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Winter Water Quality of the Carmel and Salinas Lagoons, Monterey, California: 2000/2001

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Preface

In the Californian winter of 2000/ 2001, the rains arrived late. Midway through January 2001, high-level Monterey County decision makers met to discuss the management of the two largest lagoons in the area. The lagoons were predicted to fill in coming days and threaten both residential and agricultural lands with inundation. The lagoons were still pent up behind sandbars between them and the ocean. Breaching of the sandbars was to be induced, or at least assisted, using heavy equipment. At the time, both lagoons most likely supported migratory Steelhead Trout juveniles waiting to head out to sea. The question was asked: "What water quality exists for these fish, and how will it change upon breaching?"

The Watershed Institute at CSUMB was invited by County agencies to perform some basic monitoring, ***gratis***.

This complimented the aims of our more general work on the status of the Salinas Watershed, currently funded by the Central Coast Regional Water Quality Control Board as the "Salinas Sediment Study".

With the lagoons filling fast, six field trips were hastily convened, the lagoons were breached, and this report was produced to provide timely information to planners whilst the issues remained furtive. In this particular year, some houses unfortunately were flooded. Both the environmental and bureaucratic processes surrounding the management of the lagoons are complex.

Acknowledgements

We acknowledge the following agencies for their motivation and advice:

- Monterey County Public Works
- Monterey County Water Resources Agency (MCWRA)
- Monterey County Planning & Development
- Monterey Peninsula Water Management District (MPWMD)

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1 Introduction

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

The Carmel River supports a large restored run of many thousands of up-migrating adult Steelhead each year[2]. The Salinas River once supported such a run[3], but now is now limited to perhaps 200 [4].

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

Monterey County Public Works (in the Carmel Lagoon) and the Monterey County Water Resources Agency (in the Salinas Lagoon) intervene each year by either causing or assisting the breach using heavy earth-moving equipment. This activity is subject to permitting requirements, which in turn require water quality monitoring. The impact of the breaching process on Steelhead populations is unknown. The juveniles require a substantial amount of time for smoltification. A precise means of determining when they are ready, or the conditions under which they would be most likely to be ready, is not known for these runs. It is

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

[2] See MPWMD web page.

[3] Anecdotal evidence has been documented (see forthcoming Salinas Sediment Study report for citation).

[4] This figure is highly uncertain, and is the number given by a NMFS status report published on their web page.

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 may be difficult to access the sandbar using heavy equipment. There is a need for better understanding of lagoon hydrology and steelhead response, as well as the ability to predict the best time for breaching given the multiple constraints just outlined.

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The lower Carmel River began flowing around December 2000, thereby filling the lagoon. At commencement of monitoring on January 5th, it was nearly full, and breaching or flooding was predicted to occur within days, supported by heavy rains forecast for the week starting January 7th.

The lower Salinas only began flowing in earnest after the January rains, at around January 9th. At commencement of monitoring on January 12th, it was predicted to breach or flood the following day.

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The objectives 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. The objectives were *not* to study or analyze fish behavior and response to changing conditions, or make judgements as to optimal lagoon management.

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

- Temperature
- Salinity
- Dissolved oxygen
- Depth
- Nitrate
- Phosphorus

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)
- Pathogens
- Cover from predators
- Food
- Turbidity
- Hydraulic diversity
- Invasive species
- Fish population estimates
- Fish age-distribution estimates

2 Study Area

2.1 Carmel Lagoon

The Carmel Lagoon lies at the mouth of the Carmel River (Figure 1.1). Its surface area shrinks considerably during summer, and expands in winter to inundate terrestrial vegetation before breaching. The northern backwater is approximately circular (*circa* 300 m diameter) and comprises a network of small channels and "islands" of vascular aquatic vegetation. The smaller, southern arm is linear (*circa* 200 m long), and confined to seaward by small granite cliffs beneath a low hill. At high water levels, the majority of the lagoon waters are vegetated and not open. At low levels, there are many exposed sandbanks. Fringing the lagoon to the north are low-lying houses in Carmel-by-the-Sea and the buildings of Mission Ranch. Inland, to the east, lies the river and a wastewater treatment plant in low-lying country. Upon the hills to the south are houses in Carmel Meadows.

The river inflow is gauged at Highway One about a mile upstream from the lagoon. The lagoon water level is gauged using staff plates both in the northern backwater, and in the south arm.

MPWMD have monitored certain water quality parameters in the lagoon for some years [5]. Time did not permit analysis of these data within the framework of the present *pro bono* report.

2.2 Salinas Lagoon

The Salinas Lagoon is quite different. It is larger, about 3 km long, and in a broad, low-lying, open agricultural setting (Figure 1.2). Its banks are better defined, so the surface area does not shrink appreciably during summer. It has a tapered linear outline, sinuously narrowing inland from a widest point of about 300 m until it becomes the river itself. The northern shores support dense thickets of semi-aquatic and water-tolerant terrestrial vegetation in patches and islands. Some large woody debris is scattered about - remnants of the last major flood. The grass, Arundo, is invading. The southern shores are actively

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[5] Canning, M.J. (1998) "Carmel River Basin Surface Water Quality Data Report. Water Years 1991-1996". MPWMD report, MPWMD Library.

eroding, with nearly vertical banks. Four closely spaced bridges cross the lagoon at a confining point most of the way inland (the site known as “Twin Bridges”).

The nearest active official streamflow gauge is a USGS gauge about 15 km upstream at Highway 68 or “Spreckels”. The Watershed Institute conducts storm monitoring of flow, sediment, and nutrients at the Del Monte bridge (adjacent to Highway One) and Davis Rd (a mile or so downstream from Spreckels), with some limited monitoring also at Blanco Rd (downstream from Davis Rd).

The Elkhorn Slough Foundation has been monitoring basic water quality parameters in the Salinas Lagoon for some years. As with the Carmel Lagoon data, time did not permit analysis of these data within the framework of the present *pro bono* report.

Figure 1.1 Carmel River Lagoon at close to maximum water level – looking inland from the sand bar.

Figure 1.2. The shallow waters of the Salinas Lagoon at its north western corner.

3 Methods

3.1 Access

The shallow waters of the lagoons are well accessed by kayak. A racing tandem kayak was chosen as the best compromise between ease of launching, ability to support instruments, and speed of moving between sites (Figure 3.1).

3.2 Mapping

A logging GPS unit was carried aboard in order to locate monitoring sites, delineate the lagoon perimeter, and coordinate bathymetric survey. On the first few days, differential correction was applied in the lab to achieve an accuracy of a few meters. We later switched to a more easily useable GPS, for which differential corrections were not able to be applied in the time available. This normally results in horizontal positional errors around ±10 m.

3.3 Water quality monitoring

A number of sites (17 on the Carmel; 22 on the Salinas) were selected in the field for detailed water quality monitoring. These were chosen to evenly sample the lagoons with respect to following likely correlates of variation in water quality:

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

At each site, subject to proper instrument functioning, the following parameters were measured:

- location
- depth to bottom
- surface pH
- water temperature (every 50 cm depth to bottom)

- salinity (every 50 cm depth to bottom)
- conductivity (every 50 cm depth to bottom)
- dissolved oxygen (every 50 cm depth to bottom)

At a few of these sites, paired water samples were taken by up-turning sample bottles at 50 cm depth. These will be analyzed in a laboratory for total suspended solids, nitrate, ammonium, and phosphorus.

A sample of seawater from the surf near Carmel Lagoon was also analyzed.

Figure 3.1 Tandem kayak used for water quality monitoring, showing: paddles, staffs, and buckets with sample bottles, GPS, and equipment for measuring salinity, temperature, conductivity, dissolved oxygen, and pH.

