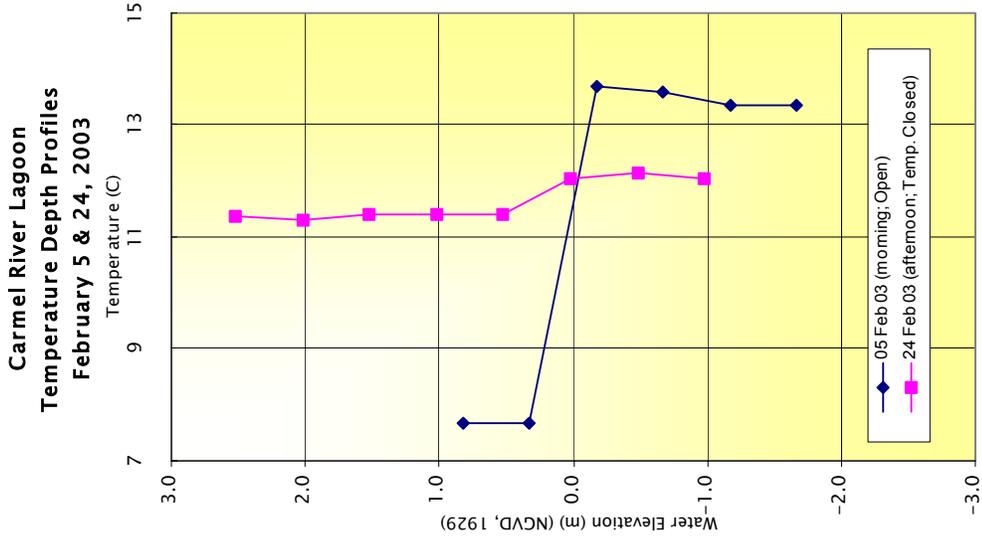


Figure 11.6 Temperature, dissolved oxygen and salinity surface to depth profiles for February 5 & 24, 2003, Carmel Lagoon.

March 5, 2003

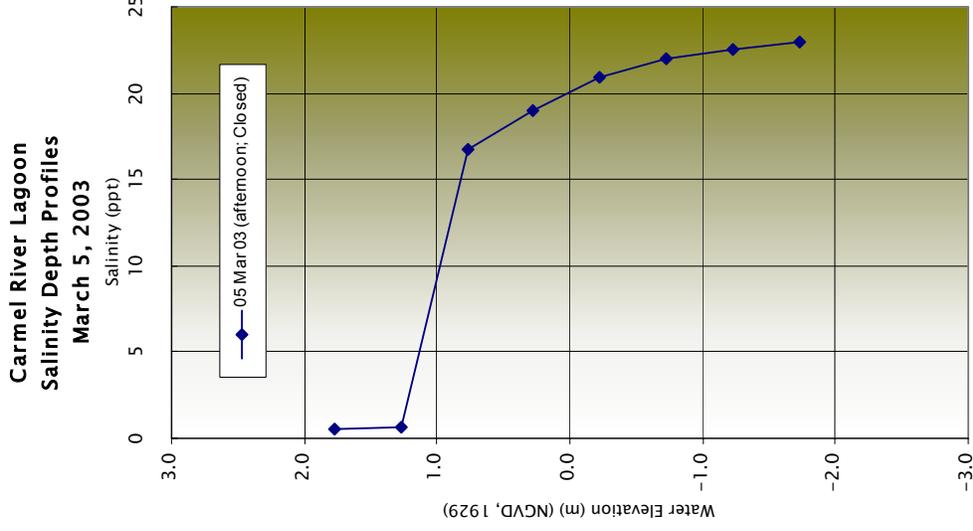
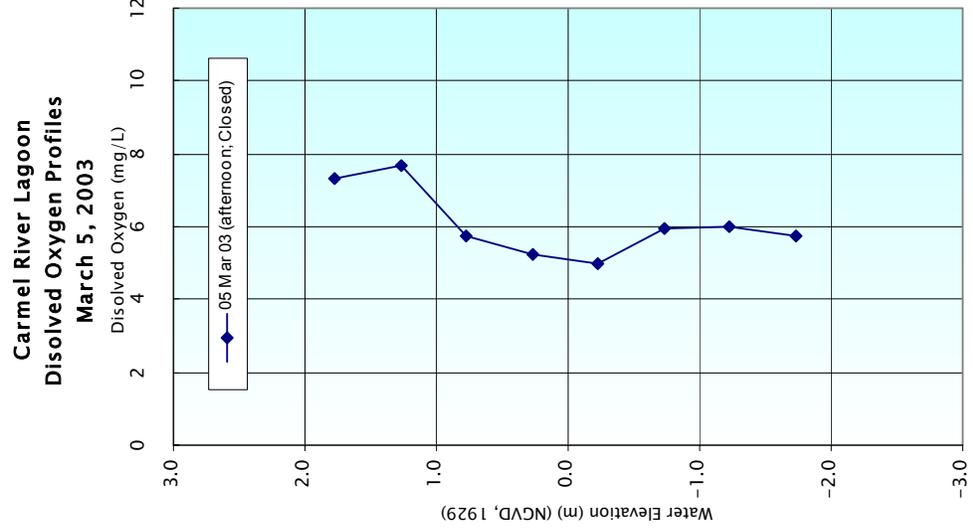
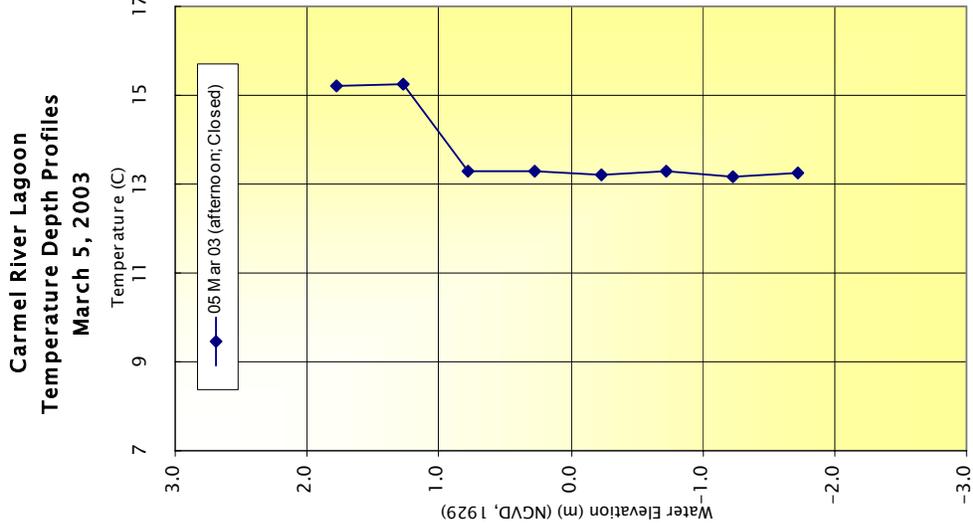


