Beach Recovery After an El Niño Winter along the Santa Cruz County Coast

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ABSTRACT

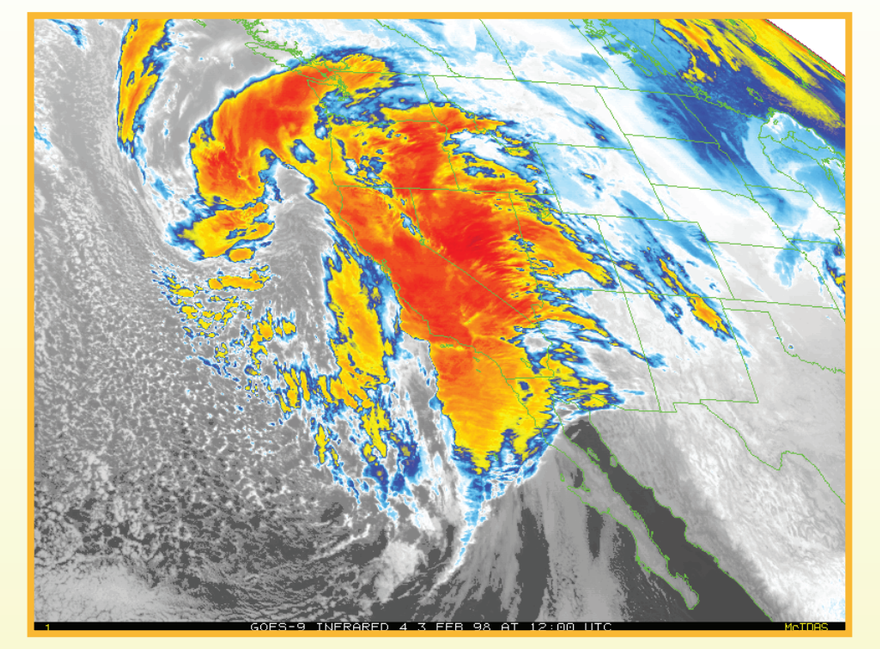
Beach profile response to an El Niño winter winter was monitored at ten beaches along a 40km stretch of Santa Cruz County Coast. The monitoring program, initiated in October 1997, consists of shore-normal (SN) profile lines surveyed monthly. The ten study sites occur along the open coast and within the Monterey Bay and include (from west to east) Scott Creek, Yellow Bank, Natural Bridges, Santa Cruz Lighthouse, Cowell, Santa Cruz Main, Seabright, Twin Lakes, Corcoran Lagoon and Capitola Beaches. This study reviews the coastal effect of an El Niño event along the Santa Cruz County coast and assesses the correlation of beach profile response to wave energy distribution during an El Niño winter.

The coastal effects of the 1997-98 El Niño winter along the Santa Cruz County coast include increased sea level elevating tidal ranges, increased beach groundwater levels enhancing erosional processes and a large southerly wave event intensifying wave power reaching the coast. Precipitation records and wave data indicate that a large, wet, southerly storm passed over central California January 29, 1998 through February 8, 1998. Record rainfall and extreme wave heights combined to cause extensive erosion of south facing northern Monterey Bay beaches. A comparison of Point Reyes offshore wave data with Santa Cruz Harbor data further demonstrates that the wave energy of an offshore southerly swell carries more wave energy to the inner bay beaches than does a northerly swell. Beach profile response to the 1997-98 El Niño wave conditions confirms the effect of swell direction on wave energy distribution. Only whereas extensive beach retreat results in response to an extreme southerly wave event. This effect of swell direction on beach retreat is congruent with Natural Bridges and Santa Cruz Lighthouse beaches, initially categorized as open-coast beaches based on offshore gradient. Beach profile response and morphology indicates wave exposure similar to inner bay beaches placing the northwest limit of the Monterey Bay at Terrace Point based on the initial occurrence of significant wave refraction. Variations in the amount of beach retreat between sites are attributed to coastline geometry and its influence on wave energy distribution along the inner bay. Determining the effect of swell direction on open-ocean beach morphology is inconclusive and requires continued monitoring. extreme northerly wave event along the inner bay,

The profile data show a progression of beach erosion from October 1997 to February 1998 with rapid erosion occurring in late-January and early-February in response to an extreme southerly wave event. Yellow Bank beach deviates from the erosional sequence and beach change is mostly influenced by an extreme northerly wave event. Inner Monterey Bay beaches suffered more extensive erosion than the open-ocean beaches. Yellow Bank Beach underwent the least amount of retreat (-18m), with Corcoran Lagoon Beach suffering a maximum amount of retreat (-87m). The decrease in berm elevation varied from -0.9m at Santa Cruz Main Beach to -4m at Corcoran Lagoon Beach. The open-ocean beaches maintained a high berm and steep beach face throughout the winter and adjustment to a flatter dissipative erosional beach face was minimal. A retreating, elevated berm throughout the erosional series of most inner bay beaches may provide insight to the process of raising base beach elevations.

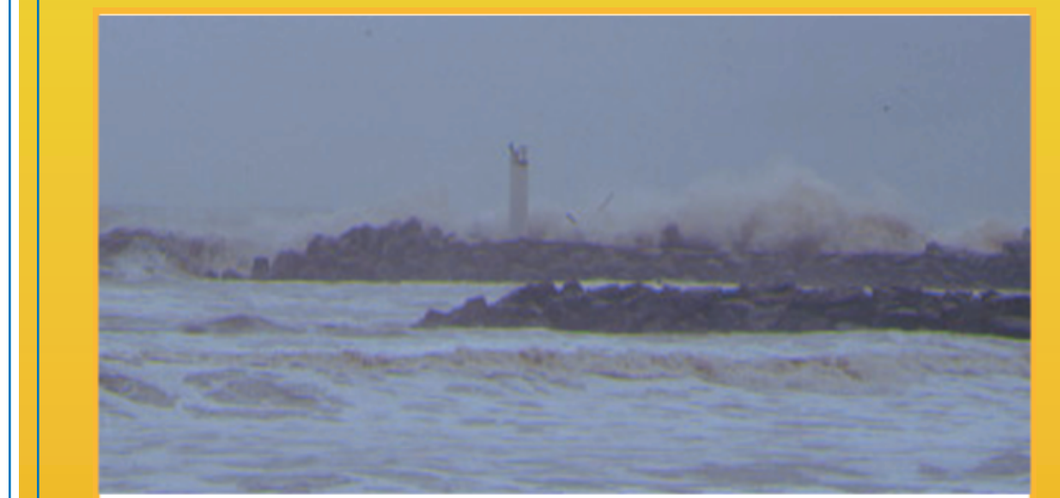
The erosion was followed by substantial recovery. Recovery profiles on wide flat beaches preserve a portion of the February 1998 erosional beach profile as a backbeach scarp. Prompt beach recovery occurred with most beaches returning to or exceeding the previous summer's beach width by October 1998, however, with a slightly decreased beach berm elevation. Paleo-channels offshore of profile locations are ideal for storing and/or supplying sediment to replenish beaches and may have promoted the rapid beach recovery. All profile locations with the exception of Santa Cruz Lighthouse beach recovered to within 10m of the pre-El Niño beach width.

