Littoral Processes and River Breachings at Carmel River Beach

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Introduction

This short report examines beach and littoral processes at Carmel River Beach. The issue here, as I understand it, is maintaining a sufficient water level within the lagoon for fish habitat during the process of breaching, i.e. not flushing too rapidly. The proposals being considered are to breach the river either to the north or to the south where there is bedrock to act as a sill, or weir, to slow the flushing of the lagoon. A question is which breach is more effective in protecting fish habitat. The problem with the north breach last year is that it caused cliff erosion along Scenic Drive. The concern with a south breach is that sand may be diverted into the canyon.

In the following, I have attempted to synthesize published literature, photographs of the beach from 1880 to the present, bathymetry charts dating from 1885, and observations of the beach (including my frequent visits to the beach over the last 36 years), in order to quantify past breaching processes. Below, I present a discussion on waves and beach processes and a quantitative summary of past breachings (locations and migration rates). Based on this analysis, I present estimates of the most probable consequences of various breaching scenarios.

Waves

Directional wave spectra are measured routinely at NOAA 46042 buoy, located 40 km offshore of Monterey Bay, and are refracted shoreward to provide wave heights within the bay every hour (http://cdip.ucsd.edu/models/monterey). The Carmel River Beach is protected from the predominant waves from the northwest owing to the shoreline orientation and the northern headland. Waves must be severely refracted in order to reach the beach (Figure 1). The beach is vulnerable to occasional winter storms from the west, which can focus their wave energy on it (Figure 2). The waves arriving at the beach are mostly reduced to their swell components because of the severe refraction and because the narrower aperture of the headlands filters the higher frequency wave components. Consequently, the waves arriving at the beach for most of the year are swell waves, which act to move sand onto the beach and build the berm (see below).

Longshore currents and littoral transport

Longshore currents and sediment transport are predicted to be southward at the southern end of the beach and northward at the northern end of the beach (Figure 3). Waves arriving at an oblique angle to the beach drive currents and sediment transport alongshore within the surf zone. The longshore currents and littoral transport were reported by Howell (1970) to be to the south based on wave refraction of offshore wave climatology. All subsequent reports and papers are based on this reference. However, it is obvious that processes other than simply wave refraction are important, as can be seen by standing on the shore and observing waves bend around the northern rocky reef into Stuart's Cove. The process of waves bending behind a point is called diffraction. This results in the breaking waves having a northerly direction, which drives currents and sediment transport to the north. Another, probably more important cause of north-directed currents is that waves behind the reef in Stuart's Cove are smaller than waves in the center of Carmel River Beach. When waves break, there is a change in their momentum that is balanced by a hydrostatic pressure head, which results in an increase in the mean water level above what would be the still-water level. This is referred to as set-up. The set-up is approximately 10-20 percent of the offshore wave height, and thus is larger for larger waves. In the present case, the mean water level set-up is higher in the center of the beach and lower to the north in Stewart's Cove. This creats an alongshore pressure gradient pushing water to the north within the surf zone (water flows downhill). The longshore currents can carry sand to the north from the center of the Carmel River Beach and result in a migration of the river mouth to the north.

Beach Morphology

I have visited this beach for 36 years and have hundreds of photos of documentation. I conducted experiments here in 1978. I took pictures of the beach every week for a year after the 1983 El Ninos winter to understand how the beach behaves. I conduct a field trip to the beach every year with my class. Compared with the Ocean Avenue Beach in Carmel, this is not a dynamic beach, and it does not have strong on-offshore seasonal movement. The biggest impact to this beach is from the river breaching.

Carmel River Beach is steep with the beach slope increasing from 0.12 at the north to 0.28 at the south. The steep beach is the result of the relatively large grain sand if which it is composed. The mean grain size shows a corresponding increase from medium to coarse sands, indicative of increasing wave energy from north to south. The beach is classified as reflective with the waves breaking as collapsing (shore break) or surging (high swash up the beach. The high berm is built by waves rushing up the beach face and carrying sand along with the swash. Much of the water of the swash percolates into the coarse bed and deposits the sand at the top of the berm. The back beach is built by the larger waves overtopping the berm at high tides and by prevailing onshore winds blowing sand shoreward.