Figure 11.7 Temperature, dissolved oxygen and salinity surface to depth profiles for March 5, 2003, Carmel Lagoon.

11.2 Appendix B: Salinas Lagoon Events

The following figures illustrate, separately, temperature, dissolved oxygen and salinity at several locations in the Salinas Lagoon during each monitoring event.

December 17, 2002

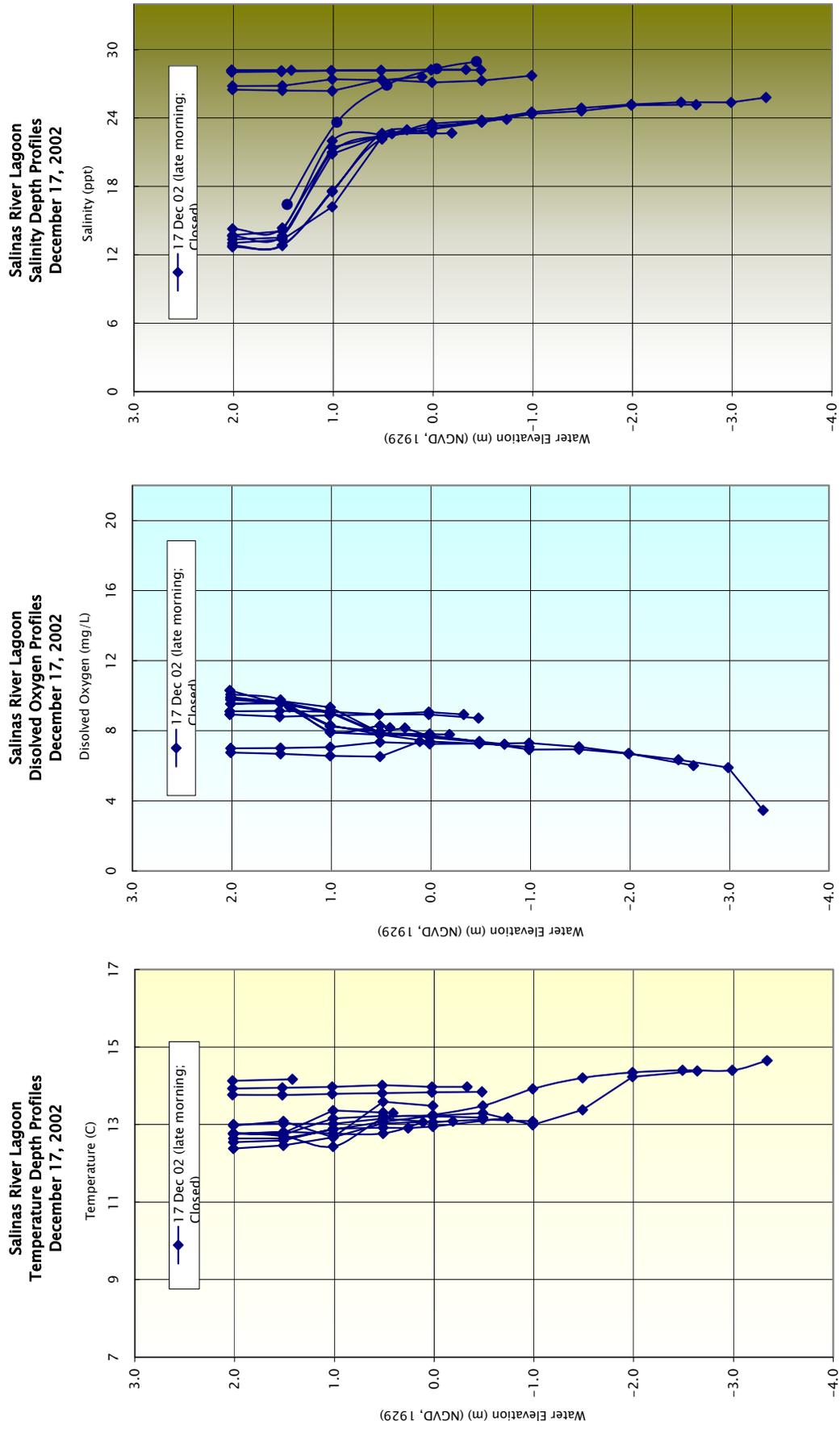


Figure 11.8 Temperature, dissolved oxygen and salinity surface to depth profiles for December 17, 2002, Salinas Lagoon.