February 3, 1998

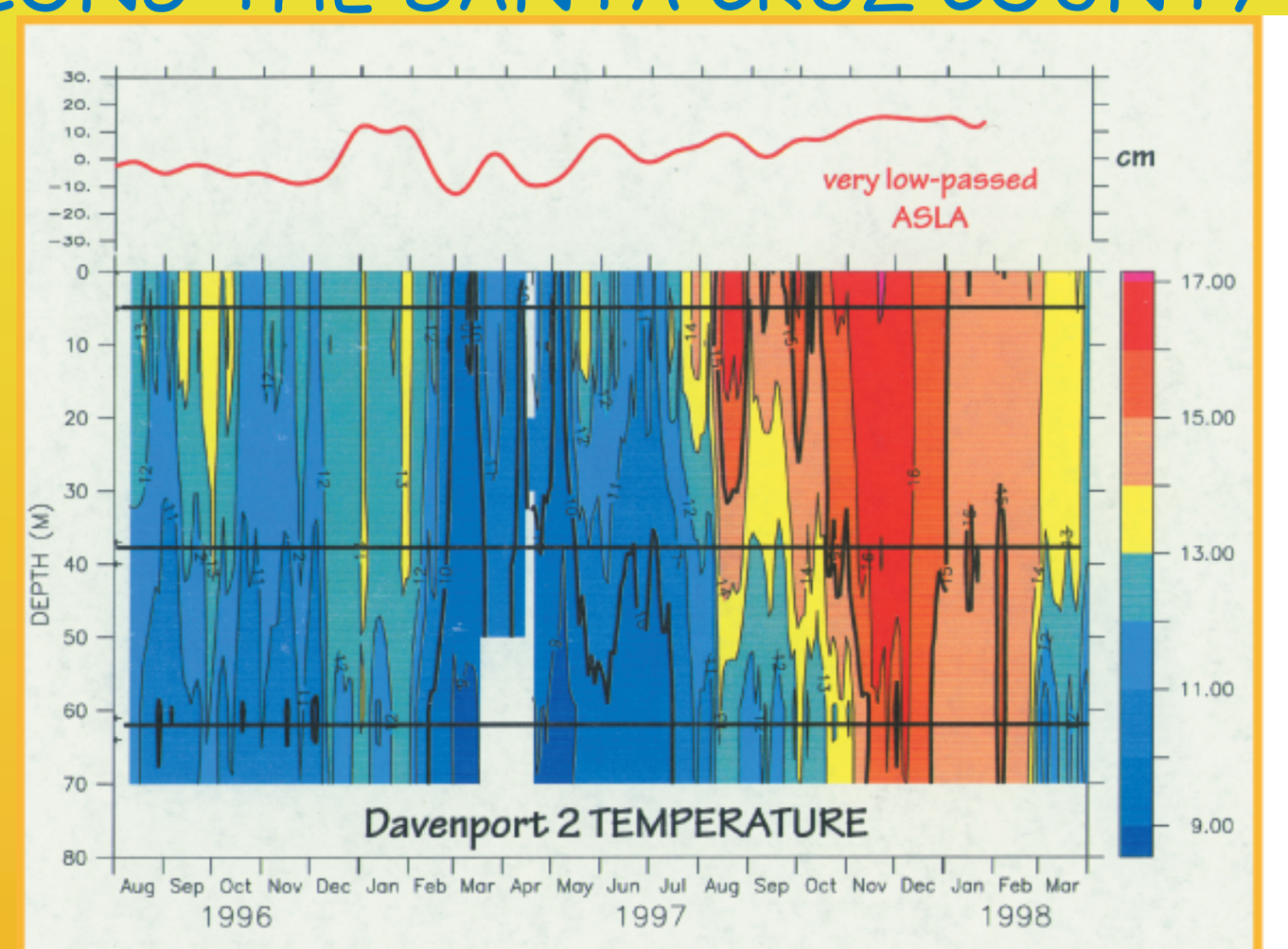


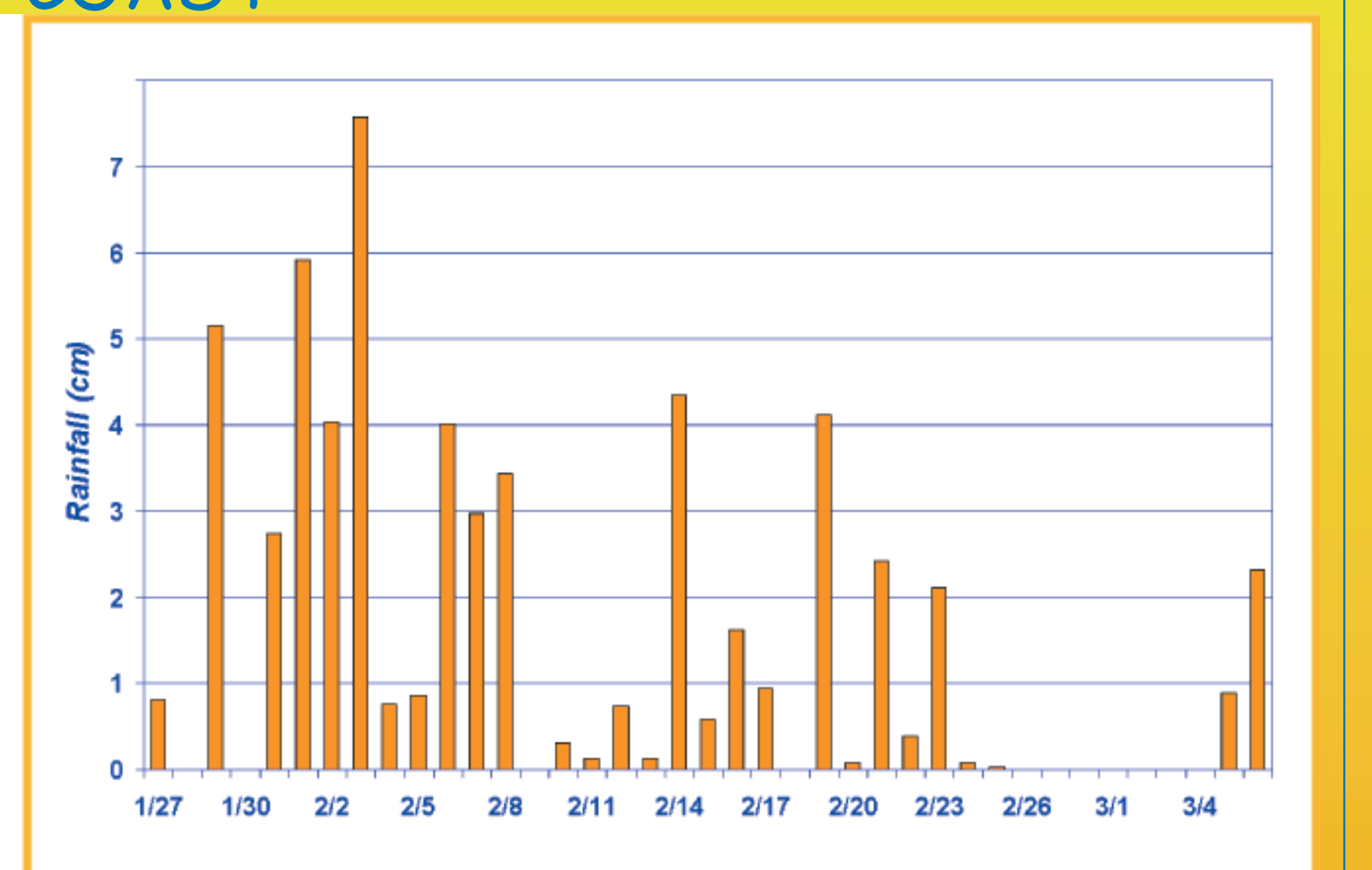
THE 1997-98 EL NI„O WINTER ALONG THE SANTA CRUZ COUNTY COAST

During El Niño conditions, the atmospheric pressure gradient across the equatorial Pacific deteriorates and switches causing a weakening or reversal of the trade winds (NOAA, 1998, Stortlazzi and Griggs, 1998). The warm surface water accumulates along the eastern Pacific and spread laterally along the coast of the Americas increasing sea surface temperatures resulting in increased precipitation as well as elevated sea levels.



Extreme waves reaching inner bay on February 8, 1998. Photograph taken from Twin Lakes Beach toward harbor entrance.

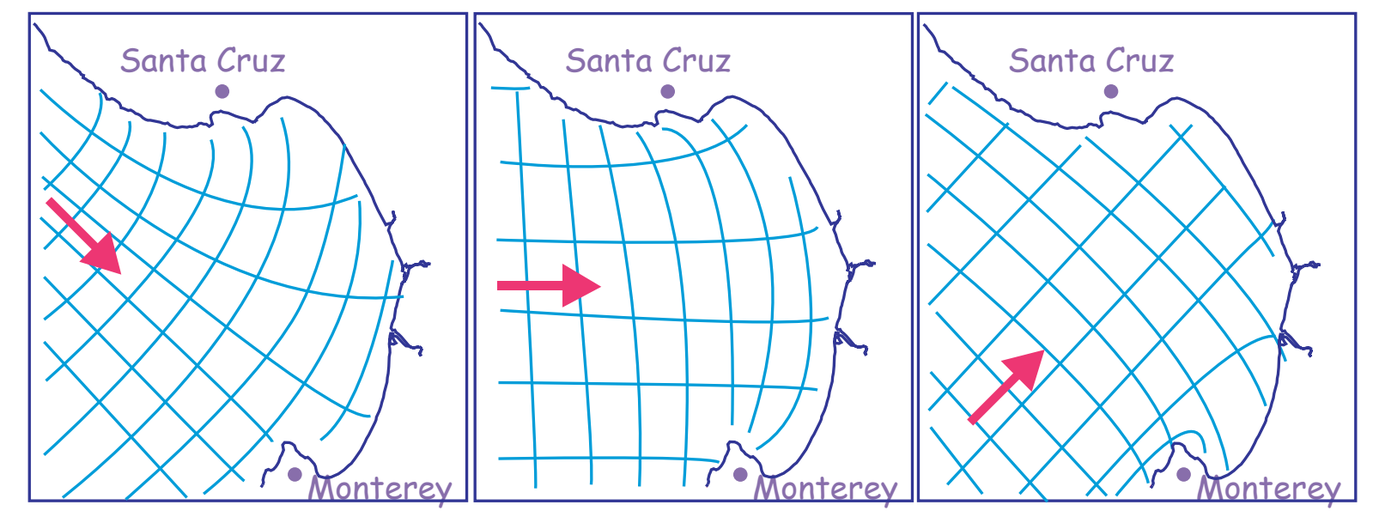




Off the Davenport coast along central California, sea surface temperatures increased to 16¼C mid-November 1997 to a depth of 60m and remained high (14¼C) until late-February 1998; an increase from the previous year of 2-4¼C (Ryan, H.F., personal communication). The increased water temperature enhanced evaporation leading to one of the warmest and wettest periods in 104 years (NCDC, 1998). From December 1997 through February 1998 the central California coast received 210%-230% the average precipitation calculated for these months, totaling 96cm for the Santa Cruz area. The February 1998 rainfall record for Santa Cruz shows that between January 29, 1998 and February 8, 1998, a total of 37cm of rain fell with the highest daily rainfall measuring 7.5cm on February 3, 1998 (USGS, 1998, 1999). The amount of rain received in this short time is significant and may affect beach processes by elevating beach groundwater levels leading to 1) decreased infiltration of swash and backwash and 2) increased beachface seepage, both inducing fluidization of sediment and promoting entrainment (Baird and Horn, 1996). Unfortunately, we did not monitor beach groundwater changes over the course of the study, but should be noted as conducive to erosional beach processes.

Early February, sea surface elevations off the coast of Davenport reached a maximum. Strong southerly winds, very low atmospheric pressure, and thermal expansion combined to elevate sea level 70cm above the predicted tide level (Ryan, H.F., personal communication). The increase in base sea level elevation affects beaches by increasing tidal heights thereby increasing wave run-up heights.