The approximately 2500 foot shoreline is concave and anchored at the north end by a rocky headland and at the south end by a rock reef. Rocky reefs extend offshore as determined by divers and evidenced by the Macrocystis kelp beds visible from shore. Macrocystis kelp requires a holdfast on a rock bottom to survive the high energy wave environment along this coast. The north rocky reef is extensive and is devoid of sand, indicating that no sand is transported around the point. The south rocky reef is interspersed with sand, indicating that sand is moved over the rocks. Significant sand deposits (depths greater than 5 feet) reside offshore of the river (Howell, 1972).

Nature continually strives to reach equilibrium. The concave shape of this beach came about because a shoreline tends to align itself with the breaking wave crests to obtain an equilibrium shape in the alongshore. This would suggest that the longshore currents and littoral transport are most probably weak on this beach.

The beach appears to be in quasi-equilibrium. The river delivers its sediments to the beach and discharged some of them offshore. Some of the offshore sand is then brought back onshore by the waves to rebuild the beach and berm. Some of the sand is lost to the Carmel Submarine Canyon. Sand from at least as deep as 60 feet will be moved back onshore. The building of the beach goes on year-around. The beach width does not appear to be growing or diminishing significantly. The rebuilding of the beach does not appear to be dependent on a north or south breaching of the river. When I visited the beach in November 2004 with my class, I noted that the beach width and berm height were as wide and high as I could remember. However, the beach at present is in a vulnerable state owing to breaching of the river to the north last winter.

Quantitative measures of beach width were made by Storlazzi and Field (2000), who compared aerial photos for 1949, 1970 and 1990. These measurements qualitatively suggest a decrease in width of the north and central portions of the beach and an increase in width of the south portion. However, standard statistical hypothesis tests fail to show any significant change in beach width (i.e., 3 data points are not statistically meaningful). Dave Reid, a contractor with the USGS, has been summarized beach widths for much of the State of California, and I am trying to obtain information from him. In comparing aerial photos (starting in 1929) and old charts (starting in 1885), the beach qualitatively does not appear to change much from year to year. Qualitative comparison of the bathymetry chart of 1885 with the 1987 aerial photo indicates that there has not been significant change to the beach configuration during that period.

River Breachings

The river is mechanically breached each year to avoid flooding. The breachings historically have been straight offshore, nearer the southern end of the beach. After initial breaching, the river sometimes has migrated either north or south. The river openings will tend to migrate in the direction of littoral sediment transport, and the migration direction depends on where the initial opening occurred. The breach will only stay open if the outflow is greater than approximately 200 cfs (James, 2005). Hence, the river may open and close a number of times during a year, dependent on river flow, tide elevation and wave energetics. Breaching locations are summarized in Table 1 based on the past 13 years of observations by James (2005) and including examination of photos dating back to 1880 and bathymetry charts dating back to 1885. For many of the photos, the river mouth was closed, and the direction of outflow can only be inferred from the antecedent lagoon channel. The observations by James (2005) show that the river mouth can open and close a number of times and its location can migrate. For example during highest flood year 1997-98 winter, the river was opened in the center and then migrated to the north and then to the south. Only observations and photos of locations of the river flowing are included in the analysis. To account for the different opening locations in a single year, a percent of openings was assigned for each location. In summary, the river migrated to the north, stayed in the center or migrated to the south 11, 56 and 34 percent of the time. Only actual observed openings are used for the summary statistics and 2005 is not included.

Migration rates were determined by measuring the displacement of the openings between subsequent dates with positive displacement to the south and negative to the north. Since the migration rates are based on end state locations, it is possible the migration rates could have been much greater as some (or much) of the time between observations the river opening may have been stationary. It is assumed the river was always initially opened in the center or slightly south of center. The river did not migrate much of the time. The migration rates to north were higher with a weighted (based on amount of time) average of 19 ft/day, as compared with an average weighted migration rate of 10 ft/day to the south. The maximum migration rates to the north were 140 ft/day and to the south 150 ft/day. The river mouth migrated to the north about a third of the years, stayed in the center about a third of the years, and migrated to the south a third of the years. Once the river migrated to either the north or the south, it tended to stay there.

When the river migrated to the south it tended to flow along the back beach over a rock sill. An example is in 1995.