December 20, 2002

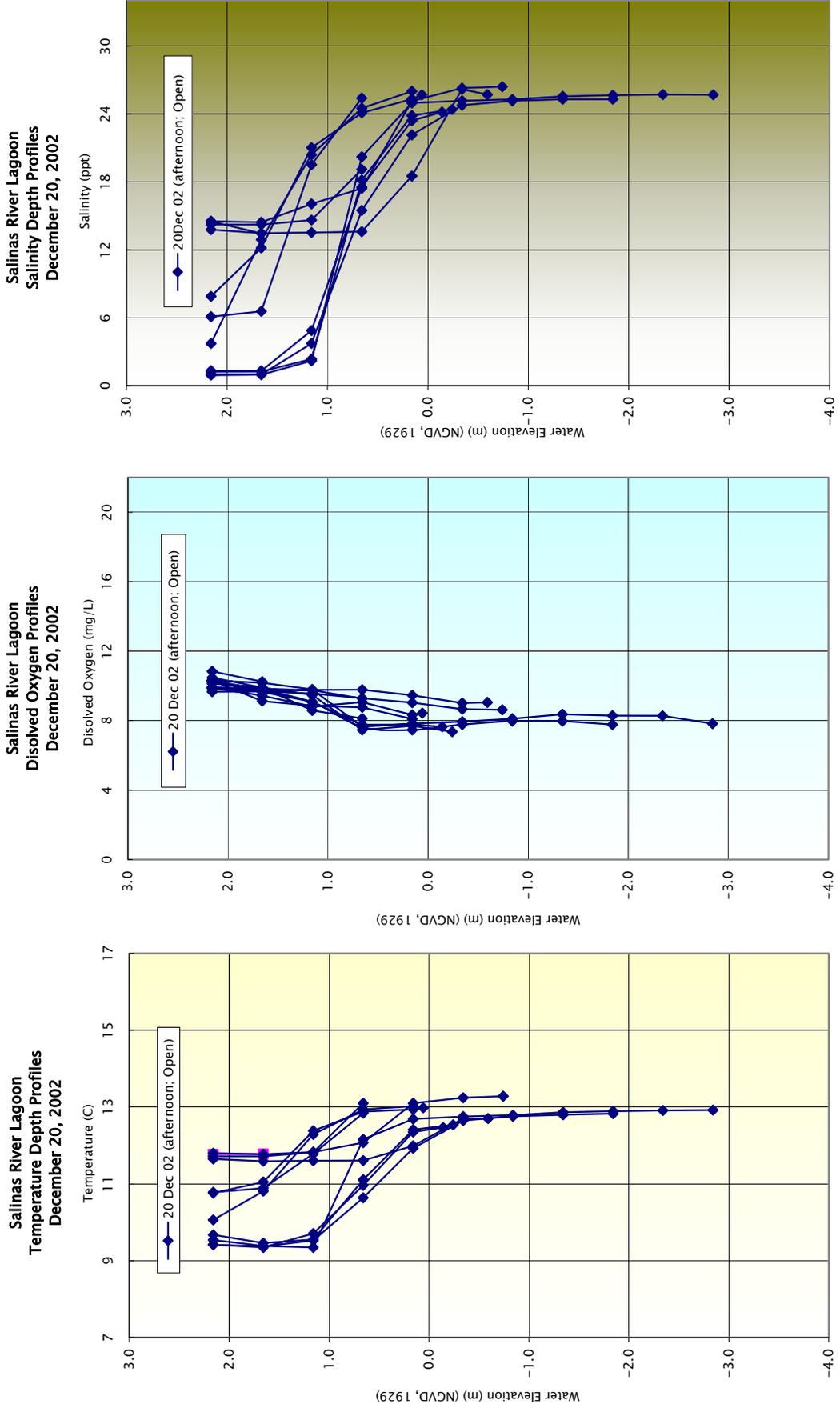
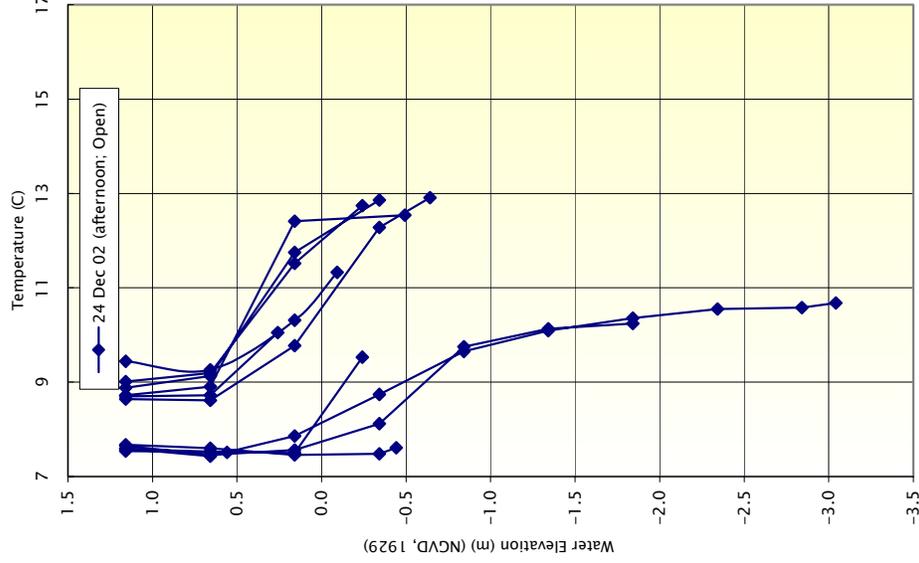