Due to constraints of working aboard a kayak in inclement weather on short notice, equipment failure occurred several times:

- GPS: failed to work through waterproof housing on 1st day
- DO: membrane burst on one day
- conductivity: Instrument waterlogged on one day

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

- mounted storage bins
- duct tape
- DH-48 sampler (not used)
- staff for measuring depth (cumbersome)
- plum-bob for measuring depth (better)
- rite-in-the rain notebook
- pencils
- zip-lok bags
- spare paddle
- camera

4 Results – general

4.1 Timing

Stage	*Carmel*	*Salinas*
Request for work	Jan 3 2001	Jan 11 2001
Pre-breaching monitoring	Jan 5 2001 S, C	Jan 12 2001 S, B
	Jan 9 2001 R, B	Jan 13 2001 S, W
Breaching	Jan 11-12 2001	Jan 13 2001
Post-breaching monitoring	Jan 19 2001 S, B	Jan 17 2001 S, C
Draft report distributed	Feb 1 2001	Feb 1 2001
Final report distributed	Apr 5 2001	Apr 5 2001

R = raining
S = sunny

W = windy
B = breezy
C = calm

4.2 Weather

On most days, the wind was not such that significant surface mixing would be expected – except for January 13th in the Salinas Lagoon, where some increased mixing activity might be expected to about 1 m depth.

On the sunny days, surface heating would be expected. Although generally, the winter weather was cold, leading to cold surface temperatures.

5 Results – Carmel Lagoon

5.1 Mapping & bathymetry

Figure 5.1 details the Carmel Lagoon and some of the sites for which GPS coordinates were obtained from aboard the kayak. Figure 5.2 shows a profile of the bathymetry.

Much of the lagoon is between 1 and 2.5 meters deep – except a trench by the cliffs along the entrance to the southern arm, which is much deeper, to over 5 m. The deepest parts are well below mean sea level. We understand that the trench is the result of deliberate excavation of the lagoon a few years ago in order to provide deep water Steelhead habitat [6], [7]. The area is well away from the zone of likely river scour, but may be in the path of extreme floodwater scour. The presence of cliffs immediately adjacent to the deep section suggests the steep cliff walls may concentrate hydraulic action at this location. Detailed examination of bottom material and small scale bathymetry suggests that the river flows past the north end of the trench and has deposited, through bedload movement, a berm of coarse sands and fine gravels. However, because (in non-flood years) no river flow occurs beyond this river/trench interface, the bedload movement stops there and the trench does not fill up. Only suspended particles would find their way into the trench, but evidently these are in short supply from the sandy Carmel River. The trench has not filled to anywhere near sea level since it was excavated.

Some areas in the south exhibit dense reeds and other vegetation in water measured to be well over two meters deep. For the most part, the rushes in the north grow in water measured to be closer to one meter deep at full lagoon height.

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[6] Phillip Williams & Assoc., Jones & Stokes Assoc., and CSUMB (1999) "Carmel River Lagoon: Enhancement and Management Plan: Conceptual Design Report". MPWMD Library.

[7] Phillip Williams & Assoc. and Jones & Stokes Assoc. (2000) "Carmel River: Reach 2 (Eastwood/ Big Sur Land Property): Conceptual Enhancement Plan". MPWMD Library.

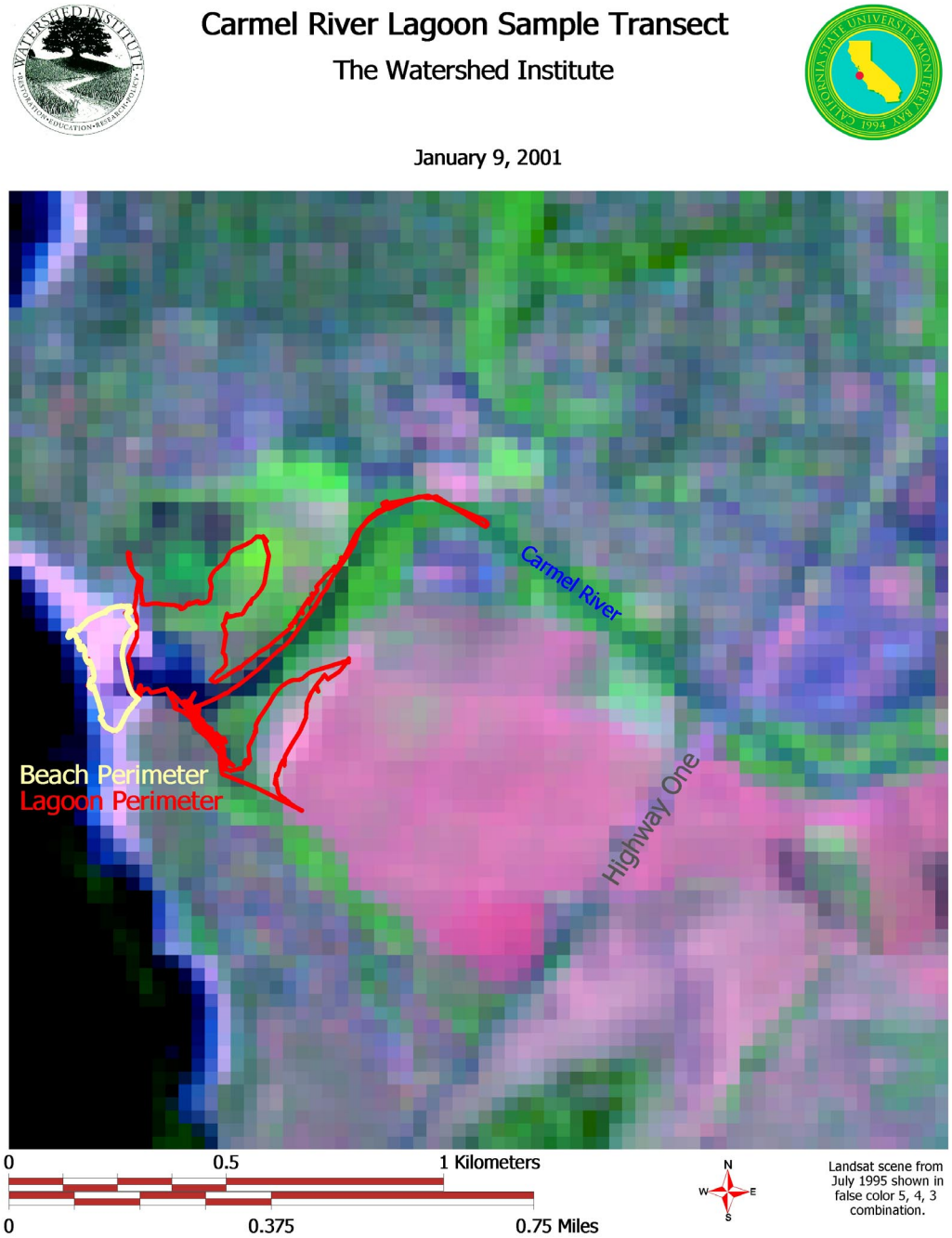

Figure 5.1. Map of Carmel River Lagoon, showing: satellite image in background, and some GPS data taken during monitoring. The red GPS line is the lagoon perimeter paddled by kayak. The yellow GPS line is the sand bar perimeter surveyed by walking.