WAVE REFRACTION TO VARYING SWELL DIRECTIONS

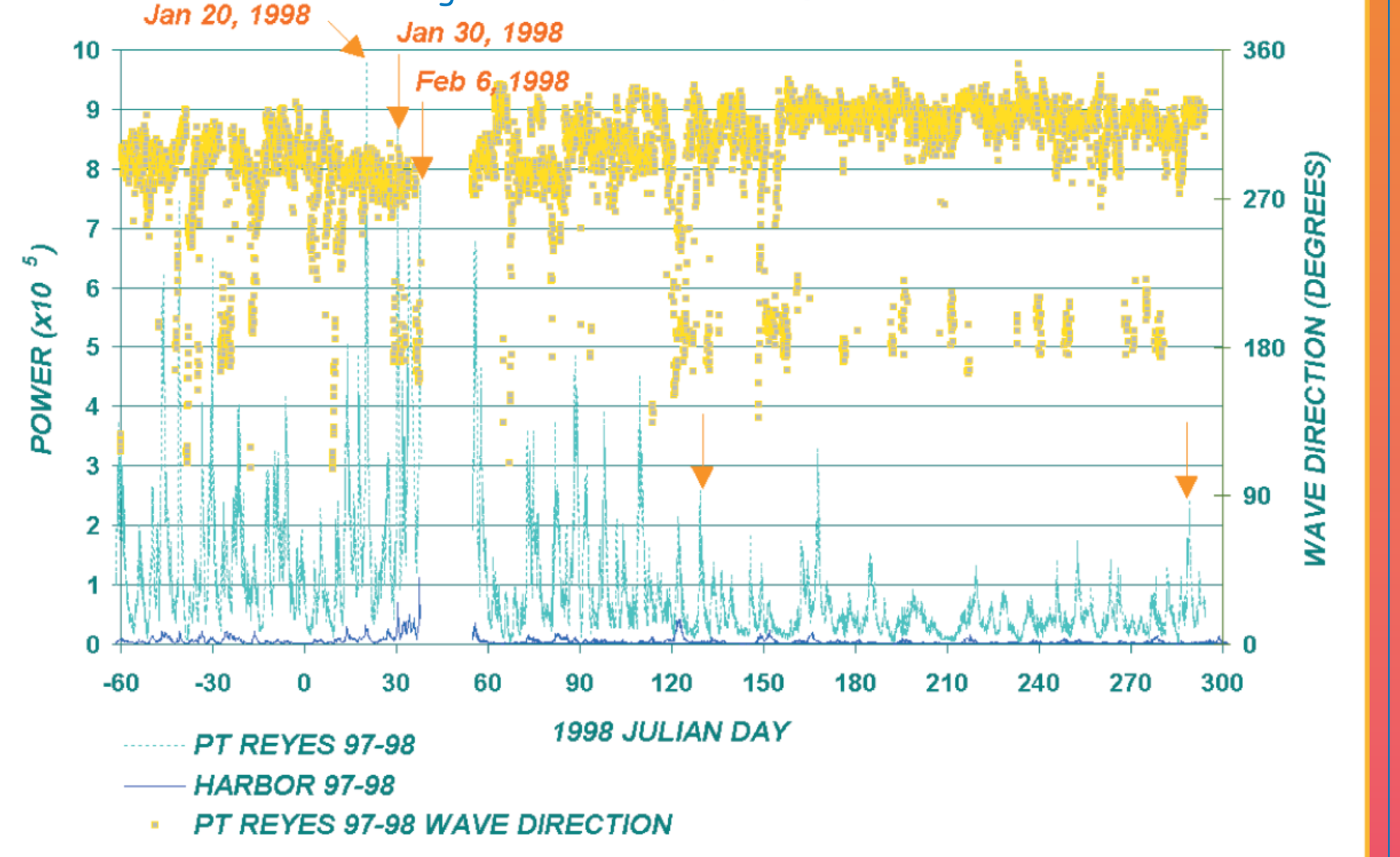


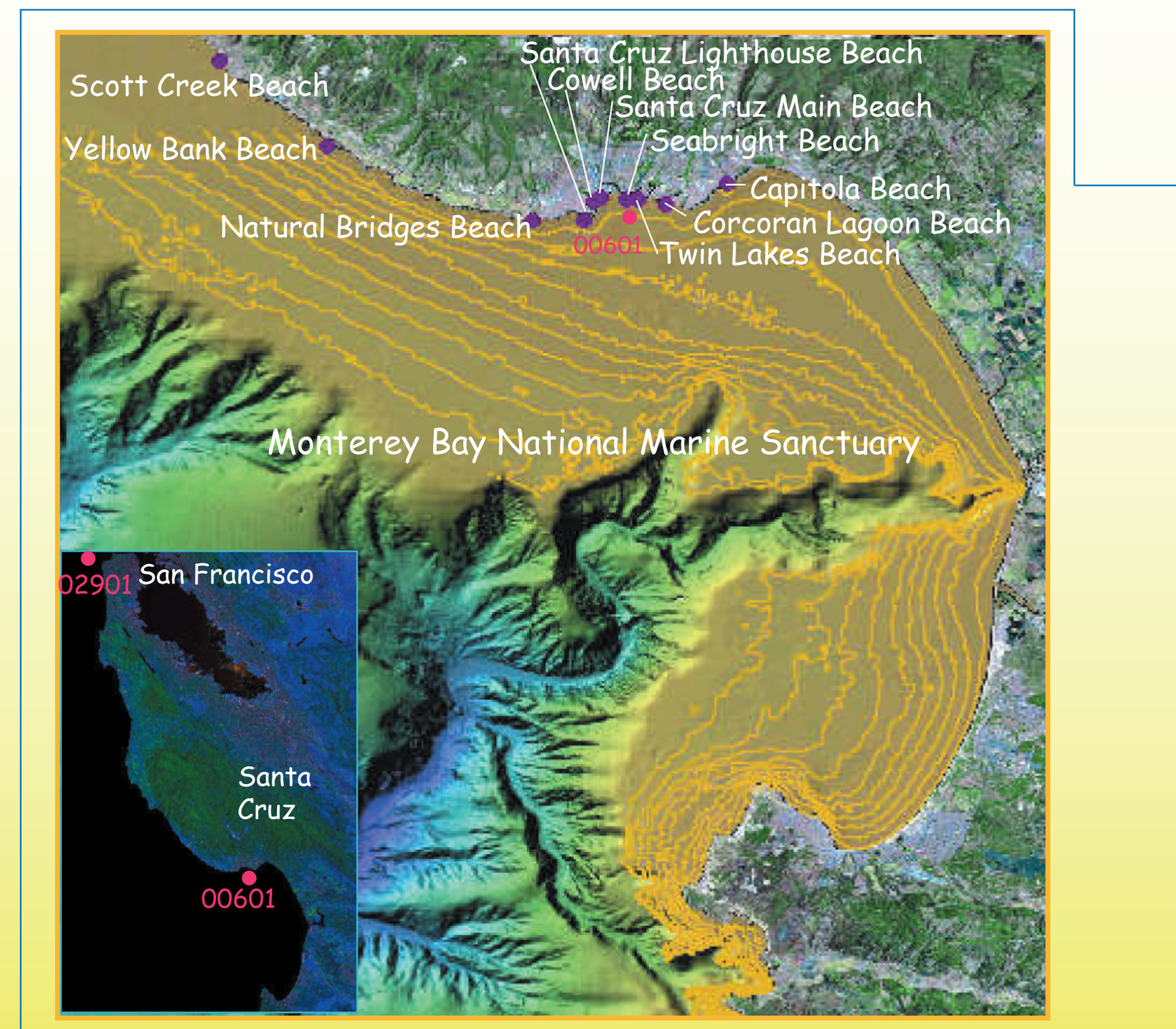
Adapted from Wiegel 1965

During an El Niño winter, waves predominantly approach from the northwest, although changes in atmospheric pressure gradients and their locations increase the likelihood of large wave events approaching from the south (Stortlazzi and Griggs, 1998). The change in wave approach greatly affects the wave energy distribution along the south facing Santa Cruz County coast (Wiegel, 1965). Terrace Point, Point Santa Cruz and Pleasure Point shelter portions of the Monterey Bay coastline from the predominant northwest wave approach. Wave energy refracted around these points is distributed over a large area, decreasing the amount of wave power reaching the sheltered inner bay beaches. A southward shift in wave direction has a more direct approach leading to higher wave energy reaching the Santa Cruz coast. The wave energy distribution along the outer bay is much less affected by variations in wave direction as little dissipation occurs with varying swell direction.