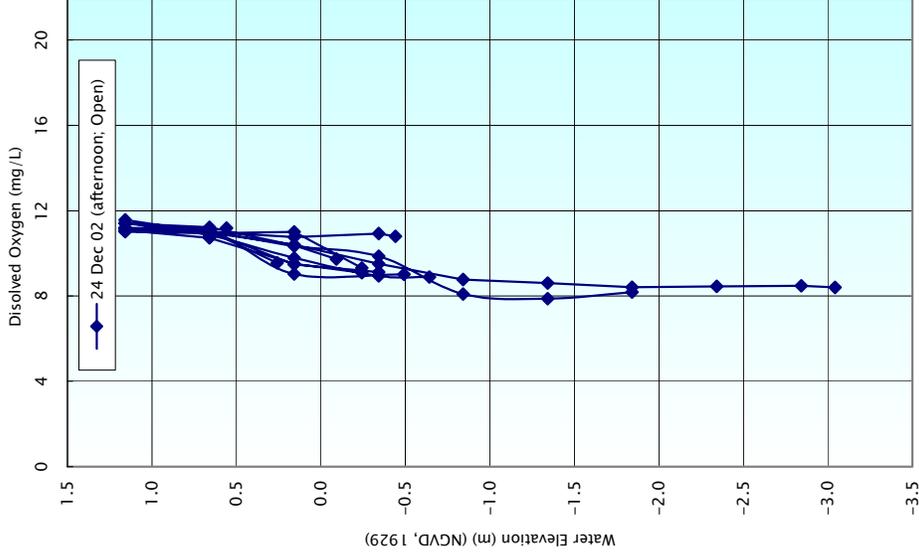
Figure 11.9 Temperature, dissolved oxygen and salinity surface to depth profiles for December 20, 2002, Salinas Lagoon.

December 24, 2002

Salinas River Lagoon
Temperature Depth Profiles
December 24, 2002



Salinas River Lagoon
Dissolved Oxygen Profiles
December 24, 2002



Salinas River Lagoon
Salinity Depth Profiles
December 24, 2002

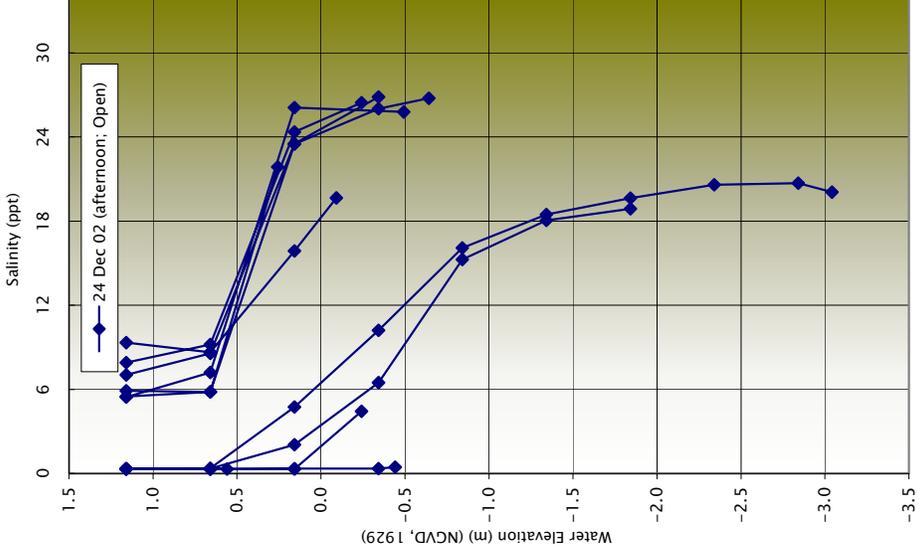
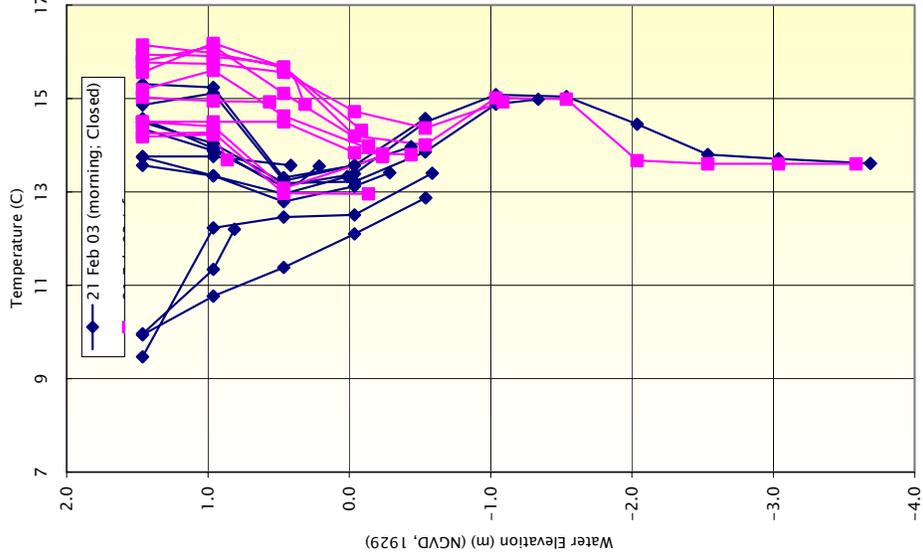


