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San Onofre Beach Study

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### Publication Date

1989-10-01

SAN ONOFRE BEACH STUDY

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October 1989

SIO Reference Series #89-20

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## SUMMARY AND CONCLUSIONS

The protracted construction activity at San Onofre Nuclear Generating Station (SONGS) over the 20-year period from 1964 to 1984 caused significant changes in the local beach configuration. In particular, large quantities of sand supplied from cliff and offshore excavation contributed to substantial long-term, though temporary, beach widening. The occurrence of unusual flooding in the winters of 1978, 1980 and 1982 also contributed substantial quantities of sand to the area.

The construction of laydown pads, especially the long-lived pad in existence from 1974 to 1984 used for Units 2 and 3 construction, interrupted the longshore flow of sand and caused substantial widening of the local beaches, especially north of the plant. After removal of the pad, the sand trapped behind it seems to have bifurcated into two bulges that have remained relatively close to the site, consistent with directional wave observations.

Relatively rapid retreat of the beach has been observed directly in front of SONGS, and to a lesser degree to the north. As longshore and offshore wave induced transport continue over the coming years it is reasonable to expect that the local beaches, including the upcoast state park, will revert to their relatively narrow, pre-1964 condition.

## INTRODUCTION

Construction of the San Onofre Nuclear Generating Station (SONGS) from 1964 to 1984 has provided extensive opportunity to study beach and inner shelf physical and biological processes. Monitoring programs have been institutionalized at SONGS out of public concern to maintain water quality, species diversity and shoreline stability. Significant beach changes have occurred at SONGS as a result of construction activities. While measurement and other documentation efforts of these changes are relatively minor (compared to the massive efforts in biological monitoring) interesting results have been obtained that may have application in other areas.

This report describes the extensive beach changes that resulted from the construction of laydown pads and from the large amounts of beach sand contributed from cliff excavation and dredging activities. Preliminary results as well as a brief discussion of study objectives and the measurement program can be found in Wanetick and Flick (1986). Unedited profile data plots gathered as part of this study are contained in a recent report by Waldorf (1989).

It is shown that the added sand supply and the interruption of longshore transport by the laydown pads significantly widened the previously marginal San Onofre beaches. Long term changes in beach width are closely related to placement of the laydown pads that existed from 1964-66 for Unit 1 construction, and from 1974-1984 for Units 2 and 3 construction.

Removal of the later pad, in early 1985, precipitated a local narrowing of the beaches adjacent to SONGS. This has been documented by beach profile measurements carried out between May 1985 and September 1987 and by a final survey in January 1989 (Waldorf, 1989). There is strong evidence from the present measurements and from Osborne and Yeh (1989) that the laydown pad sand and the upcoast filet beach split into two sand bulges that have remained within a few kilometers (one north and one south) of SONGS to the present time. Grove, et al (1987) also noted this fact. Directional wave measurements (Schroeter, et al 1989) made during 1985-86 support the suggestion that there has been no persistent tendency to transport the laydown pad material downcoast systematically, contrary to expectation (Inman, 1987; Wanetick and Flick, 1986).

#### **SHORELINE DESCRIPTION**

San Onofre beach is located near the northern extent of the Oceanside littoral cell as shown in Figure 1. A littoral cell is defined as an isolated geographical compartment, usually bounded by headlands, that contains a complete cycle of sand sources, transport paths and sinks (Inman and Frautschy, 1965). The Oceanside cell is bounded on the north by Dana Point and on the south by Point La Jolla and the Scripps-La Jolla submarine canyons.

Historically, the major sources of sand for the cell have been the ephemeral rivers and streams and erosion of the miocene cliffs that back most of the reach. Both these sources are most

important during episodically occurring wet, stormy winters (Kuhn and Shepard, 1984; Simon, Li and Assoc., 1988) but landsliding can also contribute substantial amounts of cliff material in the San Onofre region (Ajina, 1987). Cliff erosion can occur either because of uncontrolled surface runoff, which causes gullying (Kuhn et al., 1980) or because of direct wave attack at the base. Wave induced cliff undermining and collapse is most serious when the beaches are narrow and unable to provide a wave dissipating buffer.

Waves generated by storms in the Pacific Ocean are the most important factor in transporting sand on-offshore and longshore in Southern California. In general, the Southern California Bight is a very complicated region for wave processes since the offshore islands greatly affect the wave exposure. The islands and associated shoals both shelter the coast by blocking wave energy and refract the wave trains that pass through the gaps (Pawka, et al, 1984). Wave exposure in the bight is a strong function of location and of deepwater wave approach angle. Pawka and Guza (1983) have calculated these dependencies for the San Diego region (roughly equivalent to the reach shown in Figure 1). San Onofre is highly sheltered from the west by Santa Catalina and San Nicholas and from the north-west by Santa Cruz, Santa Rosa and San Miguel islands. In contrast, San Onofre is relatively exposed to the southwest.

Seasonal changes in width have been extensively documented on Southern California beaches (see Thompson, 1987, for example). These changes are associated with seasonal variations in wave

energy and steepness (Aubrey, et al., 1980). Higher, steeper waves of winter generally pull sand offshore, flattening the beach profile. Southern swell with longer periods, tends to push sand onshore, widening and steepening the overall profile. Deviations from this pattern have been noted where the presence of headlands or other obstructions partially compartmentalizes a beach into a sub-cell (Thompson, 1987).

Seasonally changing wave exposure also tends to reverse the longshore transport of sand. At San Onofre, this tendency may be very pronounced, with generally southward transport during winter and northward transport during summer. Limited directional wave measurements made during 1985-1986 (Schroeter, et al., 1989) show a close balance between southward and northward transport rates, implying little net transport over at least this 2-year period. Long term, net transport must, however be to the south. This is strongly suggested by the build-up of littoral sand on the northern, upcoast side of temporary barriers such as the laydown pads, or permanent installations like Oceanside Harbor.

Sand reaching the southern limit of the Oceanside cell at La Jolla is intercepted by the Scripps and La Jolla Submarine Canyon system. The material accumulates in the heads, or landward branches, until high waves flush it out to deep water (Inman, et al, 1976). On the average, about 200,000 m<sup>3</sup> per year of sand are lost from the littoral cell in this way.



### BEACH MONITORING ACTIVITIES

Monitoring activity useful for studying beach changes at SONGS consisted of beach profiling, sand sampling and aerial and ground photography. The most useful information for quantifying beach changes are the profile measurements. Sand samples have recently found use in confirming profile data results regarding dispersion of the laydown pad material after release (Osborne and Yeh, 1989). The photographs taken at SONGS were generally required to satisfy water quality permit conditions. Thus the beach usually appears at the edge of the aerial photos, making distortion a problem for quantitative measurements. Nevertheless, important qualitative information can be gathered from the many sets of both ground and aerial photos taken between 1962 and the present.

Figure 2 shows a schematic map of the SONGS area. The locations of benchmarks used over the years for beach profiling are indicated by letter designations. Power company sponsored profile measurement efforts coincided with construction work, and generally ceased in between building activities.