Records from Pt. Reyes Buoy and Santa Cruz Harbor Array illustrate a relationship between offshore wave direction and wave power reaching the Northern Monterey Bay coast during the 1997-98 winter. The maximum wave power for Pt. Reyes occurs on January 20th, but is represented in the Santa Cruz data as a conservative peak. This event coincides with a northerly wave approach, which undergoes significant refraction before reaching the Santa Cruz County coast. The wave heights associated with the January 20th event reached nearly 8m offshore and decreased to 2m along northern Monterey Bay. Both the Pt. Reyes and the Santa Cruz records show outstanding wave power peaks on January 30th and February 6th. These events coincide with a southerly wave approach. Again, the wave heights reached 8m offshore and remained as high as 4.5m along northern Monterey Bay. Unfortunately, both buoys fail after February 6th, possibly missing the peak wave conditions during this sequence of storms. Observations and photographs indicate extremely large waves pounding the central California coast on February 8, 1998.

Point Reyes and Santa Cruz Wave Power Comparison against Offshore Wave Direction




Scott Creek Beach
Yellow Bank Beach
Natural Bridges Beach
Santa Cruz Lighthouse Beach
Cowell Beach
Santa Cruz Main Beach
Seabright Beach
Capitola Beach
Corcoran Lagoon Beach
Twin Lakes Beach
Monterey Bay National Marine Sanctuary
San Francisco
Santa Cruz

BEACH PROFILE STUDY

The beach sites are located along a 40km stretch of coast. Most of the beach profiling locations are set in stream valley or lagoon-type environments, where flooding streams and lagoons could affect the beach groundwater levels during the late-January/early-February storms. All the study sites face southward with the most exposed beaches facing southwest and the most protected beaches facing southeast.

The beach locations are categorized into open coast and inner bay beaches by their offshore gradient. The four open coast beaches have a steep offshore bathymetric gradient while the inner bay beaches have a mild offshore bathymetric gradient. The two categories define possible changes in wave energy distribution as decreasing offshore gradient increases bottom friction, thereby decreasing wave energy reaching the beach.

Natural Bridges and Santa Cruz Lighthouse beaches, initially categorized as open-coast beaches correspond more directly with inner bay beach morphology and profile response. Although their offshore bathymetry better correlates with open ocean beaches, wave exposure is the primary factor contributing to their beach

BEACH NAME	FACING DIRECTION	OFFSHORE GRADIENT*	WAVE EXPOSURE	BEACH TYPE
SCOTT CREEK	SW	-16	OPEN OCEAN	STREAM MOUTH
YELLOW BANK	SW	-16	OPEN OCEAN	STREAM MOUTH
NATURAL BRIDGES	S	-16	SEMI-EXPOSED	STREAM MOUTH
SANTA CRUZ LIGHTHOUSE	SSW	-12	SEMI-EXPOSED	POCKET BEACH
COWELL	SE	-7	PROTECTED	STREAM MOUTH
SANTA CRUZ MAIN	SSW	-7	PROTECTED	STREAM MOUTH
SEABRIGHT	SSW	-7	SEMI-PROTECTED	POCKET BEACH
TWIN LAKES	SSW	-7	SEMI-PROTECTED	LAGOON
CORCORAN LAGOON	SW	-7	SEMI-PROTECTED	LAGOON
CAPITOLA	SSW	-7	PROTECTED	STREAM MOUTH

OPEN COAST / INNER BAY

Beach Characteristics
*Offshore Slope of depth given as a percent and determined by slope of depth (-60m) and distance

RESULTS

Beach Profile Extremes

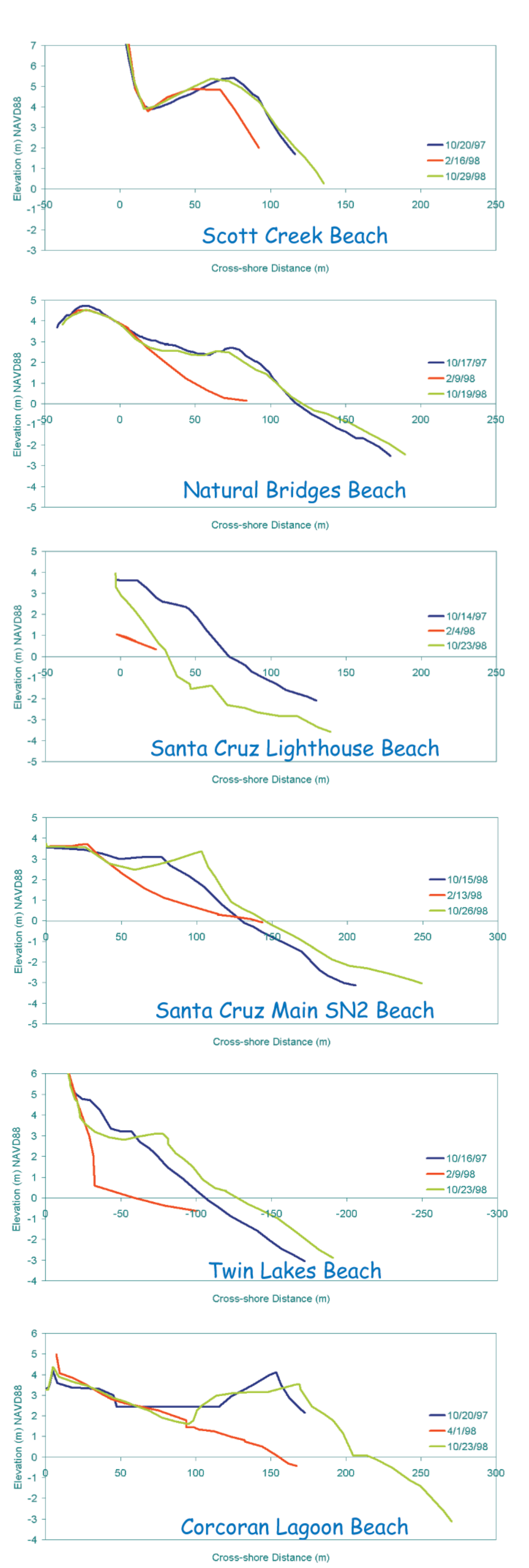
The open-coast beaches are incongruous in the amount of erosion and recovery during the increased wave activity of 1997-98. The beaches exposed to the open ocean showed the least amount of beach retreat while the semi-exposed beaches just outside Monterey Bay suffered severe beach retreat over the 1997-1998 winter. **Scott Creek** and Yellow Bank beaches show the February erosional profile displaced landward and nearly parallel to their October accretional profile. Whereas, **Natural Bridges** and **Santa Cruz Lighthouse** beaches differ markedly from the open ocean beach response possibly resulting from differences in the initial beach morphology, specifically berm elevation and wave exposure. **Natural Bridges** beach shows a non-parallel, gently curved, greatly retreated, erosional beach profile in response to the February 1998 storms. The February 1998 erosional beach face is not preserved as a beach berm on this wide, duned beach. **Santa Cruz Lighthouse** beach, a small pocket beach backed by coastal cliffs, was eroded to the base of the cliffs during the height of the winter storms. The erosional profile at **Santa Cruz Lighthouse** beach consists of four points surveyed during severe wave conditions and defines the beach stripped of sand. The amount of erosion is restricted by bedrock occurrence in this case. **Santa Cruz Lighthouse** beach exhibits the slowest recovery with only a beach face present by October 1998.