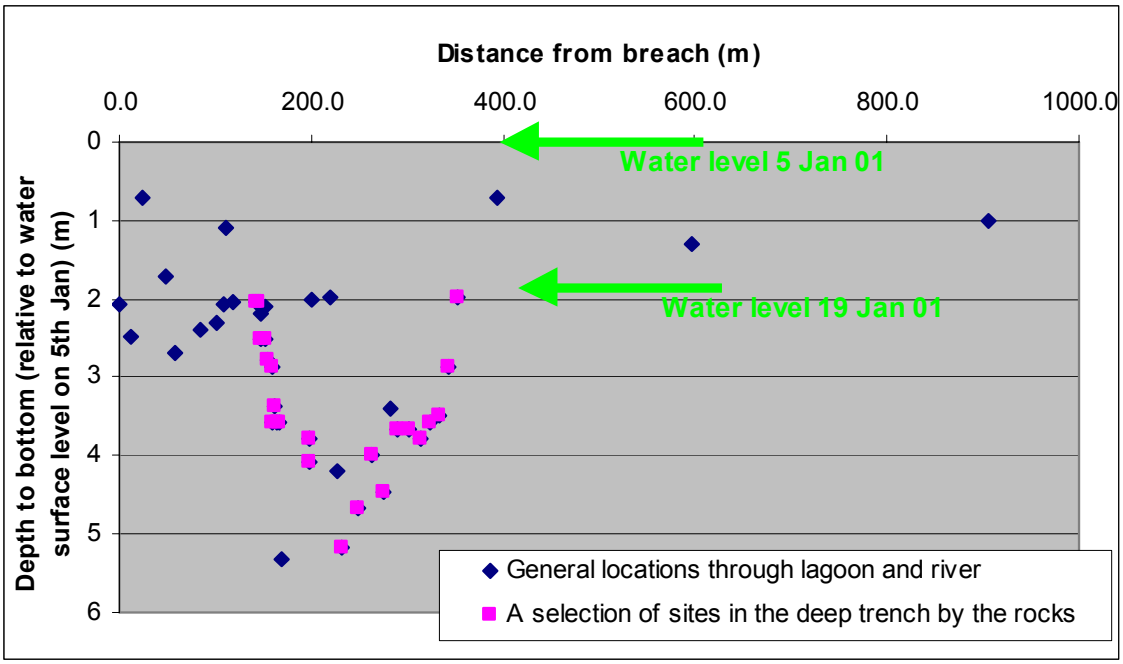

Figure 5.2 Bathymetric profile of Carmel River Lagoon. On 5 Jan and 9 Jan, most areas were less than 2 m deep, except near the sand bar (2.5 m) and a deep trench running along the rocky cliff W of the S arm (to over 5 m). On 19 Jan, many previously submerged areas were exposed, and apart from the trench, the lagoon area between the river and the ocean was only about 30 cm deep.

5.2 Water quality pre-breaching

Figure 5.3 details depth profiles of water quality at 17 sites in the Carmel Lagoon. Pre-breaching observations are shown for two days (Figures 5.4-5.6), and a third day's data show post-breaching conditions.

The following observations were made from the pre-breaching data:

1. The water was generally very cold - colder than the ocean (12.2 °C), and suitable for salmonid habitat. Surface temperatures (8.5 - 10.6 °C) did not appear related to site water depth, but aligned on a strong east/west trend - warmer near the river, colder near the ocean. There is probably a causal relationship with the depth of the general area, and not each site per se. Prior to significant river inflows, a stable, fresh cold layer existed at 1 m. Below this, there was salty water, warmer than the surface (up to 12 °C). The up-river 1 m deep site was an outlier, with warmer water at 1m than all other sites. A few days later, after increasing river inflows, the surface profile remained laterally stable, but warmer than before, perhaps due to the influx of warmer fresh water from the river. The warmer water below may be more the result of influxing of sea water warmer than influxing river water, or because these lower waters reflect warming of the lagoon during summer, while the surface waters reflect more recent cold air conditions.

2. The sea water salinity was 32.5 ppt - a few ppt lower than "normal" sea water. The lagoon water was fairly fresh in the surface 1.5 m (~1.7 ppt). A submerged "pool" of saline water was observed below 1.5 m (5-25 ppt) almost reaching the salinity of seawater below 5 m depth. The up-river and mid-river sites were the only two outliers, with fresher water at 0.5 m and above. The bottom of these river sites (1 - 1.3 m) however displayed the same salinity as at equivalent depth in lagoon sites, indicating that diffusion and circulation of salt water persists a good distance upstream. In these areas, the fresh river water flows on top of intruding salty water beneath. Very little surface flow was visible - indicating that the backwater probably extends another kilometer or so upstream.

3. Dissolved oxygen (DO) data were a little noisy, probably due to the difficulty of keeping the instrument in calibration aboard a kayak. Most sites sampled revealed adequate DO (>8 mg/L) above 2 m depth. The surface was a little less

oxygenated than the cooler 1m layer. Below 2 m, in the salty, warmer water, DO dropped below 6 mg/L, which is less suitable for salmonids. The up-river site displayed low DO at its bottom - possibly due to bacterial consumption of decaying inundated riparian vegetation from when the bed was dry during summer. A major outlier was the "false mouth" of the river, where it entered the lagoon. It displayed a reverse DO trend, with lowering levels to 6.7 mg/L at 1.5 m, and a sharp increase to 12.1 mg/L at 2 m. More data are required to explain this phenomenon. No measurements of diurnal fluctuations in DO were made. All measurements were taken in the afternoon.

4. The lagoon appeared quite turbid, with a blackish tannin-like tinge. No Secchi disk readings were taken, but transparency was estimated to be about 1- 1.5 m.

5. In general, pH readings were between 8 and 9 and did not appear to vary systematically, expect for an acidic 6.2 taken in the vicinity of the beach. This may have been due to the proximity of floating decaying wood and seaweed at this site.

6. The swamp site differed only slightly from the more open sites. It had warmer water than most sites, and high DO at 0.5 m, which is consistent with the presence of photosynthesizing aquatic vegetation.

In future work, these observations should be considered in conjunction with previous studies of the Lagoon [8],[9].

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[8] James, G.W. (1994) “Surface Water Dynamics at the Carmel River Lagoon. Water Years 1991 through 1994”. MPWMD Tech. Memo. 94-05, MPWMD Library.

[9] Canning, M.J. (1998) “Carmel River Basin Surface Water Quality Data Report. Water Years 1991-1996”. MPWMD report, MPWMD Library.