The river has migrated to the north four times since 1992 (not including 2005) from an initial opening in the center. During three of the years (1996, 1997 and 2000), the river cut a channel between the beach and the berm as the opening migrated north so that the back beach was not disturbed. However, in 1993, the river cut to the back beach and started to erode the cliff along Scenic Drive; the river was then mechanically diverted to the center to stop the erosion. This past winter, the breaching to the north resulted in the river being diverted and migrating further north so that the river channel was in the back beach with subsequent erosion of the cliff. It was my personal observation that the primary agent for erosion of the cliff was the river, with the ocean waves being only a very secondary cause. The peak flows during the times of erosion in 2005 were not unusual.

Breaching the river to the north in 2005

The beach was mechanically breached at the north end for the first time in 2005. The breaching of the river toward the north end of the beach resulted in a diversion of the river further north. This caused severe erosion of the back beach and cliff on Scenic Drive, threatening a Cypress tree, the road and the sewer line. The bank along Scenic Drive appears to be unstable at present. The beach has not recovered, particularly in the back beach to the north. River flow has been measured on the Carmel River since 1962. Extreme flood years coincided with El Nino events in 1983 and 1998. Peak flow however occurred in 1995 when the Carmel River Bridge failed. The total flow in 2005 was above normal, but peak flows were below the average. If the river is diverted to the north this coming year, it is my opinion that if a comparable moderate rain year occurs as in 2005, the bank most probably will fail. This could mean the loss of portions of the road along with the cypress tree and sewer line.

Scenarios

What happens this winter is highly dependent on total and peak river discharges, as well as wave energy. These are not predictable. In the following scenarios I assume similar conditions to those of last year, in which the peak flow was below normal, the volume of flow was above normal, and the wave climate was average.

1 October 2005 until it rains- The beach and berm will continue to grow. The berm is presently being overtopped at each high tide even for moderate waves. This is good as this is how the berm is built up. However, I do not anticipate that the northern end of the beach and the back beach will recover from the damage of last year. The berm at this year's northern breach is very narrow (Figure 6) and is vulnerable to opening again with the first rains. It is noted that the Scenic Drive cliffs are not vulnerable to wave erosion unless the breach is to the north.

Breach to the north this winter scenario- Most probably the river would take up the same course as last year as the back beach is in depression and has not recovered. This would result in erosion of the cliff along Scenic Drive, which was left unstable from last year (it slope is greater than angle of repose in places). Most probably this cliff would fail with possible loss of road, tree and sewer line.

Breach to the south this winter scenario- Most probably, the river would migrate further south owing to the prevailing sediment transport, as it has in the past when the river mouth was in the south.

Migration measures

1. If is desired to breach the river other than in the north, the north beach should be repaired mechanically by filling in the lagoon to the north. Otherwise, the rive most probably will naturally breach to the north.
2. If the plan is to breach to the north, considerable protection of the cliff along Scenic Drive will be required to protect the road and sewer line.

Recommendations

1. Analyze the lagoon elevation time series during times in the past when the river breached to the north (last winter) and to south (e.g. 1995) when the discharges were comparable to determine how fast the lagoon flushes and estimate the water levels within the lagoon. These data exist.
2. Develop an engineering model of the lagoon flushing and test the model using available data.
3. Better understand the sediment processes. Dave Reid, a contractor for the USGS, may have longterm quantitative beach width measurements. I will contact him.

Brian Clure has stated that the sedimentation in the river is deficit. The bulge of sand moving down the river from the Tularcitos Creek water shed (generated after the 1977 Cone Peak fire?) will reach the ocean in 20??. What does this mean to the beach in the future? To aid in this understanding, the Naval Postgraduate School is planning a beach and offshore bathymetry survey within the next two weeks.

4. Better documentation of the river openings and closings and migration of the river mouth is desirable. To this end, I am working to get a video system installed to monitor lagoon, river and beach processes. We have four systems installed in Monterey Bay (e.g., http://www.oc.nps.navy.mil/~stanton/miso/cameras.html). The images are rectified to a plan view so that quantitative information can be obtained.

References:

Howell, B.F., 1972, Sand movement along Carmel River State Beach, Carmel, California, M.S. Thesis, Naval Postgraduate School, 71pp.

James, G., 2005, Locations of river openings.

Storlazzi, C.D. and M.E. Field, 2000, Sediment distribution and transport along a rocky, embayed coast: Monterey Peninsula and Carmel Bay, California, Marine Geology, 170, 289-316.