Cowell, **Santa Cruz Main** and Seabright beaches erode substantially, although recover to within 10m of the October 1997 beach width by the following year. The October 1998 beach morphology lacks a wedge of sand fronting the present beach scarp. The semi-protected beaches, **Twin Lakes** beach and **Corcoran Lagoon** beach, suffer extreme beach erosion in response to the wave activity of the 1997-98 winter. The occurrence of a bedrock outcrop, outlined by the February 1998 profile, limits beach retreat at **Twin Lakes** beach. This beach response is similar to that of **Santa Cruz Lighthouse** beach, however, the October 1998 profile at **Twin Lakes** shows full recovery unlike the **Santa Cruz Lighthouse** beach. **Corcoran Lagoon** beach sustained the maximum beach width decrease measuring -87m. Of all the inner bay beaches, **Corcoran Lagoon** generally maintains a high berm crest elevation comparable to that of **Scott Creek** and Yellow Bank beaches illustrated by the October 1997 profile, which may denote exposure to increased wave energy. The lagoon outlet crosses the middle of the **Corcoran Lagoon** profile indicated by the low points of both October profiles, but is absent from the February profile when wave energy scoured the entire beach exposing bedrock in the beachface and closing the road along the backbeach. Beach width recovery at **Corcoran Lagoon** beach is rapid, although the berm crest elevation does not reach its initial elevation by the October 1998 profile.

Anomalous Deposits Accumulate in Response to the 1997-98 El Niño winter.

A deposit of sand closed the entrance to the Santa Cruz Harbor after the height of the February storms. A large body of sand accumulated adjacent to Cowell beach. Possible sources include sediment from the flooding of the San Lorenzo River and/or littoral transport of sand from Santa Cruz Lighthouse beach. Debris from flooding rivers covered Cowell, Santa

BEACH PROFILE EXTREMES



Beach Profile Envelope

The beach profile envelopes are grouped into three envelope configurations depending on their offshore characteristics. The **hourglass configuration** shows extensive beach width change in the subaerial beach, minimal beach width change near the MLLW, and increasing change in the offshore, rendering the hourglass shape. Beaches with this shape include Yellow Bank, **Santa Cruz Main Beach** SN1 and SN2, and Capitola profiles. The **parallel configuration** shows extensive beach change, throughout the length of the profile. Beaches characteristic of the parallel configuration include **Scott Creek**, Natural Bridges, Santa Cruz Lighthouse, and Seabright SN2. Finally, the **narrowing configuration** shows extensive beach width change in the subaerial beach with decreasing change offshore and include Seabright SN1, Twin Lakes and **Corcoran Lagoon** profiles. The slope of Seabright SN1 profile envelop changes significantly near the MLLW elevation whereas Twin Lakes and **Corcoran Lagoon** profile envelopes narrow without change in slope. The relationship between profile configuration, beach processes and wave energy distribution can not be resolved on account of inconsistent offshore profile length.

The compiled data show that the open-ocean beaches, Scott Creek and Yellow Bank are marked by a steep beach face and an initial high berm crest elevation (4.5m - 5m) maintained throughout the winter. The rest of the profile envelopes vary between sites, but typically show a gentle, non parallel, beach face and an initial lower berm crest elevation (~3.5m) that is not always maintained throughout the winter.

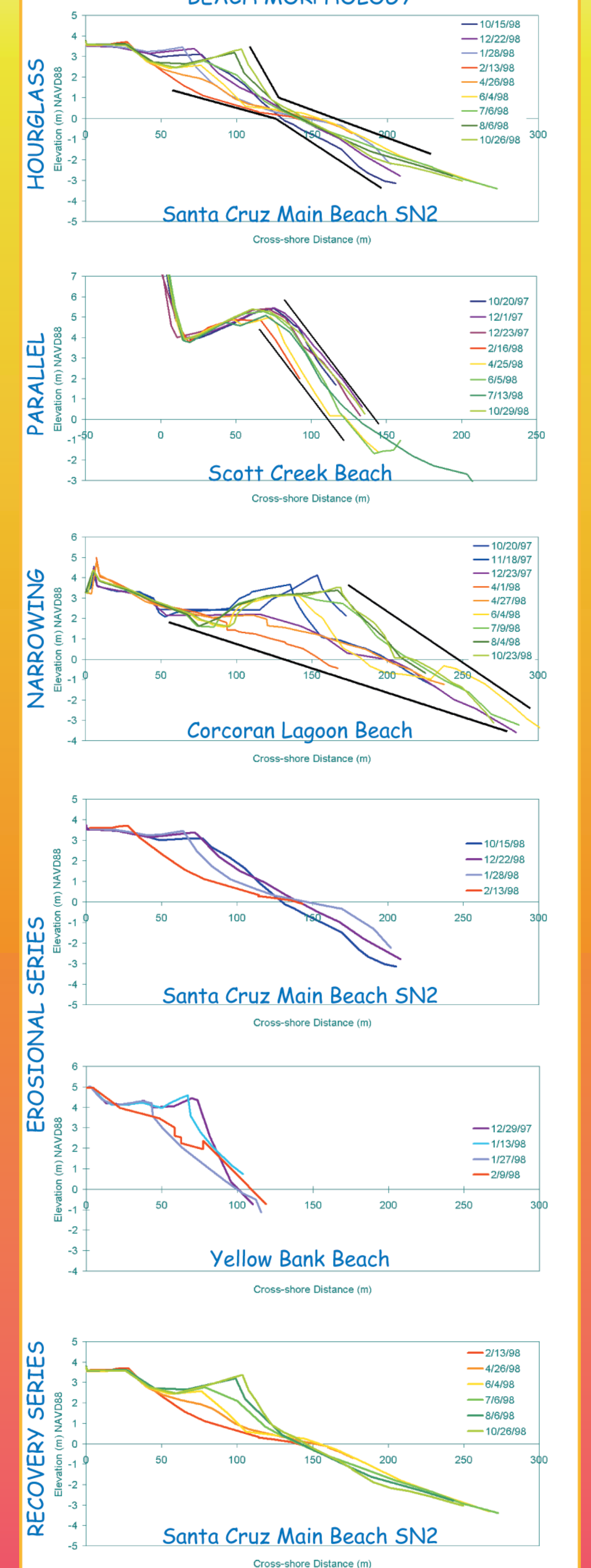
Beach Erosion and Recovery

The **Erosional Series** shows a sequential decrease in beach width beginning October 1997 and reaching a minimum in February 1998. **Yellow Bank** beach fluctuates between erosion and accretion throughout the 1997-98 winter. From December 29, 1997 to February 9, 1998 erosion is predominant. The maximum beach loss occurs between January 13, 1998 and January 27, 1998 in response to the large northerly wave event of January 20, 1998 indicating that open-ocean beaches may be less sensitive to wave direction than the inner bay beaches. At all other beaches the most erosion occurs between January 28th and February 13th, coinciding with the largest and longest sequence of southern winter storms. Along with decreasing beach width, the steep accretional, October 1997, beach face slope sequentially adjusts to a flatter, concave-up, dissipative beach face slope. The extent of the adjustment coincides with the amount of wave exposure except when flattening is impeded by the presence of underlying bedrock. The open ocean beaches show minimal adjustment whereas the rest of the beaches flatten significantly, with variations between sites.