Early data were collected in the area by Shepard (1950a,b) at 4 rangelines, 3 of which are shown in Figure 2 as squares and labelled "Crescent", "Fence" and "Surf". The method of horizon levelling was used and only selected profiles were plotted and published (Shepard, 1950b). Shepard's original survey notes are available in the Scripps Institution of Oceanography Archives, but efforts to reconstruct the profiles were unsuccessful.

Berm width statistics of the three beaches were published (Shepard, 1950b). "Fence" beach width data were taken each year from 1945 to 1949 in sufficient detail to define a "reversed" seasonal configuration. The beach was roughly 25m wider in winter than in summer and Shepard (1950b) attributes this to the existence of a rock outcrop south of the cove. The outcrop acts to block the winter-time southward transport and thus widen the pocket at that time. "Crescent" and "Surf" beach were monitored much less frequently and show virtually no seasonal changes.

Additional profiles have been collected on two rangelines designated SO 1530 and SO 1470 (stars, Figure 2) as part of the U. S. Army Corps of Engineers sponsored Coast of California Storm and Tidal Waves Study. Each rangeline was monitored once or twice per year from 1983-87 or 88 (Table 1). These data have not been obtained and are not considered in this report.

Benchmarks A, B, C and D (x's, Figure 2) were established in 1964 and profiles were taken quarterly until early 1968 by Marine Advisors, as consultants to the power company. This period corresponds to the time Unit 1 was being built. Note that Figure 2 also shows the location of the Unit 1 laydown pad (hatched) which was in existence from 1964-66.

Benchmarks B1, B3, B5, B6 and the remote B7 (triangles, Figure 2) were established in 1974 at the beginning of Units 2 and 3 construction. These were monitored monthly from 1974 through early 1980 and again in 1985, by the power company. The Units 2 and 3 laydown pad (Figure 2) was in existence from 1974 through 1984. The survey period corresponds to the time of Units

2 and 3 construction and the period just before sand pad release. Table 1 gives a list of the historical benchmarks and their Lambert and MRC coordinates for easy cross-reference.

The final set of profile measurements (dots, Figure 2), carried out as part of the present study, were begun in May 1985 and concluded in September 1987, with 9 sets of profiles taken.

A follow-up survey was carried out by Waldorf (1989) in January 1989, and these profiles are included in the present discussion. Wading depth profiles were measured every 500 m along the beach, generally from -2000 m (north) to +3500 m (south). The longshore distance designation corresponds to the MRC coordinate system shown in Figure 2.

## **BEACH CHANGES DURING SONGS CONSTRUCTION**

### **Sand Supply**

The Provisional Construction Permit authorizing SONGS Unit 1 was issued by the United States Atomic Energy Commission on 2 March 1964 (Southern California Edison Company, 1964, item 7). Construction activity began soon after, and by mid-1964, massive cliff excavations and other beach works were underway. Figure 3 is a mosaic of aerial photographs taken in 1962, before construction activity began. Note the narrow beaches typical of this area. The present location of Unit 1 and Units 2 and 3 have been superimposed as shown. Figures 4, 5 and 6 show photographs taken in June and July 1964 at a location about 3800 feet south of the construction site. Figure 4 shows two crane booms in the background lifting sheet piling into place for the Unit 1 laydown

pad. Note the extensive cobble patch and relatively narrow beach configurations, shown in Figures 4 and 5, typical of the San Onofre region before construction activities began (Shepard, 1950a, b). Figure 4 also shows evidence of cliff undermining by wave action at the base.

By July 1964 (Figure 6), a thin veneer of sand had covered the cobbles at this location. The beach was still relatively narrow, as evidenced by the kelp and debris line near the cliff base. The sand accumulation at this location between the June and July photographs was probably due to normal, seasonal beach accretion, as opposed to construction activity.

Early photographs of Unit 1 construction are shown in Figures 7, 8, 9, 10 and 11. Note from the map in Figure 2 that station "A" is located just upcoast of Unit 1 and station "B" is located just south of Unit 1. Figure 7 shows the north wall of the laydown pad being built using interlocked sheet pile driven into the sand. Figures 8 and 9 (looking upcoast) show the cliff cuts made at the site.

Approximately 1,000,000 m<sup>3</sup> of material was excavated from the cliff. Note the very clear contact line in the cliff between the lower San Mateo sand formation and the overlying darker, finer, terrace deposits (Figure 8). About 60% of the excavated material consisted of terrace deposits and 40% of San Mateo sands. The terrace deposits were unsuitable for disposal on the beach or in nearshore waters because of the turbidity they would cause (Southern California Edison Company, 1964, items 6, 8, 9, 10, 11, and 14). These were used to fill "barancas" (eroded,

small canyons) or spread evenly on the mesa tops and compacted. The San Mateo sand was partly used to fill the newly constructed laydown pad ( $120,000 \text{ m}^3$ ) with the remainder ( $280,000 \text{ m}^3$ ) bulldozed onto the adjacent beach face for beach nourishment, as illustrated in Figure 8 and 10 (Southern California Edison Company, 1964, item 9). It was recognized that the San Mateo formation contained a small percentage of very fine material, including inclusions of clay. Estimates of the fine fraction (silt and clay, smaller than  $1/16 \text{ mm}$ ) range from 6% (Southern California Edison, 1964, item 10) to about 15% (Gayman, 1986).

Figure 12 shows the cumulative amount of sand that was made available to the nearshore during SONGS construction activities, as a function of time between 1964 and 1985. The approximately  $1,000,000 \text{ m}^3$  of sand that was released over the 21 year period amounted to an average annual sand influx of almost  $50,000 \text{ m}^3$  per year. This amount is of the same order of magnitude as the average sediment delivery of San Juan Creek, located about 16 km north of SONGS, near Dana Point, and the only nearby river with long-term yield data. San Mateo and San Onofre Creeks (nearby to SONGS) combined yield between 2 and 4 times less sand than San Juan Creek (Simon, Li and Assoc., 1988; State of California, 1977).

Figure 13 shows the sediment yield from San Juan Creek plotted from data tabulated in Simon, Li and Assoc. .(1988). The upper panel shows the output from 1920 to 1983 as about  $2,000,000 \text{ m}^3$ , assuming a conversion factor of  $2 \text{ tons/m}^3$ . This amounts to approximately  $31,000 \text{ m}^3$  per year. The lower panel of Figure 13

shows the sand yield during the period 1965 to 1985, coinciding with construction activities at SONGS. Due to the occurrence of several extremely wet winters (1969, 1978, 1980, 1983) during this period, the sediment yield is above the long term average. For the 20 year span, approximately 1,500,000 m<sup>3</sup> of sediment were delivered, or about 75,000 m<sup>3</sup> per year. Figure 14 shows the mouth of San Juan Creek in late March 1980. Note the large sand delta and pulsating sediment plume resulting from the floods of that winter.

Figures 15 and 16 are aerial photographs of the reach from San Mateo Point to SONGS, showing the locations of San Mateo and San Onofre Creeks. Figure 15 was taken in September 1974, during a period of relatively low rainfall. Note that the creek beds are dry, as is typical in normal, dry summers, and that the creek mouths have been closed by the littoral sand drift. San Mateo Creek actually has a concave shaped beach at the mouth, which is visible below the cloud cover.