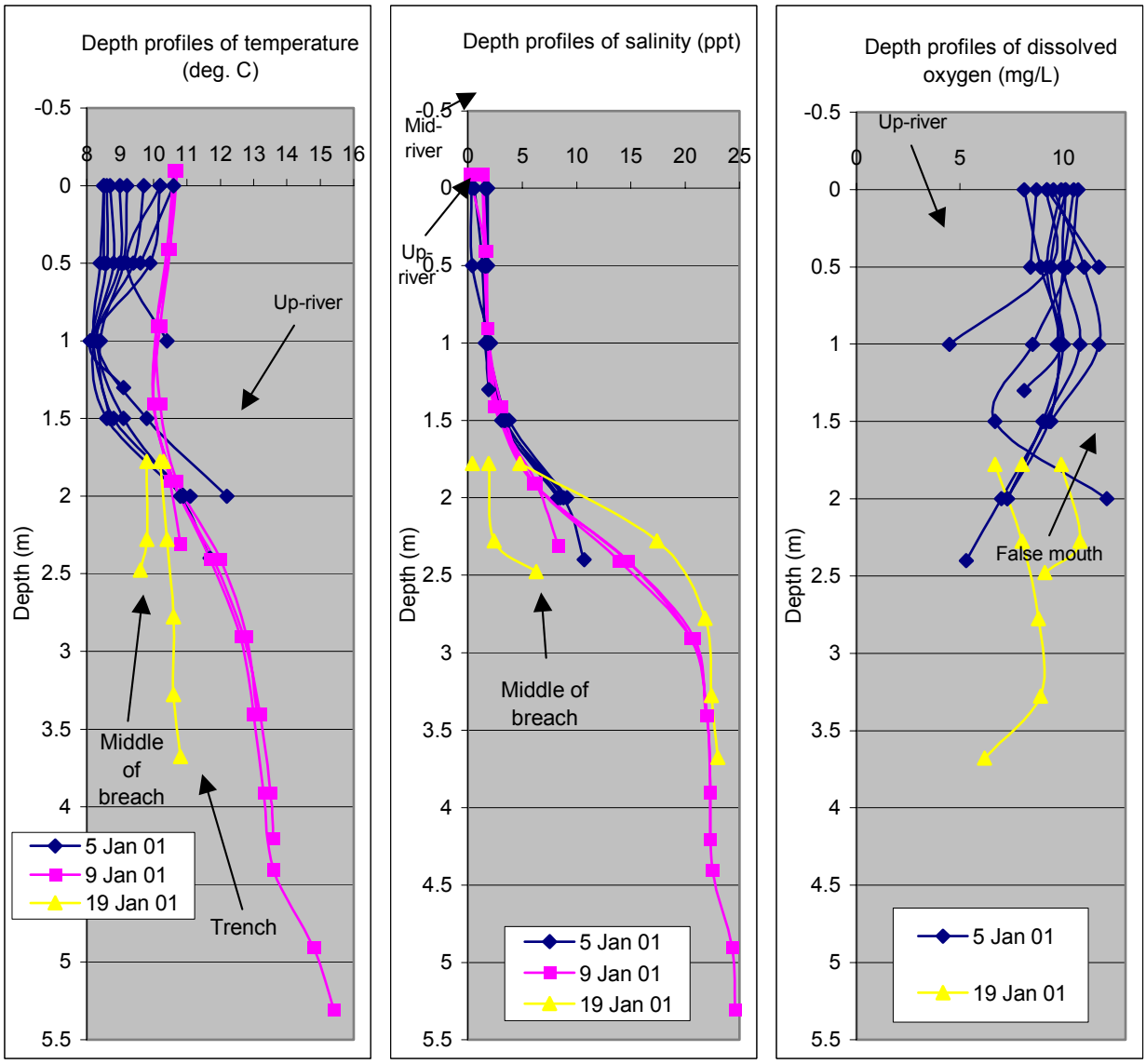


Figure 5.3 Depth profiles of water quality parameters in Carmel Lagoon before breaching (January 5 & 9, 2001), and after breaching (January 19, 2001).

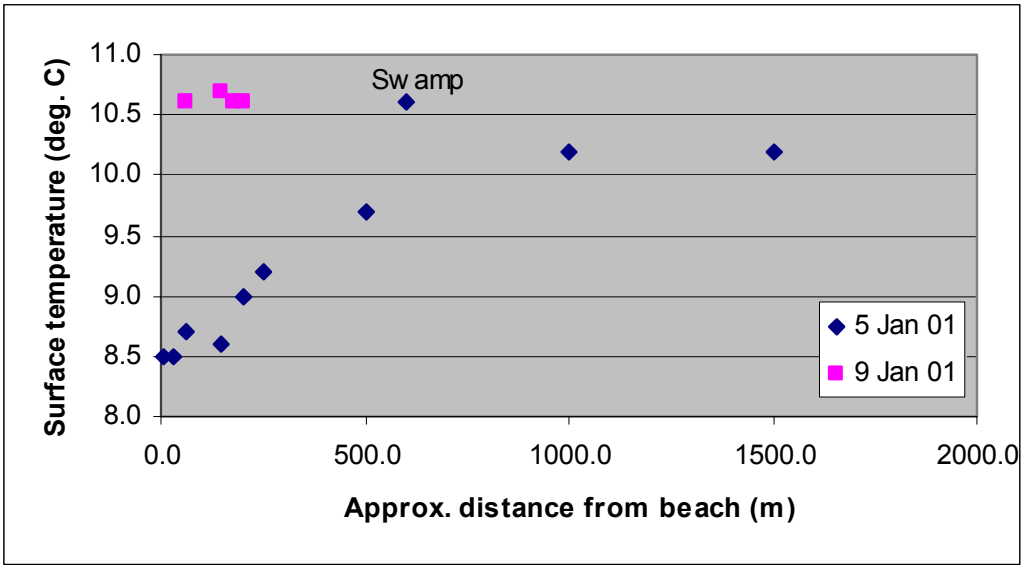


Figure 5.4 Spatial patterns of surface temperature in Carmel Lagoon before breaching (January 5 & 9, 2001)

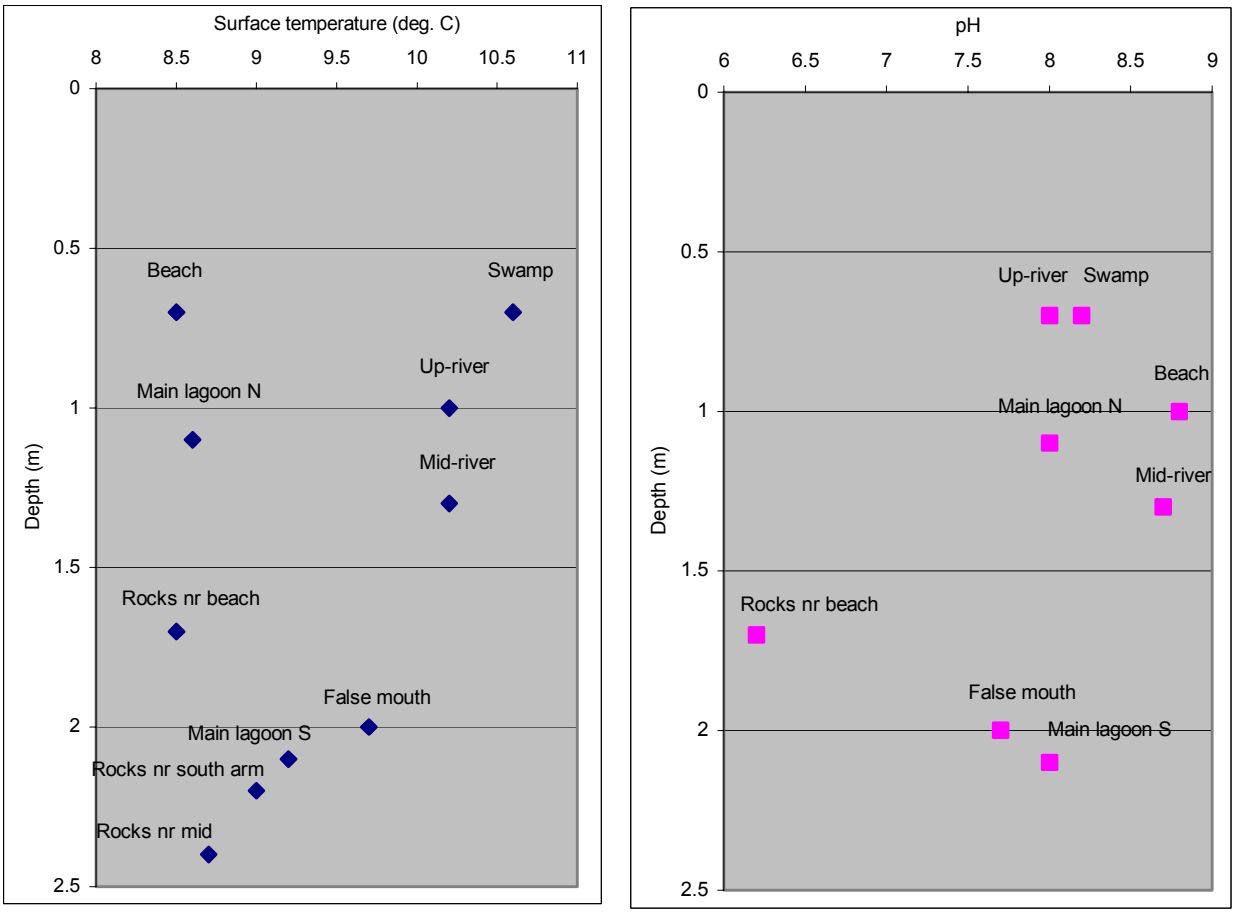


Figure 5.5 Limited extent to which surface parameters depend on depth to bottom – Carmel Lagoon before breaching (January 5 & 9, 2001)

Figure 5.6 Monterey County Public Works lowering the elevation of the Carmel Lagoon sand bar in an attempt to facilitate natural lagoon breaching.