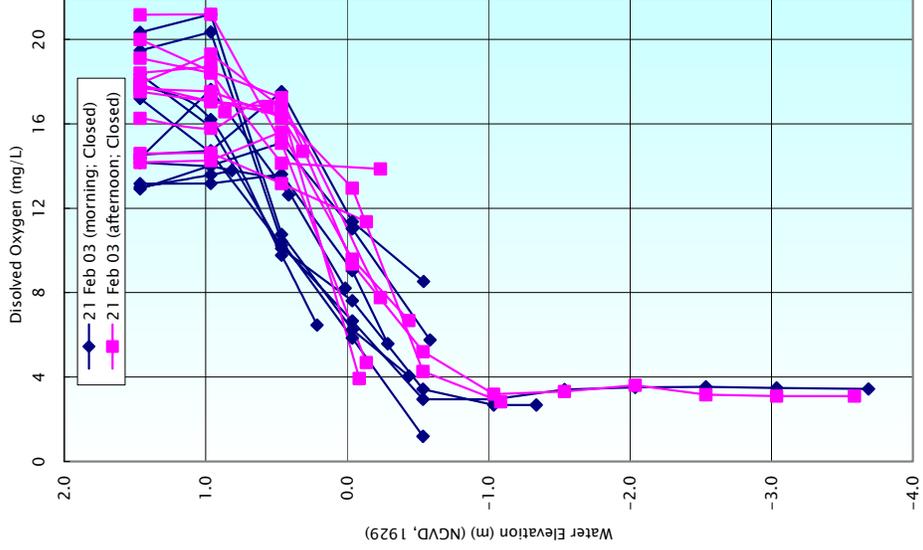
Figure 11.10 Temperature, dissolved oxygen and salinity surface to depth profiles for December 24, 2002, Salinas Lagoon.

February 21, 2003

Salinas River Lagoon
Temperature Depth Profiles
February 21, 2003



Salinas River Lagoon
Dissolved Oxygen Profiles
February 21, 2003



Salinas River Lagoon
Salinity Depth Profiles
February 21, 2003

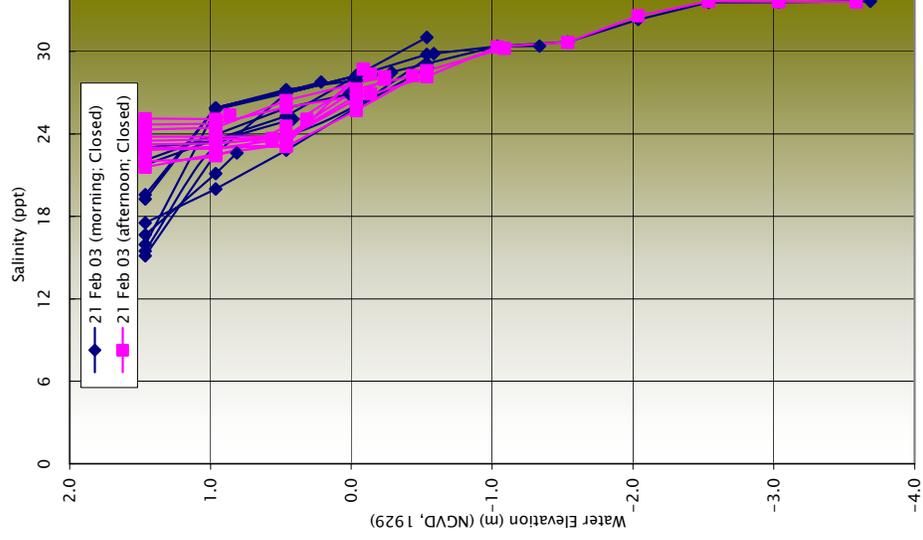


Figure 11.11 Temperature, dissolved oxygen and salinity surface to depth profiles for February 21, Salinas Lagoon.