Contrast this with Figure 16, taken in late March 1980. At this time both creeks have substantial sand deltas at the shoreline. There is also evidence of pronounced southbound littoral drift from the configuration of the sand spits near each creek mouth. Note that the beach discharge point of San Mateo Creek is almost 1 km south of the river mouth. The beach in front of San Mateo Creek has a distinct bulge at this time, compared to the concave configuration in 1974.

Sediment yield estimates from San Mateo and San Onofre Creeks over the 20 year construction period then, ranges from a

low of about 19,000 m<sup>3</sup> per year to a high of about 38,000 m<sup>3</sup> per year (Simon, Li and Assoc., 1988; State of California, 1977). The discharge from these sources would also be highly episodic, occurring mainly in 1969, 1978, 1980 and 1983. It is apparent that construction related sand contributions exceeded the natural sand supplies from the adjacent rivers, over this time span. This is especially significant in view of the fact that several very wet years occurred during this time, and that stream yield may have been more than twice its long-term mean. In other words, the 50,000 m<sup>3</sup> per year artificial nourishment during SONGS construction, may have exceeded the long-term, local river input of sand by as much as a factor of 5.

#### **Beach Changes - 1964 to 1968**

During 1965, the beach at stations "A" and "B" widened rapidly as a result of the cliff excavation. This is documented by the beach width data shown in Figure 17. Beach width was taken as the distance from the benchmark to the point where the profile crosses the mean-lower-low-water (MLLW) datum (Marine Advisers, 1969).

Subaerial volume of beach material was also plotted by Marine Advisers (1969). This quantity is defined as the area (m<sup>2</sup>) or equivalently, the volume per unit length of beach (m<sup>3</sup>/m), between the profile and the MLLW datum, over the beach width. These two statistics are not necessarily the same, since, for example, a large amount of sand stored in the back beach would increase the subaerial sand volume without increasing beach

width. All profile data presented in this report have been reduced to beach width, to facilitate comparison.

Typical seasonal beach width changes reported by Shepard (1950) at San Onofre were about 15 m at "Surf" and 20 m at "Crescent" (Figure 2). These values are slightly lower than changes observed at beaches further south in the littoral cell. At Del Mar, for example, Flick and Waldorf (1984) found 30 m seasonal variation, averaged over about 10 years from 1974-1984.

Corresponding to these beach width values, subaerial sand volume changes amount to about  $50 \text{ m}^3/\text{m}$ , again for "typical" conditions. Of course, heavy wave attack combined with elevated sea levels can cause beach narrowing of 60-90 m and corresponding sand volume cuts of  $100\text{-}150 \text{ m}^3/\text{m}$  (Flick, et al, 1986). The  $1,000,000 \text{ m}^3$  of sand supplied to the San Onofre beaches during the 21 year construction activity, then amounted to about  $50 \text{ m}^3/\text{m}$ , if we can assume it was all deposited 0.5 km up or downcoast of SONGS. This amount is equal to or larger than a typical seasonal beach changes and helps explain why the local beaches widened.

The width at both stations "A" and "B" increased about 50 m (Figure 17) between the pre-construction survey of May, 1964 and July, 1964 (Marine Advisers, 1969). After the cliff excavation was concluded, the beach at station "B" retreated through early 1965. At that time, offshore dredging activity occurred as the cooling water pipes for Unit 1 were laid. Figure 11 shows the trestle that was used for this purpose. The offshore excavation resulted in another supply of sand to the beach, although the



exact quantity and timing is not well documented. As an approximation, we could use the volume occupied by the Unit 1 intake and diffuser pipes, which are each about 4 m in diameter and 1,000 m long, or approximately 25,000 m<sup>3</sup>. This amounts to only 2.5% of the total construction sand contribution.

The beach at station "C" retreated slowly in width (Figure 17) throughout the survey period, although the subaerial volume (not shown) increased slightly (Marine Advisers, 1969). This suggests that the subaerial beach steepened during this period or that the berm became significantly higher. Not much activity was observed at range "D" which is located about 2,700 m south of Unit 1 (Figure 2). Some beach width changes occurred at "D" starting in early 1966, about 18 months after the start of construction. Whether this can be related directly to the increased sand supply using the present data is doubtful, in view of the wide spacing of profiles in space and time. Later work, described below, suggests that beach changes due to construction related nourishment can be confined to the vicinity of SONGS for years.

Following completion of Unit 1 construction in 1968, beach monitoring activity essentially ceased. Surveys and aerial photography started again in 1974 to monitor changes related to construction of SONGS Units 2 and 3.

#### **Beach Changes - 1974 to 1984**

As described above, beach monitoring during Units 2 and 3 construction was expanded. Profile measurements were done

monthly on 5 ranges, denoted B1 to B7 (Figure 2). The total impact of Units 2 and 3 construction on the beach configuration was larger than that from Unit 1. This was partly due to the slightly larger excavated sand volume (Figure 12), but was mainly due to the longevity of the laydown pad. The Units 2 and 3 laydown pad was constructed in early 1974 and removed starting in December 1985. It was filled with about 168,000 m<sup>3</sup> of San Mateo sand (Southern California Edison Co., 1974).

Figure 18 is a vertical aerial photograph dated 17 May 1974 and shows cliff excavation activity at the site of Units 2 and 3. Figure 19, taken several months later, on 3 July 1974 shows that most of the laydown pad is in place. Note the substantial fillet beach formed at the north side of the laydown pad and the beach widening taking place in front of Unit 1. The area downcoast of the new laydown pad also shows a fillet beach, no doubt because of the cliff excavation sand supply.

Figure 20 shows a history of beach width measurements starting in 1974 to 1980 and 1985. Referring again to the map in Figure 2, note that ranges B1 and B3 are upcoast of the laydown pad. Ranges B5 and B6 are downcoast of the pad, while range B7 is downcoast and remote, being about 10 km south of the pad.

Beach widths increase sharply at ranges B1, B3 and B5 during initial work in 1974. Range B5 peaks in early 1975, when the major cliff excavation is finished. Beach widths at the upcoast ranges B1 and B3 continue to increase to about 1979, where they seem to stabilize just before data taking stopped. In all, the measured widths increased by about 80 m at B1 and about 100 m at

B3 between 1974 and 1980. Range B5 shows a decline in width starting in 1975, but remains wider than pre-construction values.

Several seasonal fluctuations in B5 may be seen with peaks in beach width in winter 1977, 1978, 1979 and 1980. These are out of phase with seasonal changes visible at Range B3, and correspond to "reversed" conditions for Southern California.

Dashed lines are used in Figure 20 to join the last measurements in 1980 to the first measurements in 1985. These are meant to suggest that the mean beach widths may have been relatively stable over this interval. Figure 21 shows a photograph dated 25 April 1977 taken during placement of the trestles used to construct the cooling water pipes for Units 2 and 3. Note that the fillet beach north (bottom of photo) of the laydown pad is actually wider than the pad. This suggests that wave action is effective in bypassing sand around the pad, thus limiting the growth of the upcoast beach. This would also have the effect of stabilizing the expected erosion downcoast of the pad. Again, this is consistent with measurements made at B5, where mean beach width does not change from 1977 onward. At this time the laydown pad structure may be thought of as an extension of the natural "point" landscape present at this location (Figure 18). Once sand bypassing has commenced, there is very little net effect on the shoreline due to the structure.