Table 1. River mouth openings partitioned into locations of north, central or south by water year (see Figure 1 below). X's indicate observations of openings to ocean. i's indicate inferred from antecedent beach conditions in photos. The total percentages are only based on actual observation of opening indicated by x's and do not include 2005.

date	north	central	south
1880		x	
29			i
39			i
49			i
54			i
56			i
60			i
66			i
68			i
71			i
72		i	
79			x
87		i	
92			x
93	0.6x	0.2x	0.2x
95		0.3x	0.7x
96	0.1x	0.4x	0.5x
97	0.3x	0.3x	0.3x
98		0.3x	0.7x
99		0.8x	0.2x
0	0.5x	0.5x	
1		X	
2		X	
3		X	
4		X	
5	x		
Total %	11	56	34

Table 2. Migration rates are calculated as the distance between sequential river mouth opening locations from James (2005) divided by interval between dates.

dates		days	south ft/day	north ft/day	zero days days
1992	3/30/-				
1993	1/18-2/11	24		90	
	2/1-3/25	55			55
1994	not data				
1995	3/7-4/3	26	2		
	4/3-4/19	16	4		
	4/19-5/3	15	7		
	5/3-5/22	19	5		
	5/22-5/31	9		47	
	5/31-6/5	6		20	
	7/5-7/10	5	28		
	7/10-7/17	7	10		
	7/17-7/18	1	150		
1996	12/7-2/12	67	1		
	2/12-3/18	36	1		
	3/18-4/9	22		64	
	4/16-4/25	39	14		
	4/25-6/6	42			42
	6/6-6/12	7	14		
1997	12/9-2/5	58		25	
	2/12-3/7	23	33		
1998	1/20-4/2	72			72
	4/2-4/20	18	37		
	4/20-5/11	31			31
	5/11-6/10	29	4		
	6/10-7-14	34			34
	7/14-8/12	29	4		
1999	4/20-5/19	30			
	3/12-4/20	39			39
2000	2/1-3/15	15			15
	3/15-4/6	22		9	
	4/6-5/12	37		49	
	5/12-6/20	39			39
2001	1/19-3-23	62		10	
	3/27-5/17	51			51
2002	1/17-4/12	87			87
	4/12-4/22	10	5		
2003	1/17-6/23	159			159
2004	12/30-2/23	75		5	
2005	1/14-1/19	5		140	
	1/19-2/1	13	12		
	2/1-2/16	5		23	
	2/16-5/23	102			102
	Weighted velocity average		10 ft/day	19 ft/day	