March Rain Event

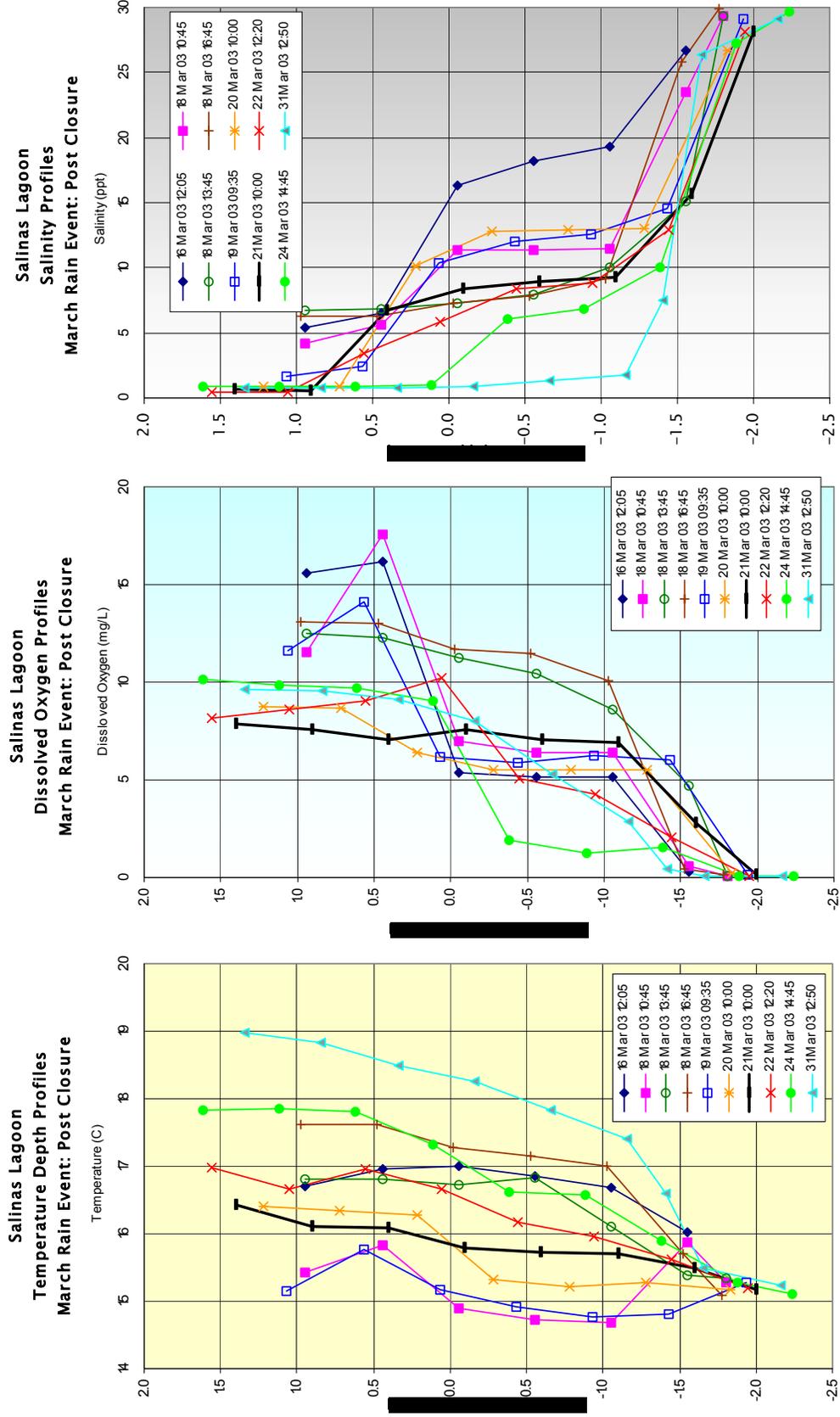
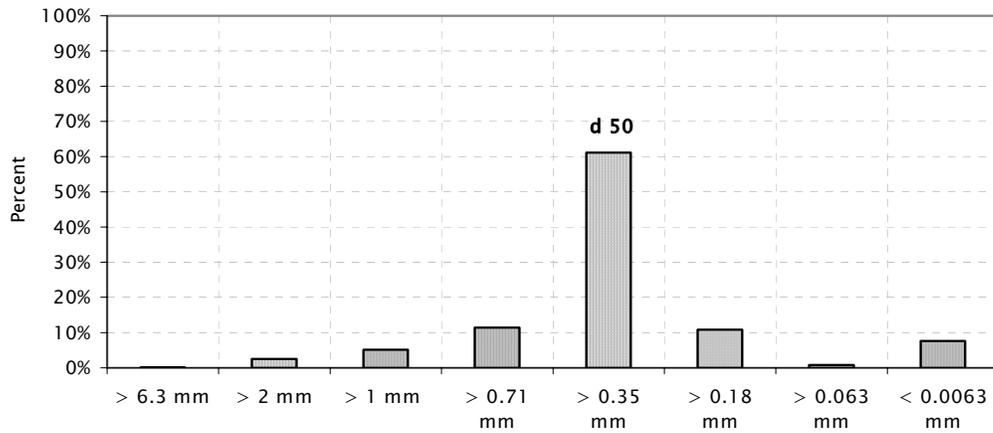


Figure 11.12 Temperature, dissolved oxygen and salinity surface to depth profiles for March rain event, Salinas Lagoon.

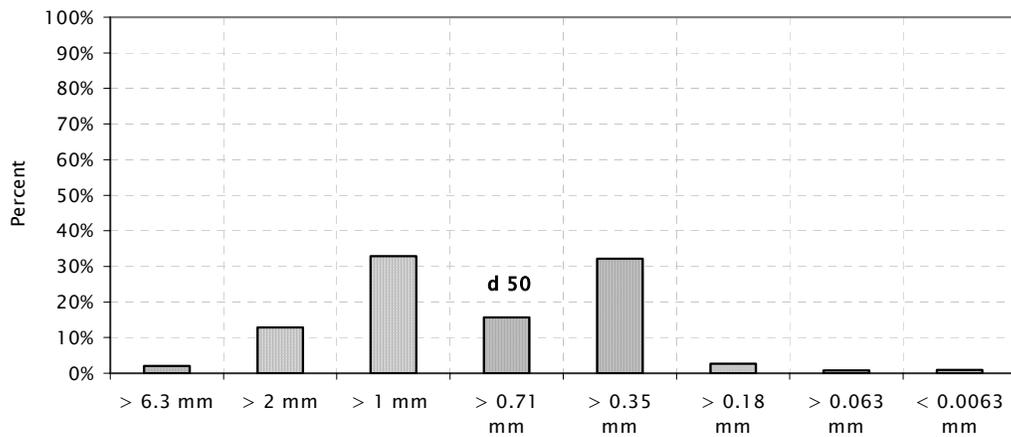
11.3 Appendix C: Carmel Lagoon Bottom Sediment Size Distribution

The following figures are particle size distributions for bottom sediment samples collected in the Carmel Lagoon. Three samples were collected in the main body of the lagoon near the sand bar and three additional samples were collected in different parts of the South Arm of the lagoon (Fig. 4.11).