Data from Ranges B6 and B7 show very little net or seasonal change over the measurement period. Both these ranges (especially B7) seem to be too far downcoast to be affected by either the sand nourishment or the laydown pad.

By early 1980, when the photograph in Figure 22 was taken, river flooding had increased local sand supplies yet again, as described above. This had the effect of widening the beaches to an additional, unknown degree in the entire area. This can be seen qualitatively in Figure 22 which clearly shows substantial sand volumes in front of the laydown pad. Unfortunately, quantitative data is lacking for this period. Data taking resumed in late 1984, at the start of laydown pad removal. As suggested in Figure 20, there was no large, net change in beach widths during the interval, although short term increases may have occurred after the floods of 1980 and 1983.

The laydown pad was completely removed by early 1985. This served to contribute another, and final, 168,000 m<sup>3</sup> of sand to the beach (Figure 12). From this time onward, the history of beach widths is essentially one of retreat. However, there are a number of important features to this retreat that were unanticipated.

#### **Beach Changes 1985 to 1989**

Comparison of the beach widths in front of the area between Unit 1 and Units 2 and 3 shown in Figure 22 with those in Figure 23 (allowing for the 2X scale factor) illustrate the dramatic narrowing following laydown pad removal. The photograph in Figure 23 was taken 21 March 1986, a little over one year after pad removal. Figure 24 shows a photograph taken 25 January 1988. Note that the beach adjacent to Units 2 and 3 has by this time retreated almost to the seawall.

Quantitative beach width change measurements taken as part of the present study and by Waldorf (1989) are shown in Figure 25. The area of the laydown pad is stippled in the upper panel, which also shows the shoreline position at the start of measurements in May 1985. The shoreline position is plotted relative to the MRC longshore coordinate system (shown with tics from -2000 m to +3000 m, north to south) and relative to an arbitrary on-offshore coordinate system, centered at the mean shoreline position for convenience. The Unit 1 outfall can be seen clearly on Figure 24, at the center of the turbid area about 850 m offshore of Unit 1. The outfall is the coordinate origin for the MRC reference system, and approximate distances can be gauged up and downcoast relative to it.

Referring to Figure 25, the lower 9 traces show shoreline changes relative to the original May 1985 shoreline. Each trace is offset by 50 m (dashed axis) for clarity. Beach profile measurements were made from fixed benchmarks spaced every 500 m alongshore from -2000 m to +2000 m. Later, the area was expanded to +3500 m, in anticipation of downcoast transport of the laydown pad material. Beach width was measured off each profile line as the distance from the benchmark to the intersection of the profile with the mean-sea-level datum. The changes in beach width for each profile date (shown on the right) relative to May 1985 is plotted in Figure 25. Positive values indicate widening, negative values denote erosion.

Interestingly, there was relatively little change in beach width from May 1985 through October 1985, except for a small

accretion at range -1000 m. This is consistent with the idea that material from either the laydown pad or the adjacent fillet beach moved northward, upcoast, under the summer wave regime. Wave measurements published by Schroeter et al (1989) suggest that the mean longshore transport potential was indeed to the north from about April to October, 1985.

Noticeable changes in beach width occurred between October 1985 and the next set of profile measurements in March 1986. There was narrowing everywhere from -1000 m to +500 m, and the development of two bulges, one at -1500 m and the other at +1000 m. The narrowing represents a cut of about 10 m, and the downcoast bulge at +1000 m is an accretion of about 20 m. This shoreline configuration is the first evidence of a bifurcation of the laydown pad sand material into two bulges. The bulges are persistent for at least two years and perhaps three, as evidence for them can be seen in the latest profile change data, taken in September 1987 and January 1989 (bottom of Figure 25).

Beginning with the March 1986 data, there is a continuous narrowing of the beach adjacent to the power plant, around range 0. The final profile data (January 1989) show nearly a 50 m decrease in beach width compared to May 1985. The downcoast bulge, which apparently moves farther south than +1500 m, grew to about 25 m width by September 1987 and eroded slightly by January 1989. The upcoast bulge near -1500 m continued to decrease in width from March 1985 to at least May 1987 when data taking stopped on that rangeline. The downcoast bulge is clearly

visible on the photograph shown in Figure 23, where there are a series of rhythmic features about 1500 m south of Unit 1.

Overall, there is a net shoreline width decrease, averaged over all sampled rangelines over the sample period. This is reflected in the statistic shown under the survey date next to each line in Figure 25. For example, there was a retreat of 5.91 m over all ranges on the October 1986 survey, again compared with the May 1985 baseline. By January 1989, the net erosion was 14.13 m, as shown. The net decrease in beach width and presumably sand volume, is consistent with at least some offshore transport. The relative volumes of offshore transport and longshore transport out of the area cannot be evaluated with the present data, since the profiles only extend to wading depth, generally -1 m or so. The fact that no rapid or even consistent downcoast transport of the sand bulges occurred suggests however, that substantial sand volumes did move offshore.

It is extremely interesting that the laydown pad material separated into two bulges. The fact that it did has been confirmed by grain shape analysis studies published by Osborne and Yeh (1989). This work showed that sand grains from the laydown pad were transported both north and south a distance of about 1.5 km. Samples from these locations were found to be enriched in grains of lower angularity (smoother or rounder) than the San Mateo sands that were used to fill the laydown pad. This smoothing of San Mateo grains was presumably caused by the heavy equipment traffic on the laydown pad crushing and grinding the sand grains. Osborne and Yeh (1989) report smoothed grains at

two horizons, one corresponding in time to the Unit 1 laydown pad (1964-66), and the other to the Units 2 and 3 pad (1974-84).

Figure 25 suggests that after formation of the two sand bulges, these features moved alternately up and downcoast with time, depending presumably on the prevailing wave momentum (longshore transport potential). Measurements of wave direction statistics from late 1984 to late 1986 have been presented by Schroeter et al (1989), as mentioned above. These data are qualitatively consistent with the observed motions of the bulges over the same period as shown in Figure 25. Another striking feature of the wave data, at least over the indicated time interval, is that there is a close balance between southward directed and northward directed momentum flux. This is consistent with the observation (Figure 25) that the laydown pad material remained in the vicinity of SONGS, or at most, moved offshore, as discussed above. It is contrary to the expected, relatively rapid downcoast dispersal anticipated at the beginning of this study (Wanetick and Flick, 1986) and predicted by Inman (1987).



**ACKNOWLEDGEMENTS**

The authors gratefully acknowledge the Southern California Edison Company which supported this study through a research contract with the University of California, San Diego, Scripps Institution of Oceanography. We thank Mr. Robert S. Grove, Edison's project manager, for making this investigation possible, and for his genuine interest in coastal studies.