5.3 Water quality post-breaching

The assisted breaching of the Carmel Lagoon was problematic in 2001. The breaching was delayed as much as possible in order to minimize potential fisheries impacts. Thereafter, very high waves combined with high tide and rising stream flows all at once. The lagoon filled rapidly with both sea water and fresh water, but the high seas prevented safe access to the breaching point by earth moving equipment. Flooding and damage to property occurred.

Some interesting lagoon dynamics can be inferred from the post-breaching data.

1. At equivalent elevations above datum, temperatures were cooler in the formerly deep warmer waters. This is most likely because the surface waters had flowed away, exposing the formerly deep waters to mean air temperatures that were significantly cooler than the water. Nighttime minimum temperatures during January were generally below freezing.
2. Salinity in the trench remained close to pre-breaching levels, indicating that the same water is present (i.e. the trench water did not move during the emptying of the surface waters), and that since-the breach only marginal influx of seawater may have occurred.
3. Salinity in the breach itself reflects a mixture of in-fluxing seawater wave action (salty water at depth), and out-fluxing river water (fresh water at surface) (Figures 5.7 & 5.8).
4. Dissolved oxygen profiles are similar to pre-breaching conditions, but displaced downwards approximately two meters. This phenomena may be an artifact of the temperature dependence of dissolved oxygen measurements, which is difficult to take account of when suspending the probe several meters below a kayak. It also may be related to corrections that were made to the readings for changing salinity values. Or, it may be a real physical pattern. As readings were not taken in the deeper parts of the trench before breaching, comparison is difficult.

In summary, it appears that the surface two meters of water flowed out to sea, leaving behind dry land, a flowing fresh river, some occasional waves washing into very shallow lagoon waters, and a deep residual trench of highly saline water. This water is unlikely to be flushed very quickly under low to moderate river flows. High river flows may however induce eddy-related mixing into the

deep waters. If this were not the case, one would expect the trench to remain at ocean salinity or higher in perpetuity.

Figure 5.7. Recording salinity and temperature in the Carmel Lagoon breach area.

Figure 5.8. Mixing of ocean and river water in the Carmel Lagoon breach area.

6 Results – Salinas Lagoon

6.1 Mapping & Bathymetry

Figure 6.1 shows the map of the Salinas Lagoon and some GPS coordinates from one of the field days. Figure 6.2 plots a profile of the bathymetry.

At full water level prior to breaching, much of the lagoon was about 2 meters deep – except the narrow channel beneath the bridges, which is much deeper, to over 5 m. The channel is well below mean sea level, which is most likely a result of flood scouring where the bridge foundations constrain the river.

After the breaching, the surface waters emptied and the river subsided. The lagoon became tidal. At high tide, it formed a more or less continuous, shallow waterbody. At low tide, mud flats became exposed, revealing a sinuous meandering bottom structure. At this time, the middle sections of the lagoon thalweg were only about 60 cm deep, with deeper water at either end.

Figure 6.1 Map of Salinas River Lagoon, showing: satellite image in background, and some GPS locations taken whilst monitoring from aboard a kayak.

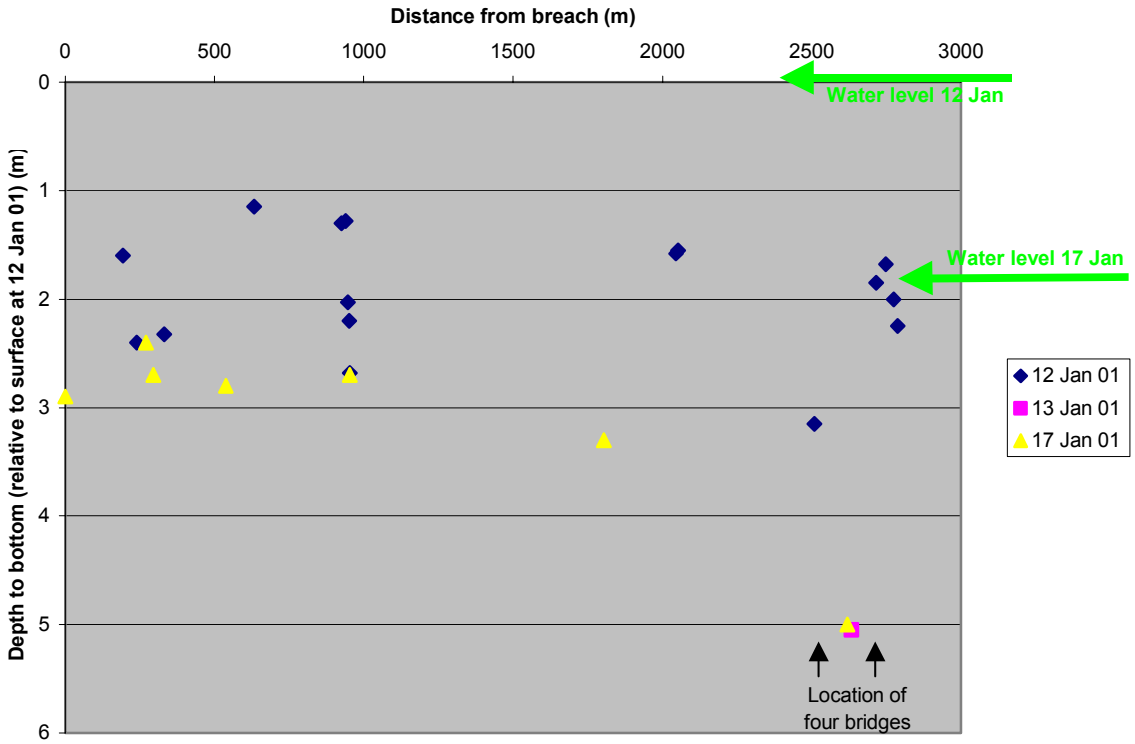


Figure 6.2 Bathymetric profile of Salinas River Lagoon.

6.2 Water Quality pre-breaching

Figures 6.3 to 6.6 show depth profiles of water quality at 22 sites in the Salinas River Lagoon, including two days of data prior to breaching, and one day post-breaching.

The following observations were made prior to breaching:

1. The water was generally cold - colder than the ocean (~12 °C), and easily cold enough for salmonids. Surface temperatures (10.0 - 11.3 °C) were not related to site water depth, but aligned on a warming trend inland, which reversed near the bridges. A stable, fresh, cold 10-10.5 °C layer existed at 0.5 m on the first day of fieldwork. Immediately below this, there was a very sharp halocline to a stable, saline 10.5-11 °C layer. Thereafter, the water gradually became warmer and more saline until reaching almost seawater salinity at 5.5 m depth (measured on 2nd day of fieldwork).

2. The surface was generally fairly fresh (< 5 ppt salinity). Only within a few hundred meters of the beach did the surface approach salinity above 20% of seawater. This was probably strongly associated with the waves crashing in from the sea during high tide and heavy swell. Only as far inland as the bridges did the surface salinity fall below 3 ppt. The halocline at 50 cm depth was very sudden, with salinity rising 15 ppt between 40 cm and 80 cm depth. This suggests that the freshwater river flows over the salt water with only the slightest interaction and mixing, as if there were a barely permeable layer between the two. In one day, between the 12th and 13th, the lagoon level rose 50 cm probably due almost entirely to river input. The data suggest that this fresh water simply stacked on top of the existing water, thickening the fresh water layer without disturbing the stratification beneath.