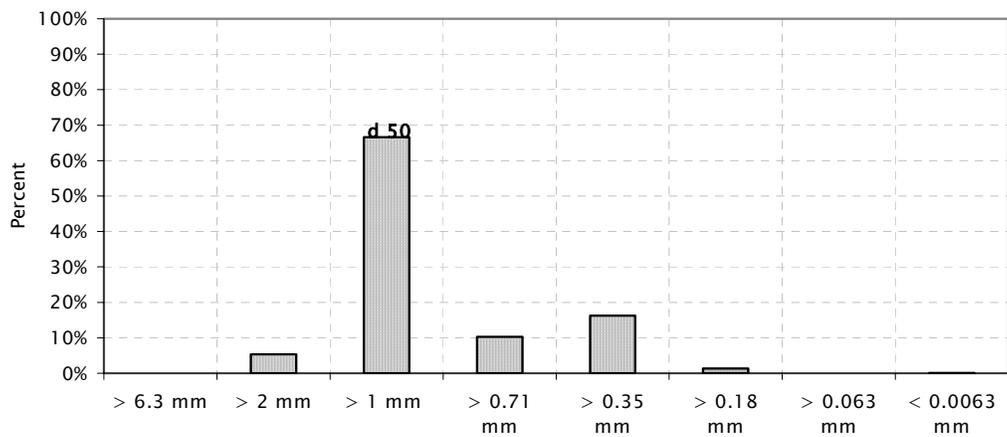
**Carmel Lagoon Bottom Particle Size Distribution
Pre Breach near Bar (Left Bank) (Zone R1)**



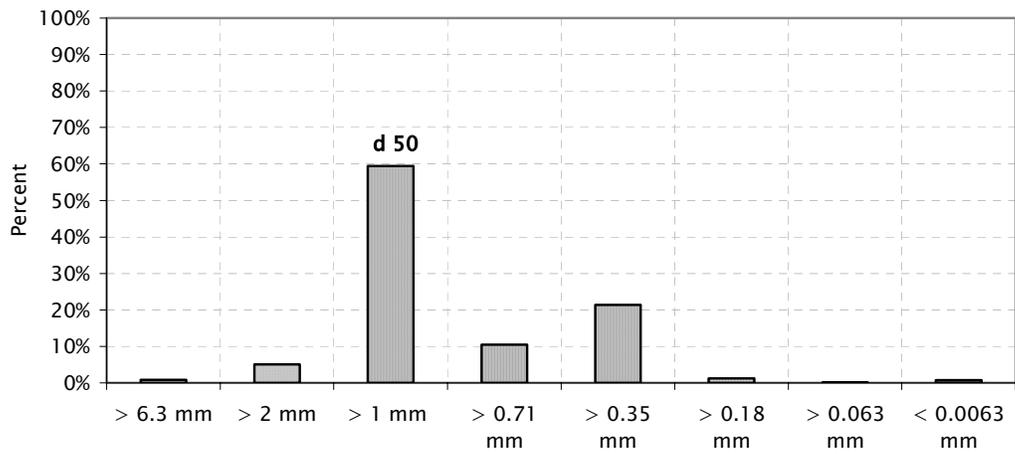
**Carmel Lagoon Bottom Particle Size Distribution
Pre Breach Main Lagoon (center) (Zone R2)**



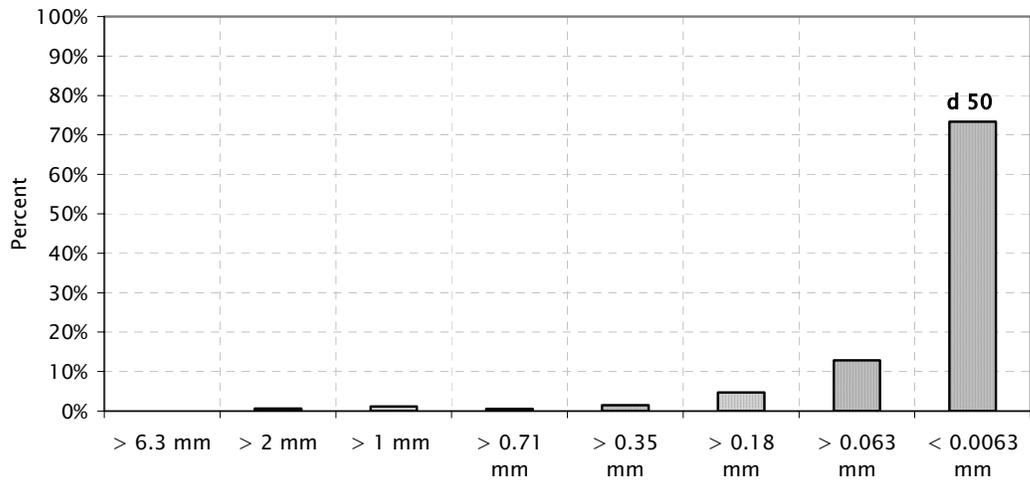
**Carmel Lagoon Bottom Particle Size Distribution
Pre Breach near Bar (Right Bank) (Zone R1)**