We are grateful to the individuals who helped with the field data collection and reduction efforts: Chris Gable, Walt Waldorf, Jim DeGraff, Bill O'Reilly, Tom Fu, Dave Aglietti, Allen Harker, Mark Merrifield, Ron George, John Byrne and Tim Norall. Tim Vanca and Ralph De La Parra of the survey group at Edison very generously supplied historical survey data, dredging data and information about survey benchmarks.

Recent aerial photographs of the San Onofre region were supplied by the U.S. Army Corps of Engineers, Los Angeles District, through the Coast of California Storm and Tidal Waves Study.

We thank Jennifer Yuge at Edison for patiently expediting administrative and contractual details.

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**Table 1. San Onofre Historical Beach Profile Benchmark Designations**

BENCHMARK	SURVEY DATES	LAMBERT COORDINATES*		MRC COORDINATES**	
		North	East X(longshore)	Y(on-offshore)	
CRESCENT	1947-49			~-1750.	~800.
FENCE	1945-49			~-1250.	~740.
SURF	1946			~-250.	~790.
A	1964-68	440,745	1,599,845	-422.	750.
B		439,605	1,601,645	225.	803.
C		438,890	1,603,260	750.	925.
D		434,620	1,608,215	2739.	794.
B-1	1974-80,1985	440,664	1,599,927	-387.	745.
B-3		440,038	1,601,034	-3.	796.
B-5		438,800	1,603,222	757.	896.
B-6		434,350	1,608,436	2842.	769.
B-7		418,779	1,623,311	9320.	-292.
SO-1530	1983-88	442,900	1,597,300	-1437.	808.
SO-1470	1983-87	437,000	1,605,300	1593.	839.

\* California State Coordinate System - Lambert Grid Zone VI (meters).

\*\* MRC coordinates - origin at Unit 1 outfall, X-coordinate positive downcoast, Y-coordinate positive onshore and 37° east of true north (meters).

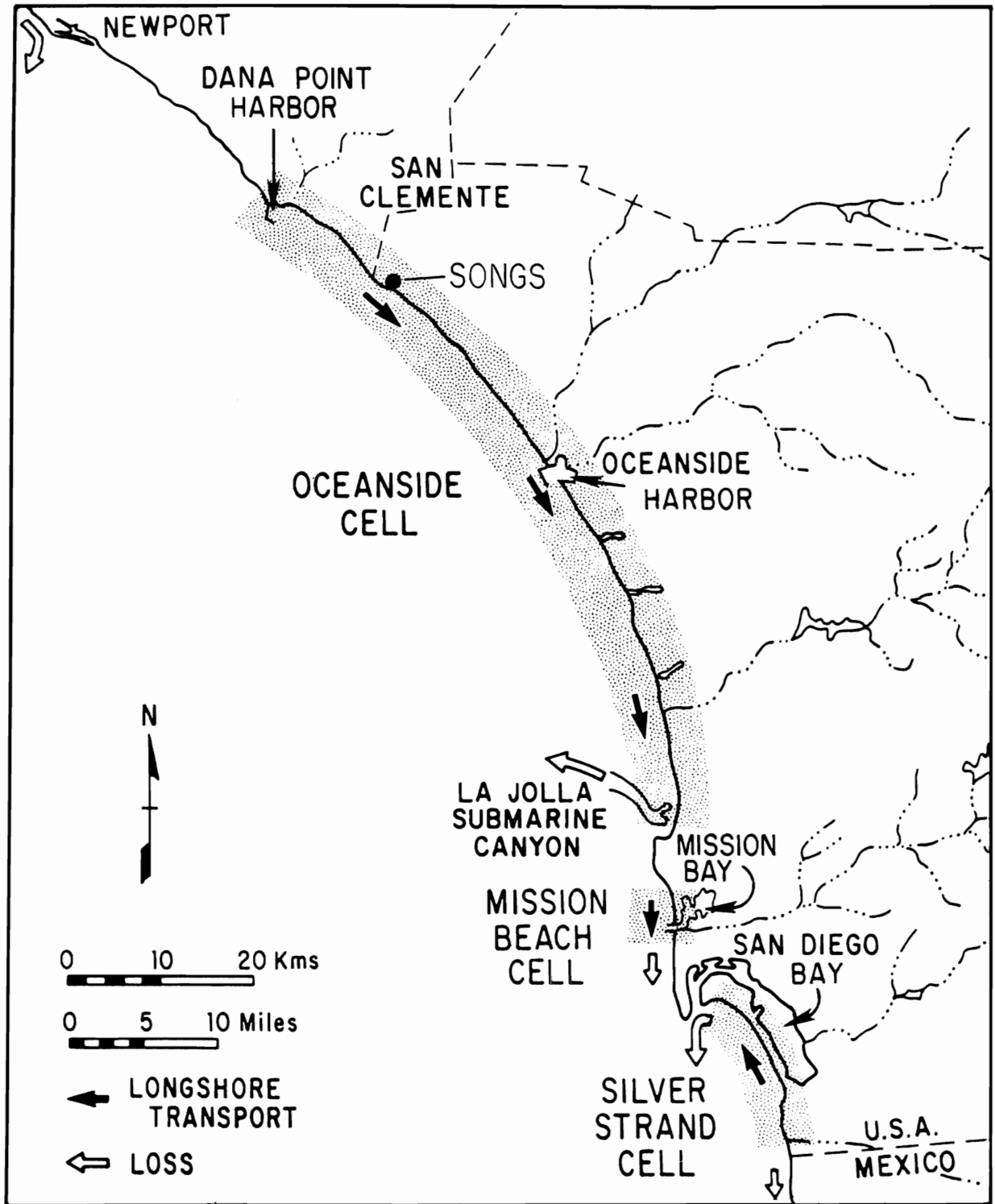


Figure 1. Map showing San Diego region littoral cells, including the Oceanside cell. San Onofre Nuclear Generating Station (SONGS) is located near the beginning of the transport path of sand which has a net southerly direction (arrows).