3. Only one dissolved oxygen (DO) profile was obtained prior to breaching. This was in the deepest part of the lagoon, in the channel under the bridges. It revealed a pattern that, based on the stability suggested by other data, is probably repeated throughout the lagoon. This is that DO is high near the surface, where mixing due to wind and river inputs is adequate. Below the halocline, the water trends towards low oxygen levels, leaving much of the deeper predator-inaccessible water with too oxygen-limited for fish.

4. The lagoon appeared was reasonably turbid, with a greyish tinge. No Sechi readings were taken, but transparency was estimated to be about 1 m.

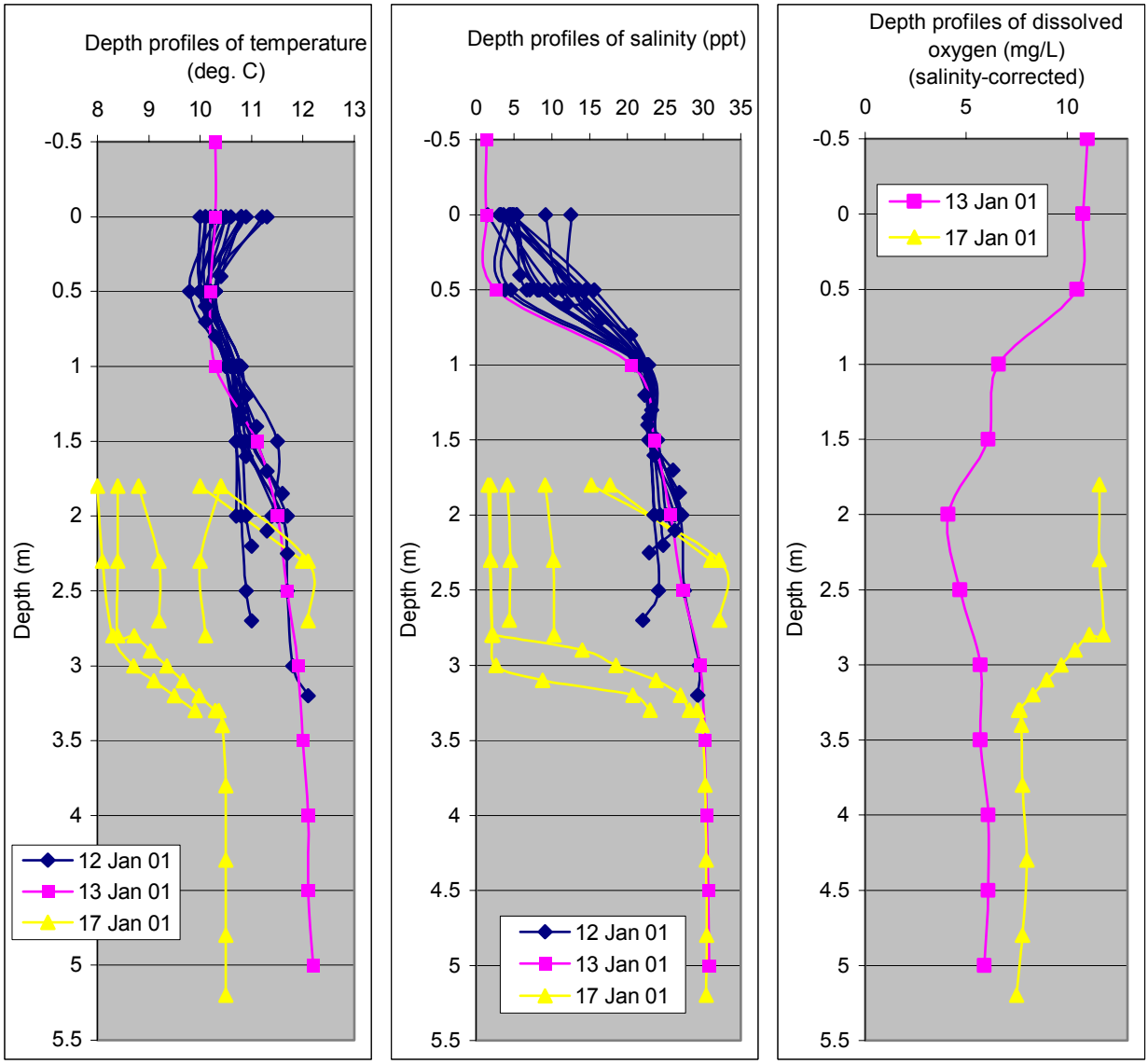


Figure 6.3 Depth profiles of water quality parameters in Salinas Lagoon before breaching (January 12 & 13, 2001) and afterwards (January 17).

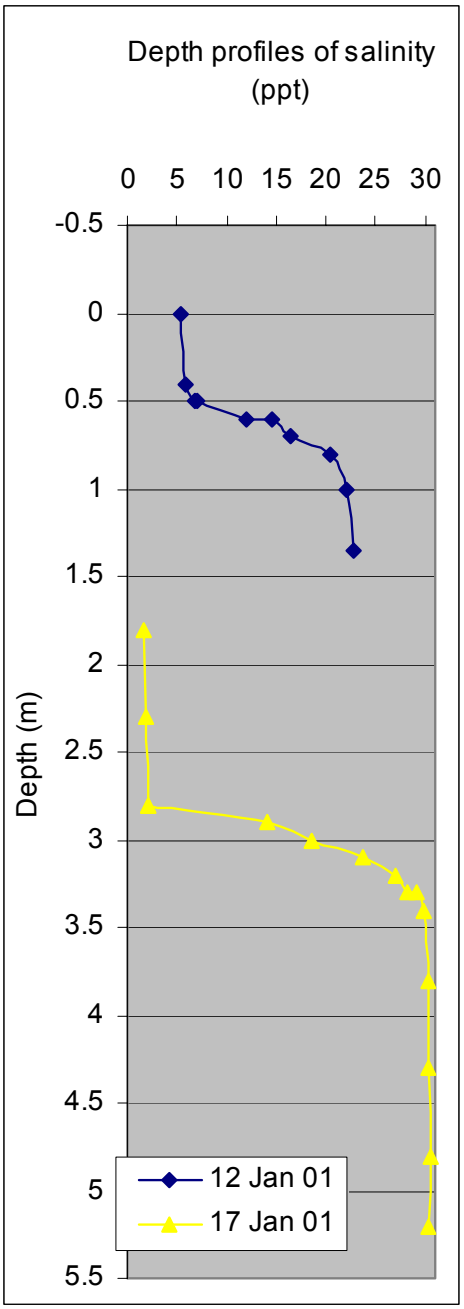
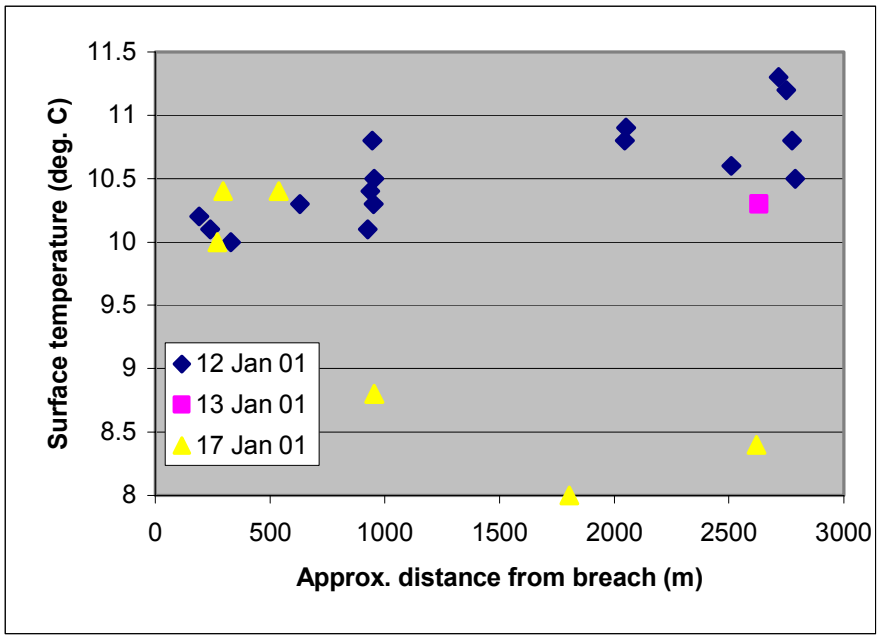


Figure 6.4 Two more-detailed depth profiles of salinity, illustrating the sharp haloclines that form above the deeper parts of the lagoon before (12 January) and after (17 January) breaching.