An elevated berm accompanying a narrowing beach is apparent at all sites except Scott Creek beach, Yellow Bank beach, Cowell beach, and Santa Cruz Main Beach SN1. At Scott Creek beach, profile frequency may not have captured this effect, and at **Yellow Bank** beach it is only evident between the December 29, 1997 profile and the January 13, 1997 profile. The presence, location and size of an offshore bar combined with a high berm elevation may affect this beach process. Cowell Beach and **Main Beach** are the most sheltered from wave energy, and waves reaching these beaches may not have received sufficient wave energy to create a retreating, elevated berm. Instead, the waves cut away at the pre-existing beach berm. The increased berm elevation during storm events may provide a vital mechanism for raising beach elevations. During moderate winters, the elevated retreating berm may be preserved throughout the summer accretional cycle followed by further increase in beach elevation during subsequent winters. This beach process will be important in raising the beach elevations following the 1997-1998 El Niño winter.

The **Recovery Series** illustrates the progressive increase in beach width and beach berm elevation between February 1998 and October 1998. Most recovery transpires by early July with a few beaches exhibiting ample recovery as early as late April. The flat, dissipative erosional beach face slope progressively steepens and accretes as the beach berm progrades seaward. The recovery does not include increase in beach elevations seaward of the February erosional profile except, perhaps at the berm crest. On wide, flat inner bay beaches (Cowell, **Santa Cruz Main**, and Seabright Beaches), the February 1998 erosional beach face is

BEACH MORPHOLOGY

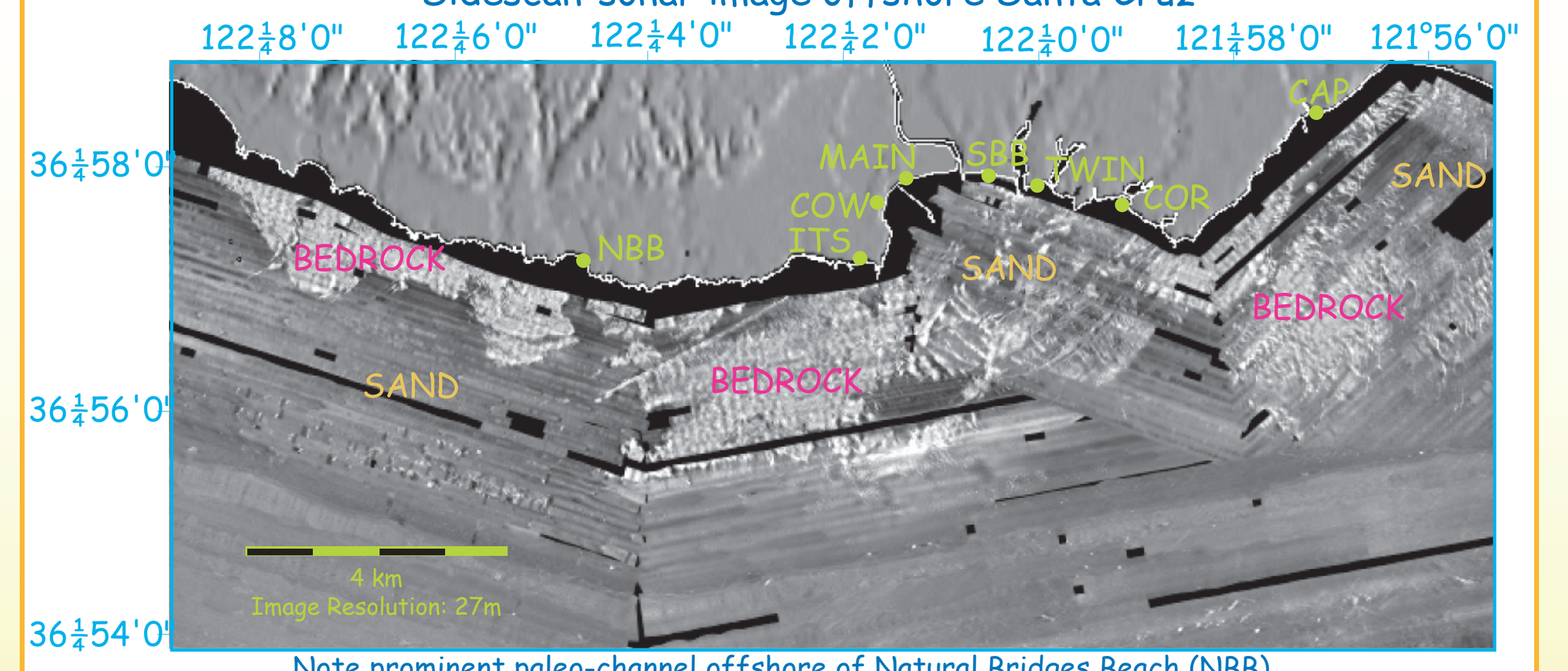


DISCUSSION

The prompt recovery of all the beaches was unexpected. Sidescan-sonar and seismic reflection data indicate offshore paleo-channels associated with beach profiling locations, except offshore of Santa Cruz Lighthouse beach (Anima, R.J., 1994). The presence of a paleo-channel offers ideal storage of sediment during high wave energy when sand is removed from the beach into the offshore. Headlands or submerged bedrock outcrops bound paleo-channels impeding rapid down coast transport of sediment. Subsequently, paleo-channels offer an ideal source of sediment with which to replenish the beach. The absence of a paleo-channel at Santa Cruz Lighthouse beach may be responsible for the slow beach recovery. Offshore bedrock offers minimal capacity for trapping and storing sand removed from the beach during high wave activity. Longshore transport readily carries the sediment beyond Pt. Santa Cruz removing a viable source for beach replenishment.