## SAN ONOFRE HISTORICAL SHORELINE CHANGES

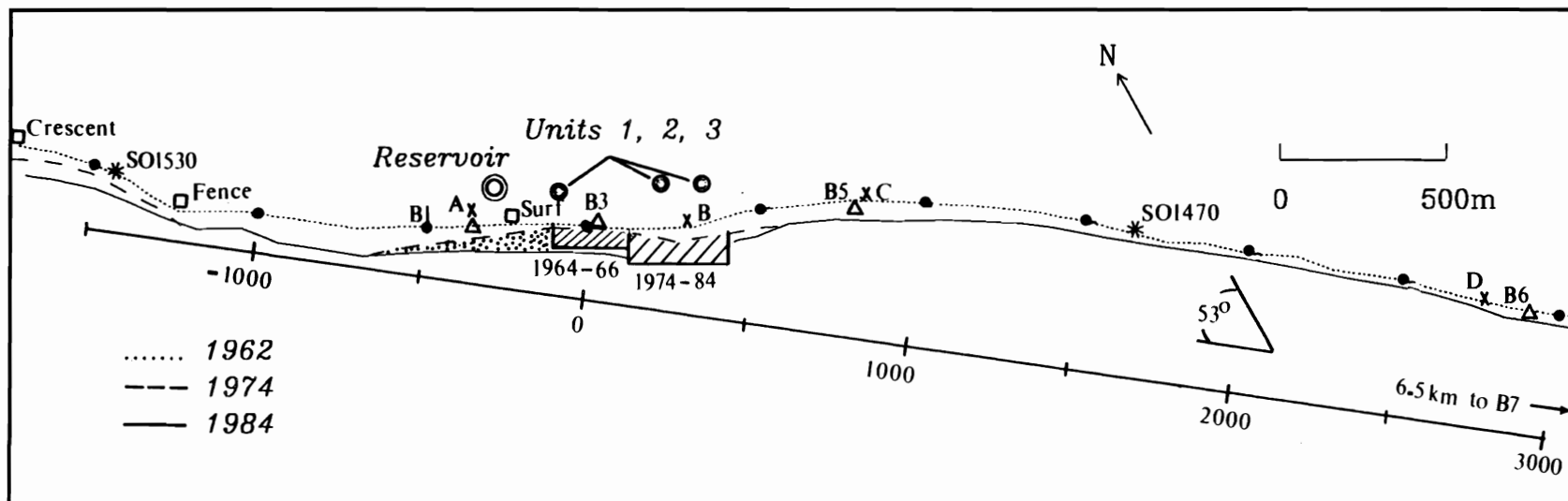


Figure 2. Schematic map of SONGS area showing historical shoreline changes, laydown pad locations (1964-66; 1974-84) and later filet beach (stippled). Benchmark designations for early profiles are shown ("Crescent", "Fence" and "Surf", 1940's; A-D, 1964-68; B1-B7, 1974-85). Scaled axis shows MRC longshore coordinate distances used for profile measurement stations (solid dots) during 1985-1989.

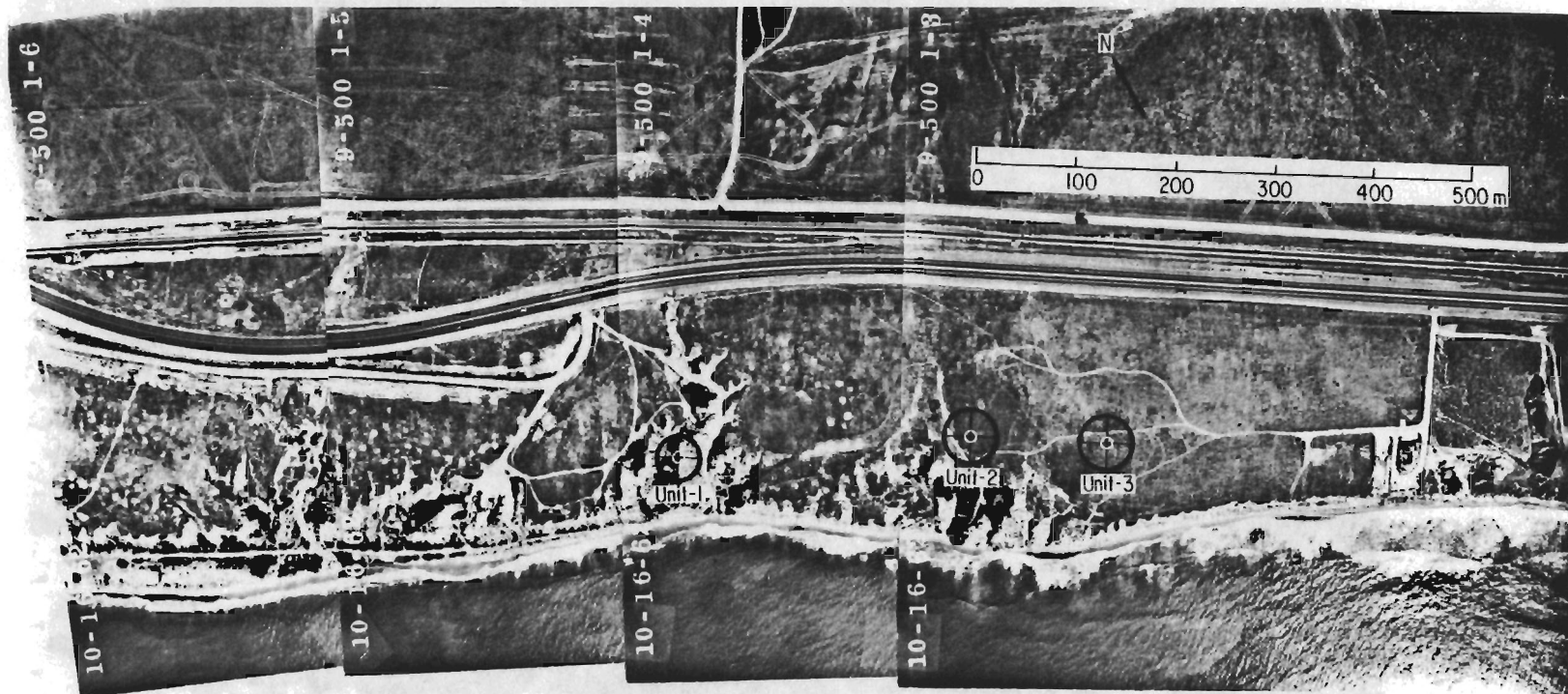


Figure 3. Composite of aerial photographs taken on 16 October 1962, before beginning of SONGS construction. Eventual locations of Units 1, 2 and 3 are shown. Note relatively narrow beach widths in the entire area.

Site of SONGS  
 Location (Elevation 1800 SONGS)  
 Looking Up-East  
 Photograph taken 16 Oct 1962  
 Latitude 30° 45' N

Figure 4. Photograph taken 28 June 1961 near the southern end of the SONGS property and looking north. Note considerable amount of bare ground. Note extensive coffee field and road notch at bottom of cliff face.





Date of Photo: June 28, 1964  
Location: Edison 38+00 South,  
Looking Upcoast  
Photograph from Files of  
Marine Advisors, Inc.

Figure 4. Photograph taken 28 June 1964 near the southern end of the SONGS property and looking north. Note construction equipment in background. Note extensive cobble field and wave cut notch in bottom of cliff face.



Date of Photo: June 28, 1964  
Location: Edison 38+00 South,  
Looking Downcoast  
Photograph from Files of  
Marine Advisors, Inc.

Figure 5. Photograph taken 28 June 1964 at same location as  
Figure 3, but looking south.



Date of Photo: July 13, 1964  
Location: Edison 38+00 South,  
Looking Downcoast  
Photograph from Files of  
Marine Advisors, Inc.

Figure 6. Photograph taken 13 July 1964 at same location as  
Figures 3 and 4, and looking south. Note thin veneer of sand  
that has covered the cobbles since 28 June 1964. Note high  
tide reaches base of cliff, as evidenced by kelp and debris  
line.

SAN ONOFRE NUCLEAR GENERATING STATION

STATION: A

FACING: SOUTH

DATE: 4 JUN 64

TIME:



Figure 7. Photograph showing construction of north wall of Unit 1 laydown pad, taken on 4 June 1964 from Station "A".