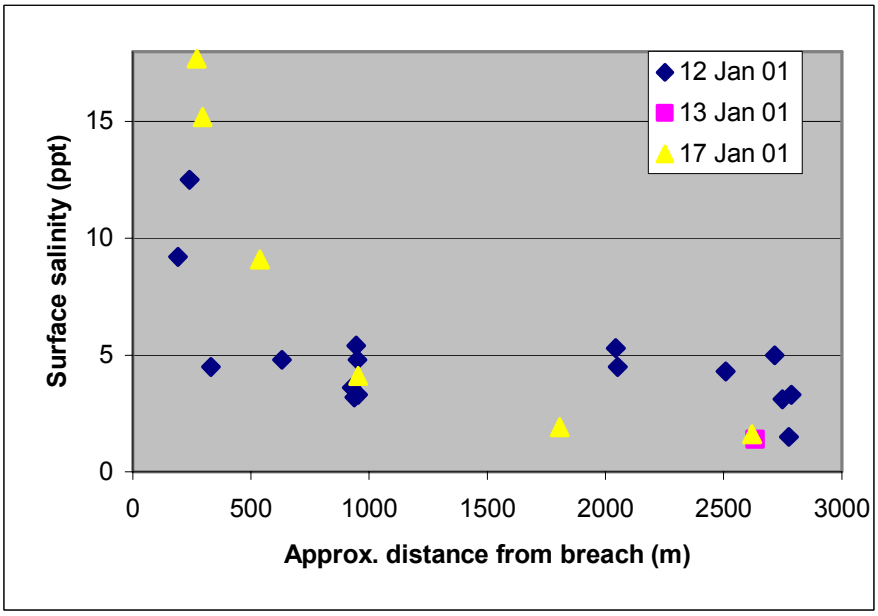


Figure 6.5 Spatial patterns of surface temperature and salinity in Salinas Lagoon before breaching (January 12 & 13, 2001), and afterwards (January 17).

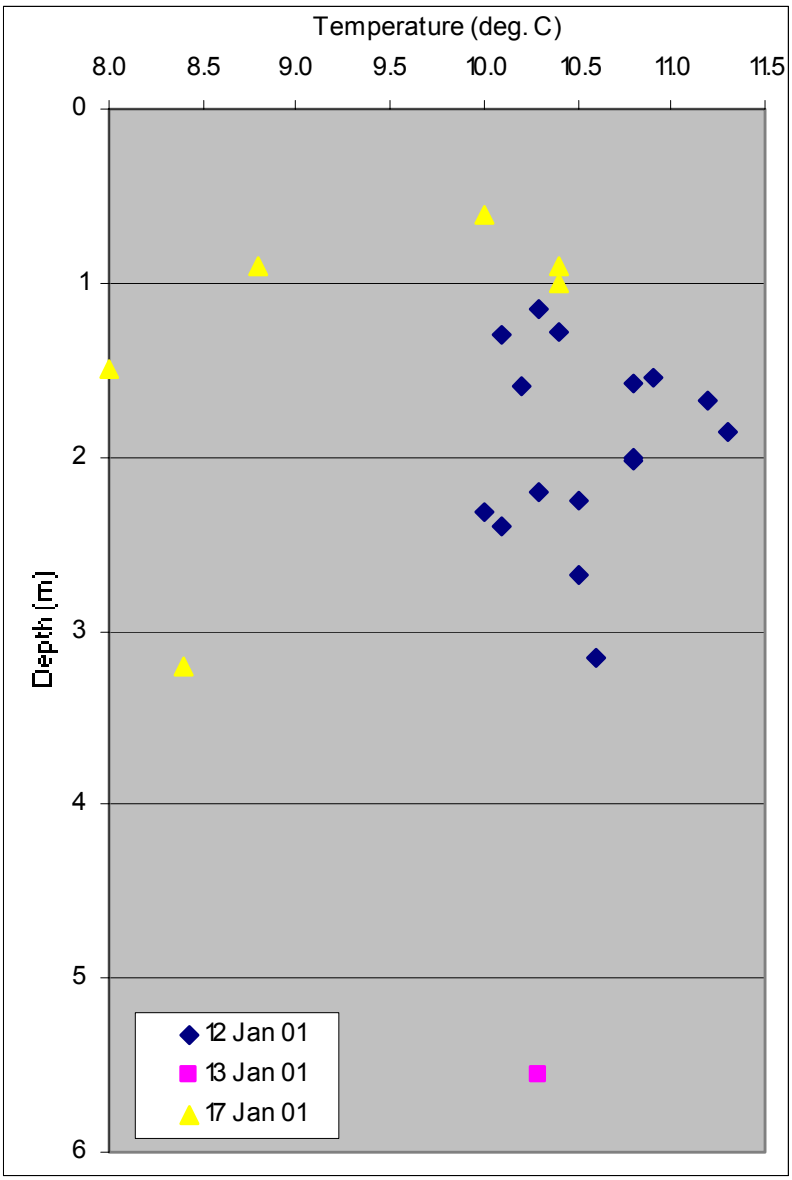


Figure 6.6 Limited extent to which surface temperature depends on depth to bottom – Salinas Lagoon before breaching (January 12 & 13, 2001) and afterwards (January 17).

6.3 Water quality post-breaching

The breaching of the Salinas Lagoon is shown in Figure 6.7. The Salinas River and Lagoon are larger and more predictable than the Carmel system. Just prior to breaching, the Lagoon water levels rose steadily with high influxes from the River and a moderate ocean wave input. Earth moving equipment was used to initiate a swift breaching just before sunset on January 13.

The Salinas system exhibited a slightly different breaching and post-breaching dynamic to the Carmel system. This is because of the linear shape of the lagoon, where in-fluxing fresh river waters have a much better opportunity to displace existing lagoon waters on their way to the ocean. There was also significantly high river flow in the Salinas River during and after the storm. Note that the Salinas River stopped flowing almost completely a few days afterwards, whereas the Carmel kept flowing at moderate levels.

1. It is likely that the top 1.8 meters drained from the lagoon during breaching, including all the fresh water and some of the brackish water. Subsequently, but before the river dried up again, the remaining brackish waters were displaced by further incoming fresh water flows from the river. This left about a meter thick layer of fresh water on top of the remaining, now shallow, deep near-bridge saline channel areas. The persistence of a strong halocline above the near-bridge channel suggests that these deep waters have not moved or mixed to any great extent, and that the breaching river flowed over them with almost no interaction. It is expected that eventually, when higher flows (say above 1000 cfs arrive), that mixing will occur and the deeper saline waters will be flushed to some degree.

2. Around the time of post-breach monitoring, the tide came and went in noticeably during the day, but the water that was being moved back and forth in the middle to upper lagoon reaches remained fresh. We infer that the ocean water was coming in and out of the lagoon only a short distance, but was pushing the existing fresh surface lagoon water back and forth. Over time, we would expect the fresh water to be gradually mixed out into the ocean with successive tidal cycles, but this had not occurred by January 17th.