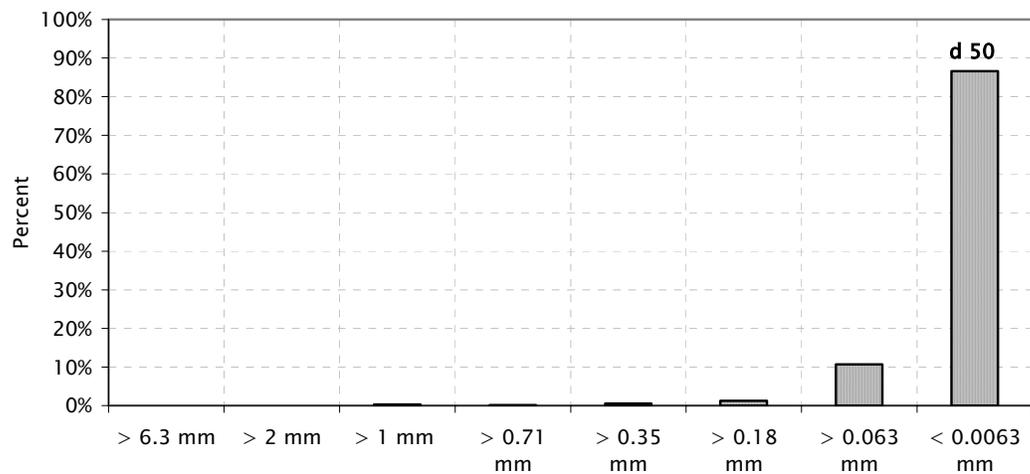
**Carmel Lagoon Bottom Particle Size Distribution
Pre Breach South Arm Entrance (Zone S0)**



**Carmel Lagoon Bottom Particle Size Distribution
Pre Breach South Arm Middle (Zone S1)**



**Carmel Lagoon Bottom Particle Size Distribution
Pre Breach South Arm near Staff Plate (Zone S2)**

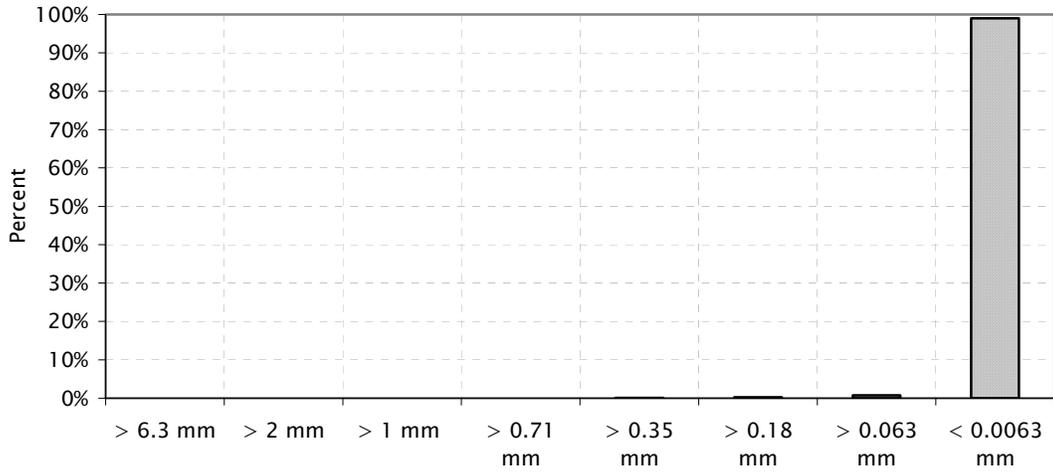


11.4 Appendix D: Salinas Lagoon Bottom Sediment Size Distribution

The following figures are particle size distributions for bottom sediment samples collected in the Salinas Lagoon. The three samples shown are in order with the furthest upstream first, followed by the next downstream sample (Fig. 5.11).

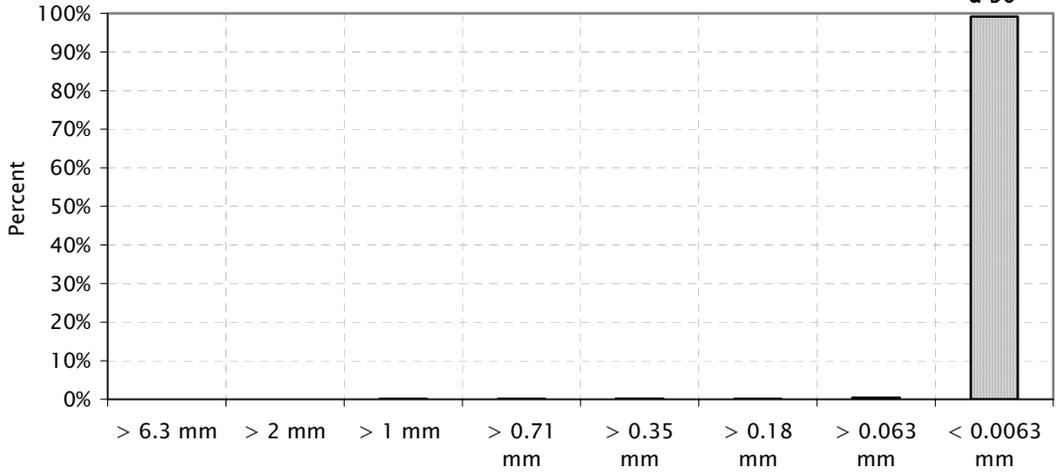
**Salinas Lagoon Bottom Sediment Particle Size Distribution
Pre Breach Twin Bridge Deep Upstream (Zone 7L)**

d 50



**Salinas Lagoon Bottom Particle Size Distribution
Pre Breach Twin Bridges (Powerline) (Zone 7L)**

d 50



**Salinas Lagoon Bottom Particle Size Distribution
Pre Breach Twin Bridges Deep Downstream (Zone 7L)**

d 50