SAN ONOFRE NUCLEAR GENERATING STATION

STATION : B

FACING : NORTH

DATE : 4 JUN 64

TIME :



Figure 8. Photograph similar to Figure 6, but looking north from Station "B". Note the relatively narrow beach to the north of the construction activity. Also note the contact line between lower San Mateo sand formation and overlying terrace deposits in the exposed cliff cut.

SAN ONOFRE NUCLEAR GENERATING STATION  
STATION: B FACING: NORTH  
DATE: 17 JUN 64 TIME: 11:53 AM



Figure 9. Photograph similar to Figure 7, but taken 17 June 1964 when west portion of laydown pad was well underway.



Figure 10. Photograph showing construction of Unit 1 laydown pad taken on 24 June 1964 from Station "A". Note sand spoil on north (foreground) side of sheetpile from continued excavations, in contrast to Figure 6.



Date of Photo: Jan. 30, 1965  
Location: Edison 1+00 South,  
Looking Downcoast  
Photograph from Files of  
Marine Advisors, Inc.

Figure 11. Photograph looking south toward Unit 1 laydown pad taken 30 January 1965. Note existence of trestle used to dredge for and lay cooling pipes.



SONGS CUMULATIVE BEACH SAND NOURISHMENT 1964-1987

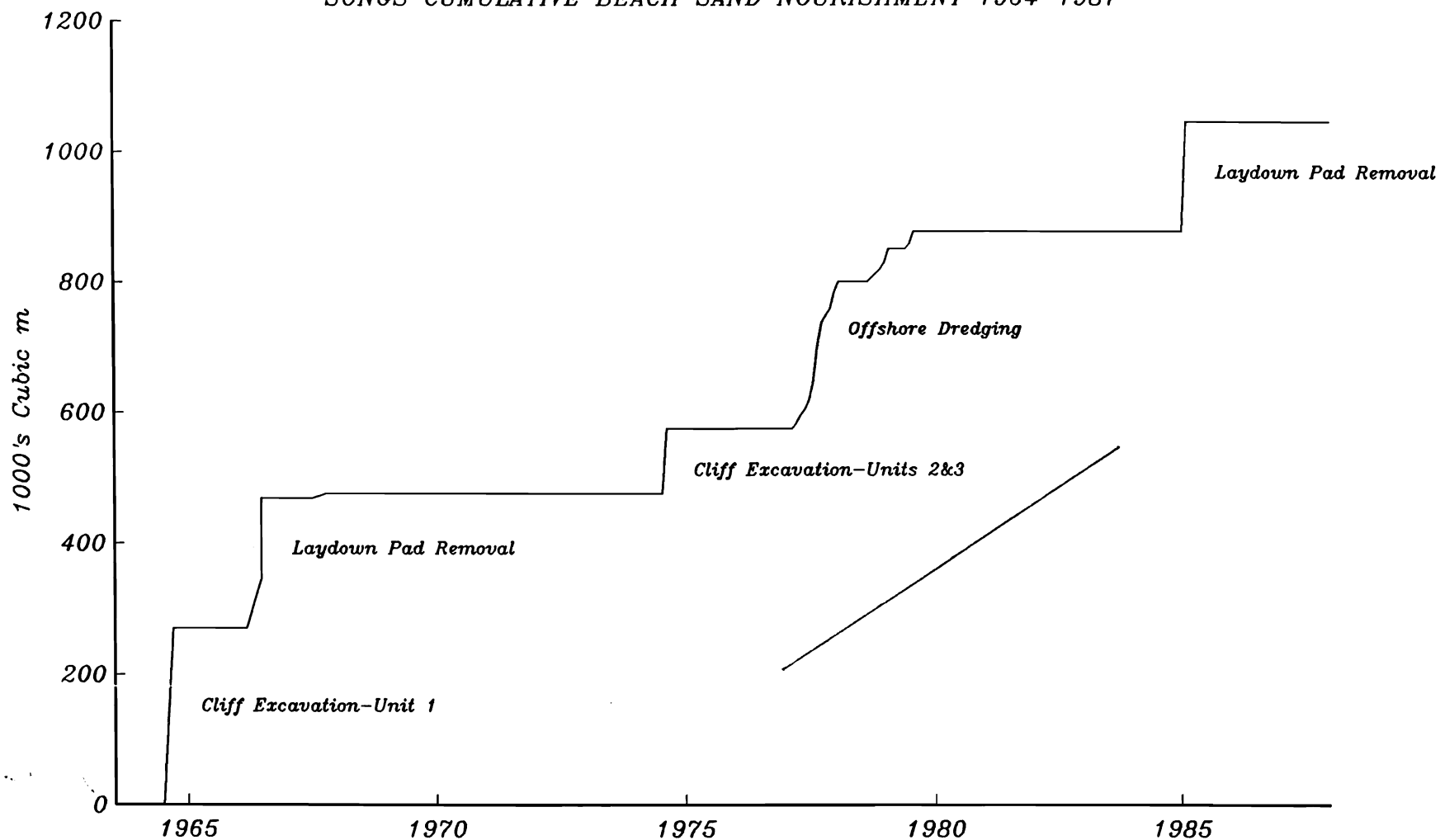


Figure 12. Cumulative amount of sand deposited on San Onofre Beach from various construction related activities between 1964 - 1985. Sloping line indicates 50,000 m<sup>3</sup> per year trend, comparable to overall rate of sand deposition.