3. As with the Carmel Lagoon, the overall temperature dropped to reflect new exposure of previously submerged layers to cold air. A new thermocline

formed, reflecting the difference between purely terrestrial cold water, and stagnant cool water whose heat was being gradually conducted away to the higher, cold layers.

4. In difference to the Carmel Lagoon, dissolved oxygen increased following breaching, possibly due to the greater proportion of new lagoon water associated with river influxes.

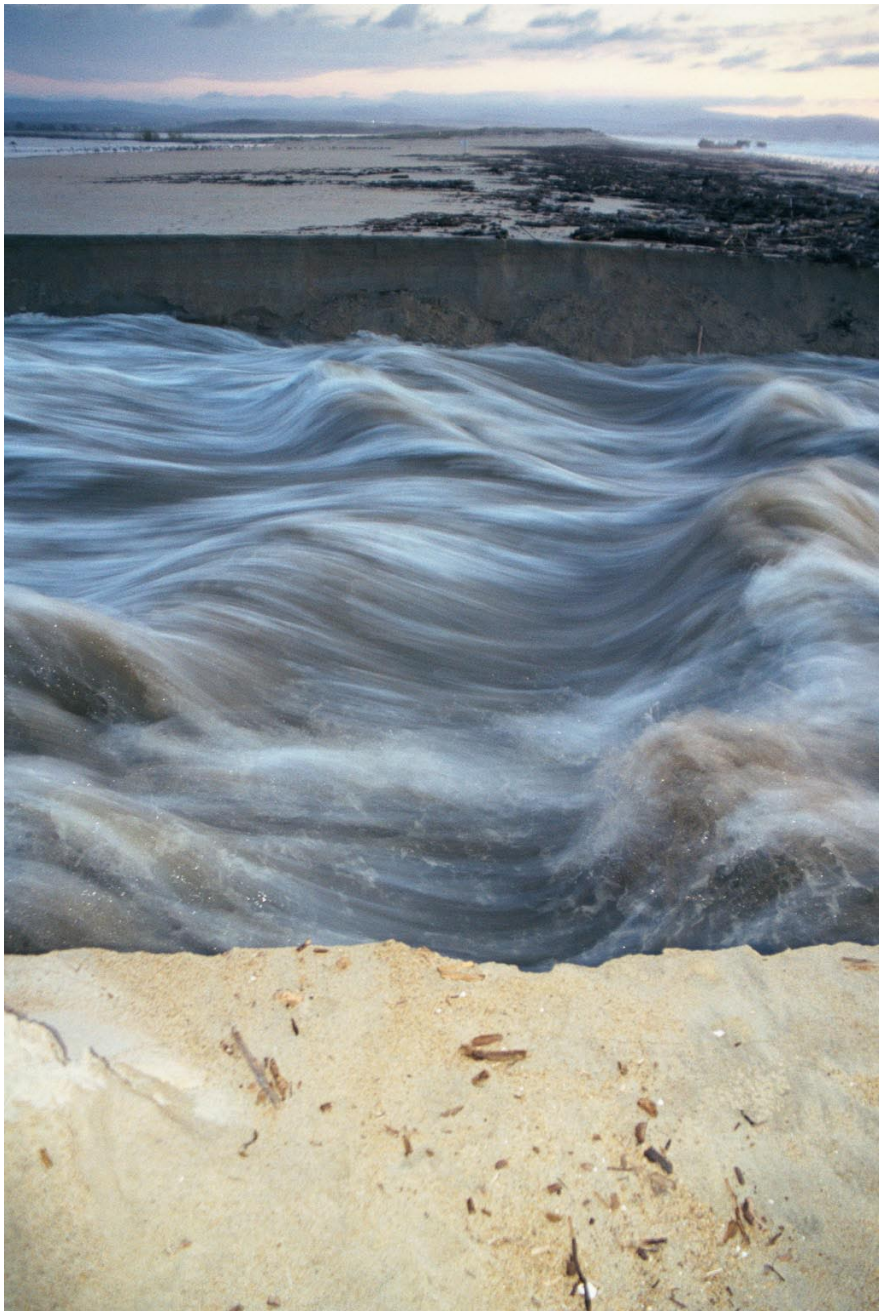


Figure 2. Peak breaching flow from the Salinas Lagoon (at left) to the ocean (at right).

7 Conclusions

7.1 Carmel Lagoon

The data collected prior to breaching suggest good conditions for Steelhead survival – cold water, and plenty of oxygen. There also appears to be good cover from predators. The swamp environs suggest that food may be in good supply also.

The salt water lens at the bottom of the lagoon indicates that juveniles may also have the conditions necessary to begin smoltification, the physiological adaptation to life in the sea. It is warmer and less oxygenated down there, but probably not overly so. Future analysis of the present data should also include comparison with previous studies on steelhead invertebrate food sources [10].

From the point of view of Steelhead, conditions post-breaching were similar in temperature and dissolved oxygen, although the habitat volume was reduced significantly. In particular, the halocline was much closer to the surface, so a fish seeking deep water would be forced to contend with salt water perhaps more rapidly than before. Also, many of the areas of aquatic vegetation became exposed, reducing a fish's options for food and cover. The path from river to sea post-breaching is very direct – passing over a rapid, clear, shallow, sandy bottom for only a few hundred meters before the point of "difficult" return. A fish seeking respite in the lagoon would have to encounter the trench off to the side of the flowing water by chance.

A specialist Steelhead fisheries biologist should be consulted for an opinion on these conclusions.

We did not see any fish, and whilst there were many birds, we did not see them preying on fish. It would be hard to see them if they were anywhere other than near the surface.

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[10] Kitting & Fleming (1990). "Invertebrate densities through Carmel River Lagoon during drought: Potential food resources for small steelhead *Salmo gairdneri* (=*Onchrynchus mykiss*) and for other fishes along a gradient of marsh habitats. Final report for Carmel River Lagoon Enhancement Plan. MPWMD library.

7.2 Salinas Lagoon

The data collected prior to breaching suggest less than ideal conditions for Steelhead survival. Whilst the water is cold enough at this time of year, its shallow depths are accessible by predators and underlain by a stable mass of low-oxygen saline water. There is much less vegetative and debris cover than in the neighboring Carmel Lagoon.

After breaching, conditions degraded somewhat. At low tide, shelter is almost non-existent in the clear shallow waters occupying much of the lagoon's surface area. Typically between 1000 and 10 000 sea birds gather there (although only they only occasionally appear to catch fish). The deep near-bridge channel is very saline, requiring rapid adjustment for any fish moving between it and the greater lagoon and flowing water.

Near the bridges, one or two beavers reside year-round amongst the good cover of old pylons, construction debris, and riparian trees. Numerous other beavers reside further up the lagoon.

We did not see any fish, and only occasionally saw birds preying on fish. It would be hard to see the fish anywhere below the 1 meter thick tidal and/or river layer.

7.3 Comparison

Whilst smaller, the Carmel Lagoon offers better conditions for smoltification. There is better cover, perhaps a larger deep section, and more oxygen. It is not known why the Salinas Steelhead run has declined. The data presented here do not contradict the hypothesis that lagoon conditions may be a limiting factor. They do not necessarily support it either. It would be useful to know whether the Salinas Lagoon has changed much since times when salmonids were abundant there. Perhaps the Salinas Lagoon has always been the way it is?

7.4 Further work

There is great scope for further work, including:

- Analysis of long term water quality data for Carmel Lagoon (MPWMD), and Salinas Lagoon (Elkhorn Slough Foundation).
- Further measurement and modeling of the seasonal hydraulics and water quality dynamics of both lagoons.
- Measurement of diurnal changes in variables such as dissolved oxygen.
- Operational modeling and prediction of optimal times for lagoon breaching.
- Improved management plans reflecting the above.
- Detailed observations of lagoon dynamics during future, possibly quite different years