The regional trend of beach width decrease mimics the shape of the coastline and may reflect the influence of coastline geometry on wave energy distribution along the inner bay coast. The open coast, Scott Creek and Yellow Bank, beaches receive large waves from both the north and south swells and appear to accommodate high wave energy well with minimal beach narrowing, whereas the inner bay beaches receive little wave energy from north swells and erode severely to large south swells. Cowell, Santa Cruz Main Beach, Seabright and Capitola beaches experience comparable beach narrowing, although, their profile morphology vary distinguishably. The variations in beach morphology may be attributed to grain size differences, nearshore morphology variations, or groundwater infiltration variations. Corcoran Lagoon Beach, located near Pleasure Point, is the most exposed along the south facing stretch of the inner bay and likewise experiences the most extensive beach retreat. Although the decrease in beach width for Twin Lakes Beach compares to that of the sheltered beaches, the bedrock outcrop limits the amount

Sidescan-sonar image offshore Santa Cruz



Note prominent paleo-channel offshore of Natural Bridges Beach (NBB)
Data and image from Anima, R.J., 1994

Regional Beach Erosion from October 1997 to February 1998

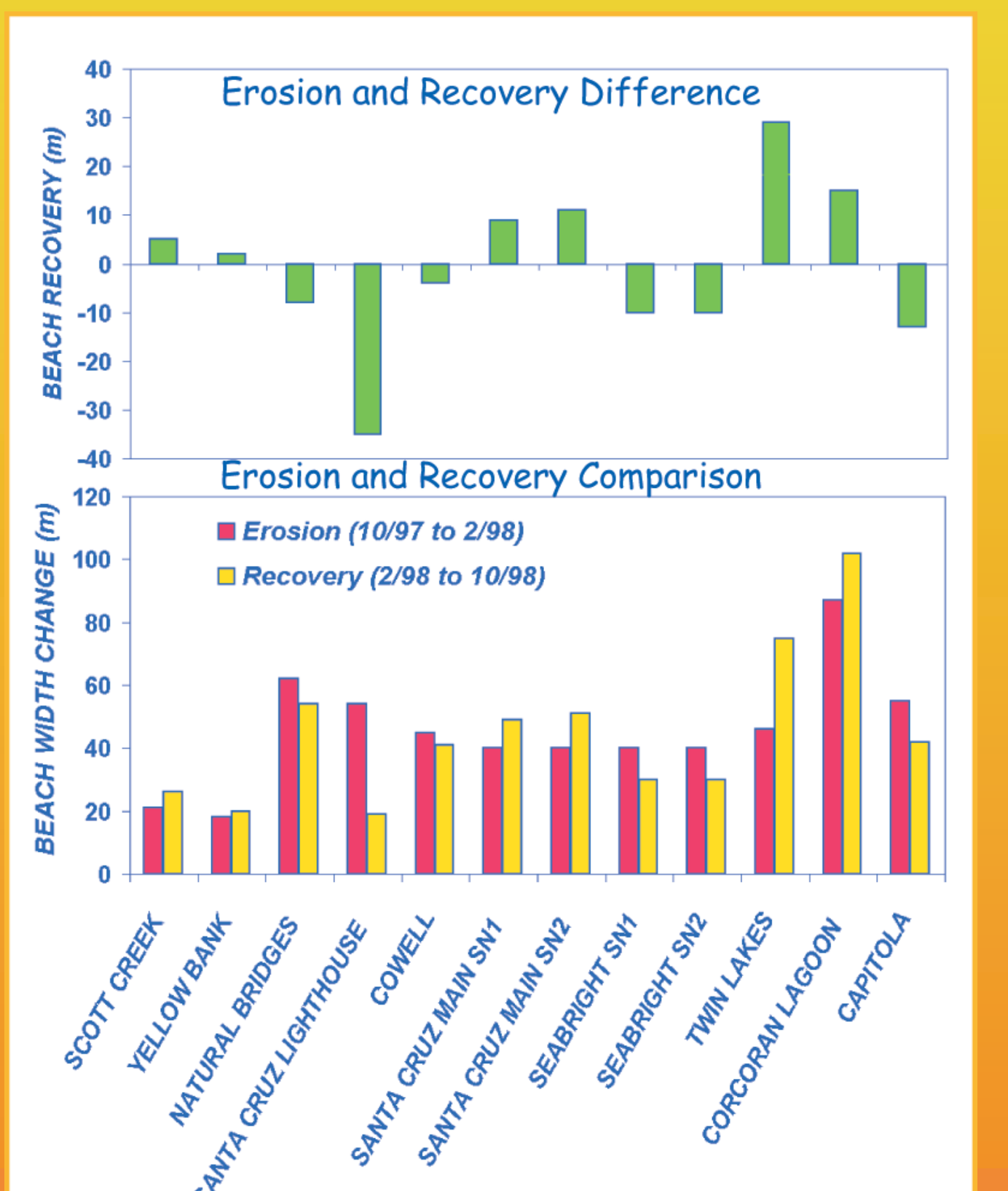
Santa Cruz Coast looking east. Point Santa Cruz west of wharf and Pleasure Point east of wharf. Profile sites along this stretch of coast include Santa Cruz Lighthouse beach east to Capitola. The beach width change is represented by the difference between the minimum and maximum beach widths at the MHHW contour between October 1997 and February 1998.
Legend of Abbreviations: ITS-Santa Cruz Lighthouse Beach; COW-Cowell Beach; MAIN-Santa Cruz Main Beach; SBB-Seabright Beach; TWIN-Twin Lakes Beach; COR-Corcoran Lagoon Beach; CAP-Capitola Beach.

Summary of Beach Change

BEACH NAME	OCTOBER 1997		FEBRUARY 1998		OCTOBER 1998		EROSION 10/97 TO 2/98		RECOVERY 2/98 TO 10/98	
METERS	BW	BH	BW	BH	BW	BH	BW	BH	BW	BH
SCOTT CREEK	117	5.4	96	3.9	122	5.4	-21	-1.5	26	1.5
YELLOW BANK	88	4.4	70	2.6	90	4.2	-18	-1.8	20	1.6
NATURAL BRIDGES	142	2.7	80	0.2	134	2.4	-62	-2.5	54	2.2
SANTA CRUZ LIGHTHOUSE	54	2.3	0	0.3	19	N/A	-54	<2.0	19	N/A
COWELL	74	3.2	29	0.4	70	3.2	-45	-2.8	41	2.8
SANTA CRUZ MAIN	117	2.9	77	1.1	126	2.9	-40	-1.8	49	1.8
	105	3.1	65	1.2	116	3.4	-40	-0.9	51	2.2
SEABRIGHT	148	3.8	108	0.2	138	3.8	-40	-3.6	30	3.6
	153	3.6	113	1.4	143	3	-40	-2.2	30	1.6
TWIN LAKES	68	3.2	22	0	97	3.1	-46	-3.2	75	3.1
CORCORAN LAGOON	180	4.2	93	0.2	195	3.6	-87	-4	102	3.4
CAPITOLA	75	2.8	20	0.5	62	2.8	-55	-2.3	42	2.3

The amount of erosion is similar to the amount of recovery with the exception of Santa Cruz Lighthouse and Twin Lakes beaches. Highlighting the difference between the amount of erosion and the amount of recovery, the beach recovery graph shows that most of the beaches returned to within 10m of the October 1997 beach width. Twin Lakes exceeds its October 1997 width by ~30m likely resulting from beach nourishment from the harbor dredging. Santa Cruz Lighthouse beach is deficient by ~30m.

Erosion and Recovery Difference



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