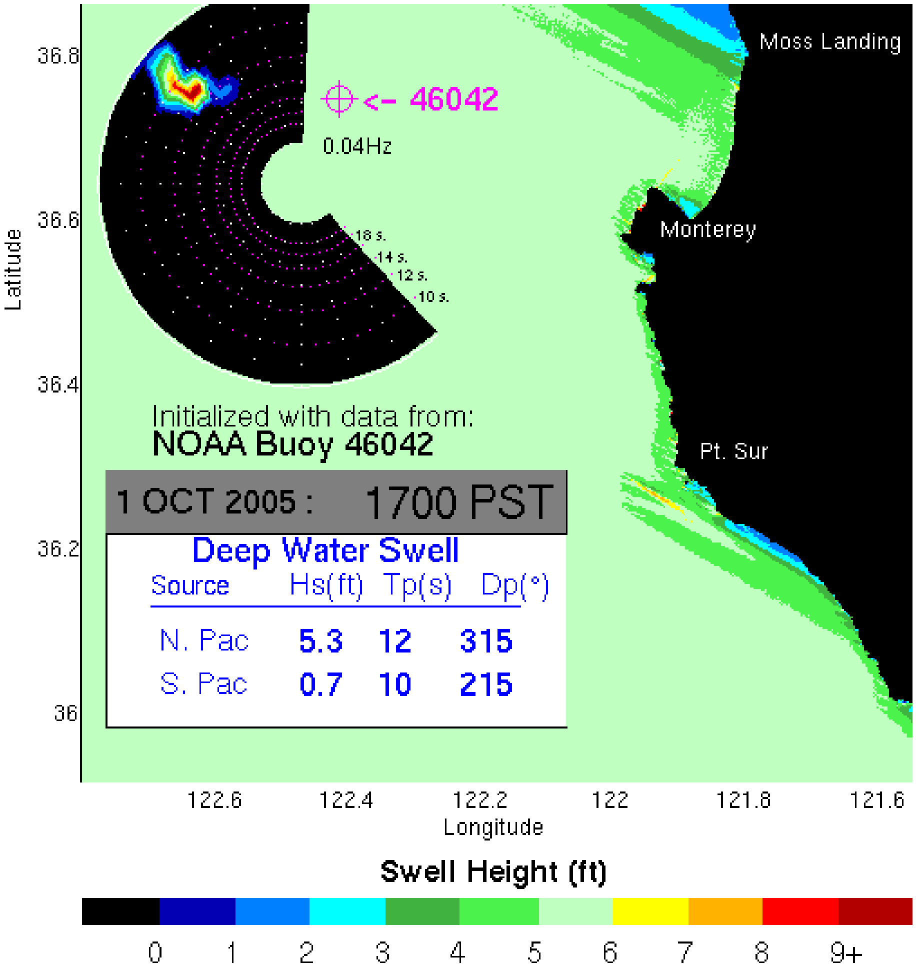

Figure 1. Predominant waves from the northwest showing Carmel River Beach is protected by the northern headlands.

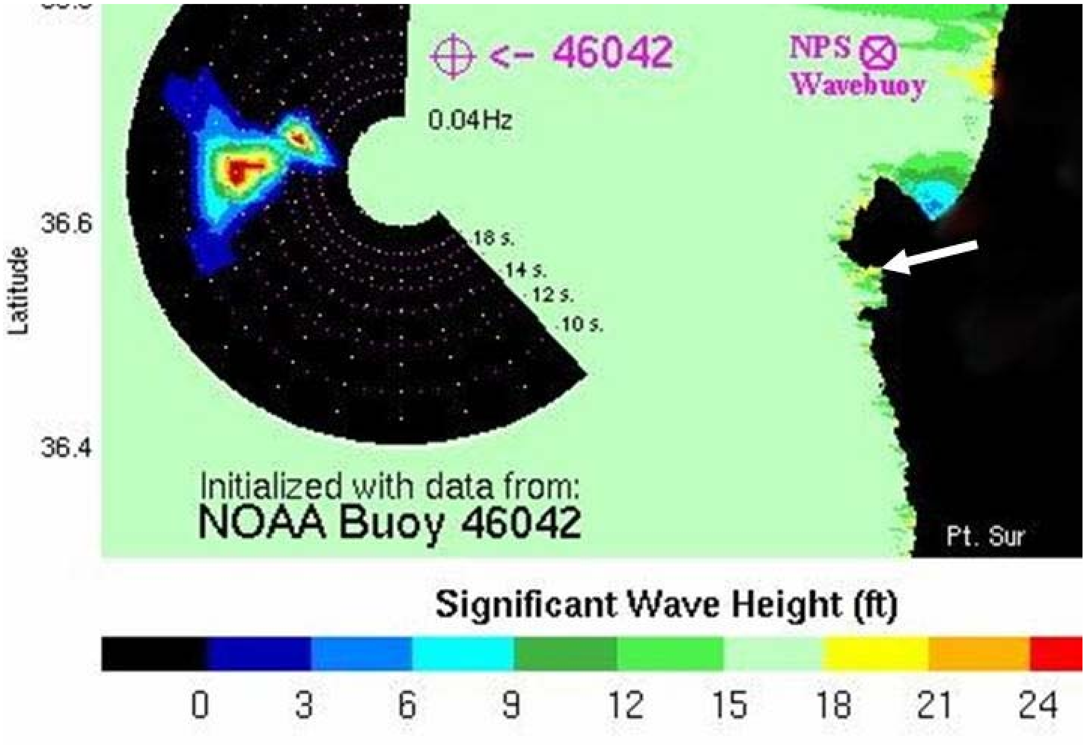

Figure 2. Large winter storm waves from the west focusing energy at Carmel River Beach (arrow).

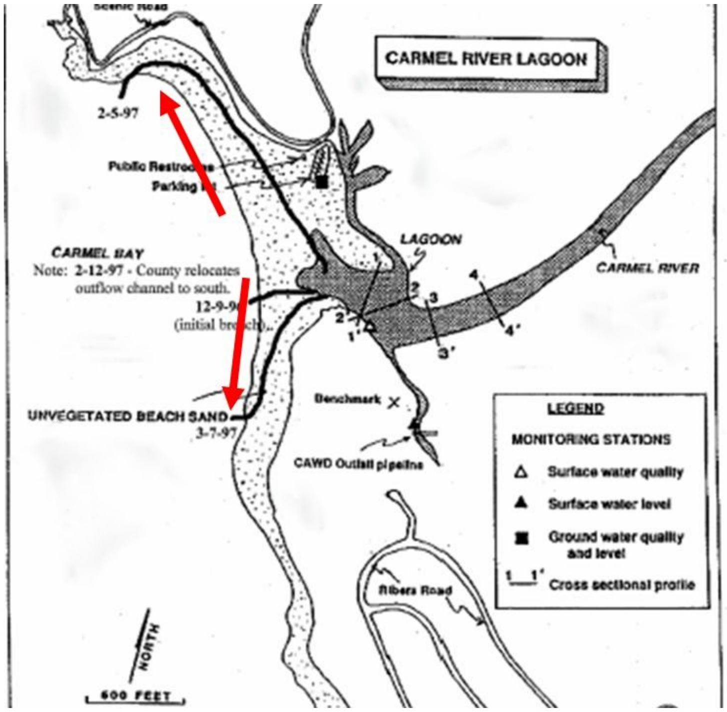

Figure 3. Direction of sediment transport (arrows) at the Carmel River Beach is to north in northern portion of the beach and to the south in the southern portion of the beach.

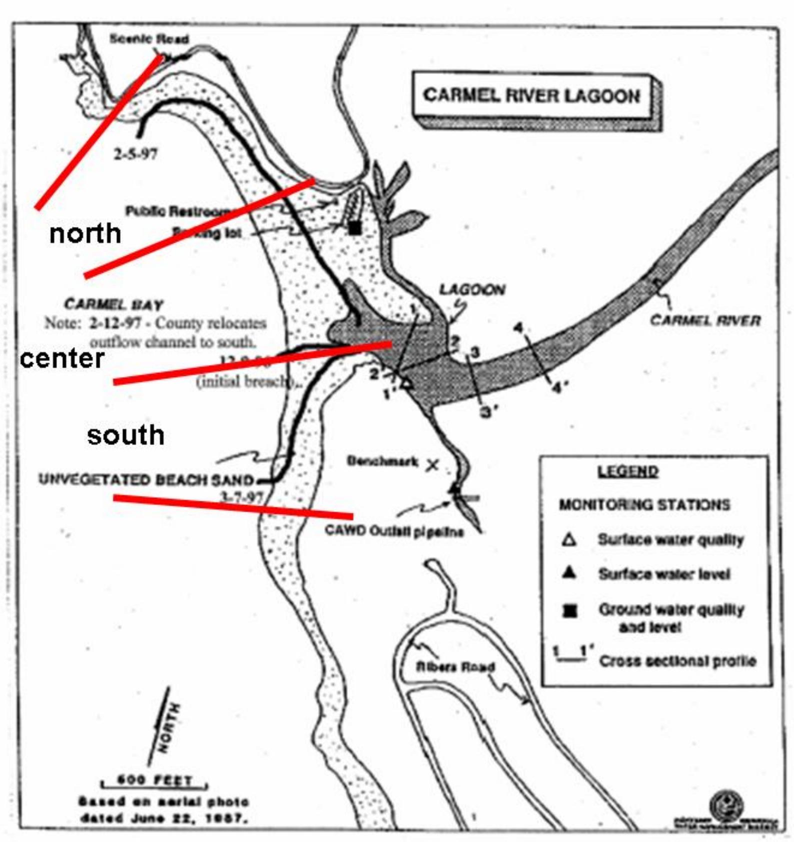

Figure 4. Lagoon opening designation areas to north, center and south for water year 1998. Adapted from G. James, MPWMD

Figure 5. 2003 aerial photo showing the rock basement of south channel.

Figure 6. Photo taken 30 September 2005 showing evidence of overtopping of berm (rack line back of berm and water in the back beach) and the narrow distance between lagoon and ocean.