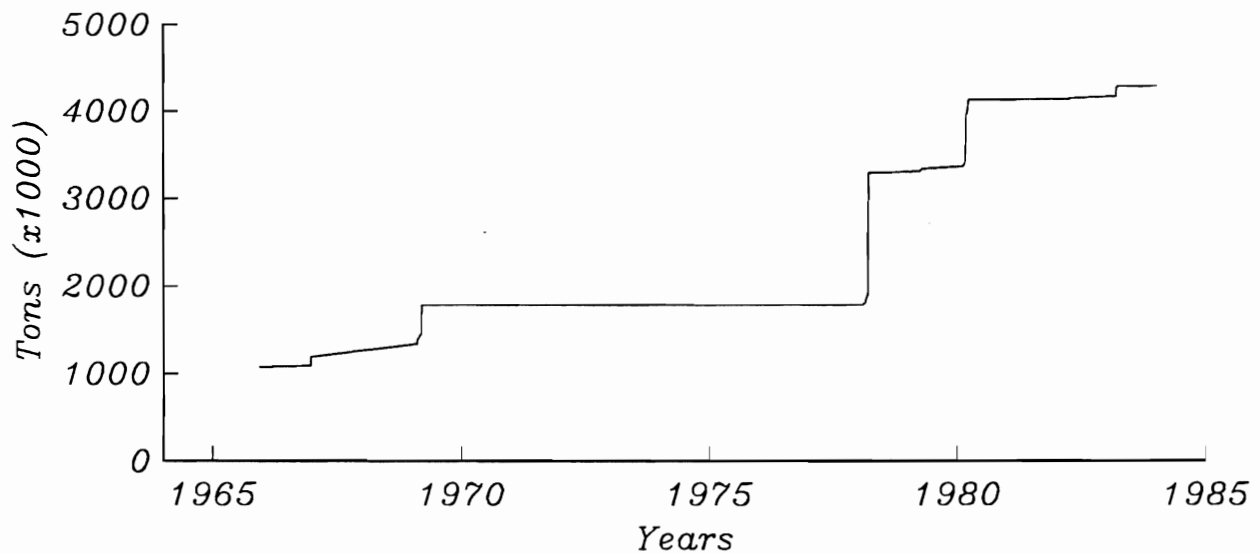
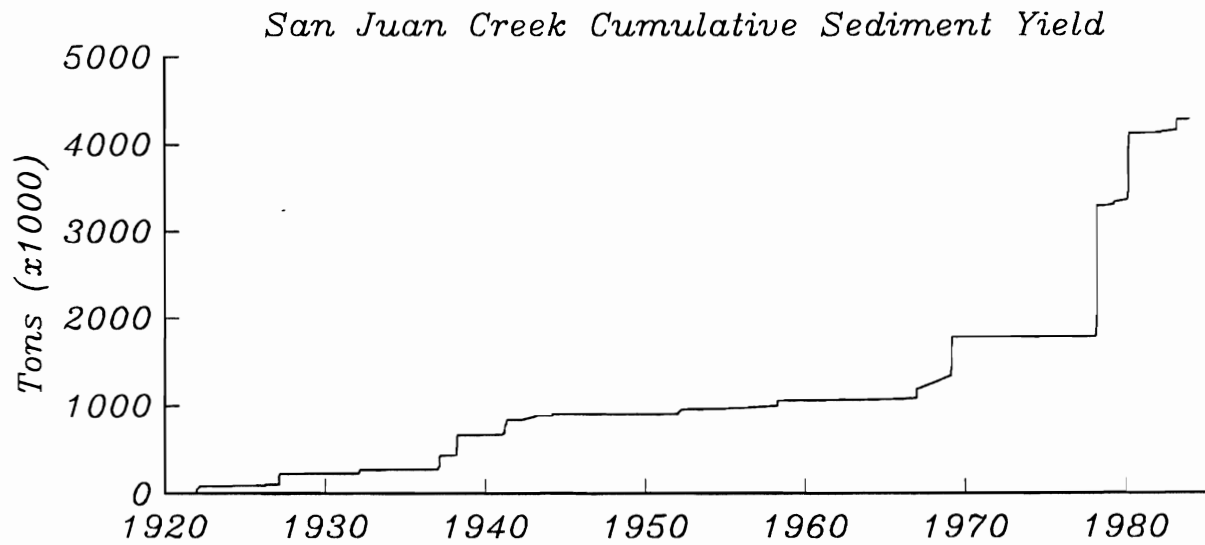


Figure 13. Cumulative sediment yield from San Juan Creek, located near Dana Point, about 16 km north of SONGS. Yield from San Juan Creek is a factor of 2 to 4 greater than sediment yield from San Onofre Creek and San Mateo Creek, which are proximate to SONGS, but have no long measurement history.

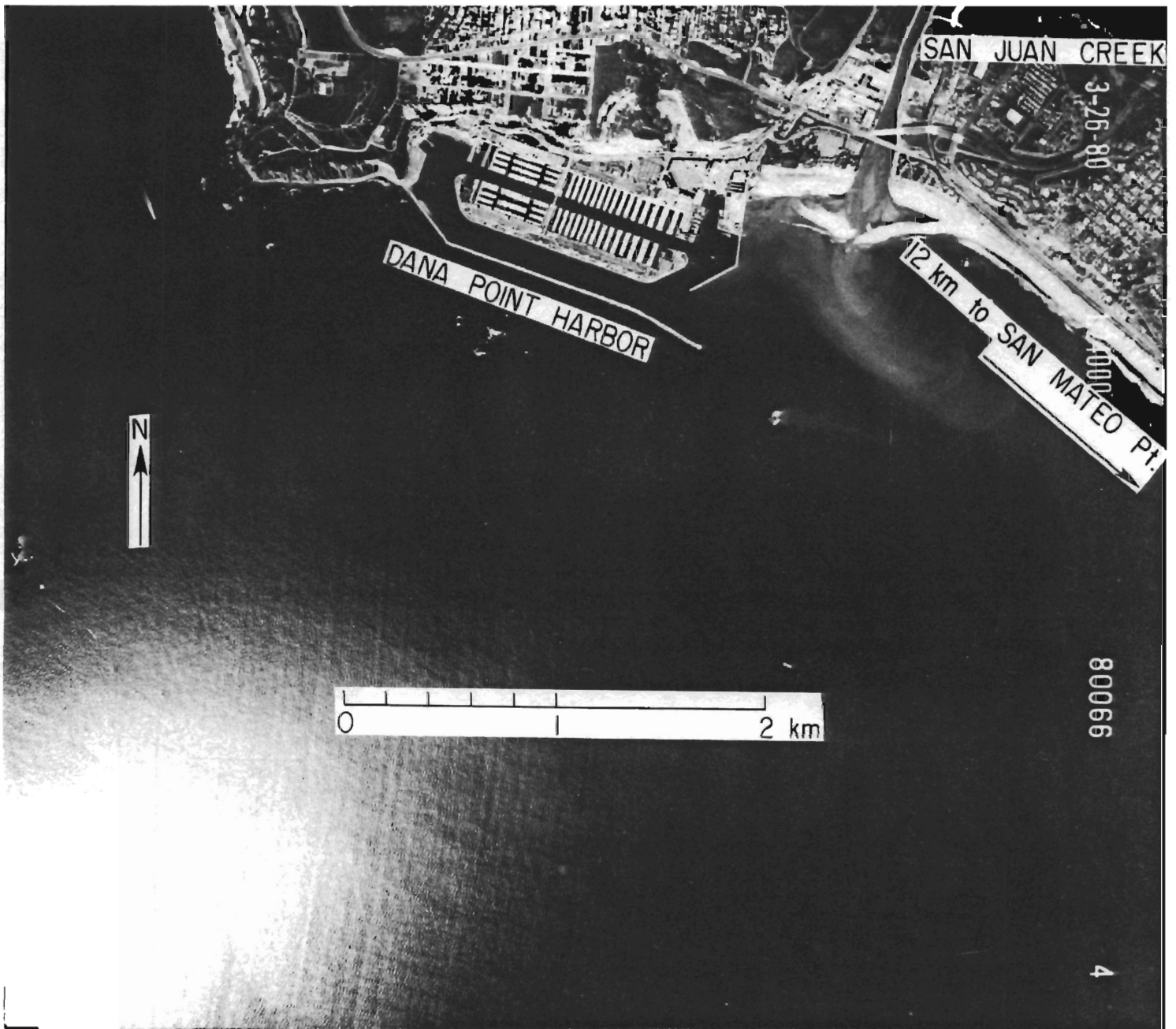


Figure 14. Aerial photograph of San Juan Creek and Dana Point area taken 26 March 1980, after severe flooding hit Southern California. Note the ebb tidal sand delta and pulsating south-bound sediment plume at the river mouth.

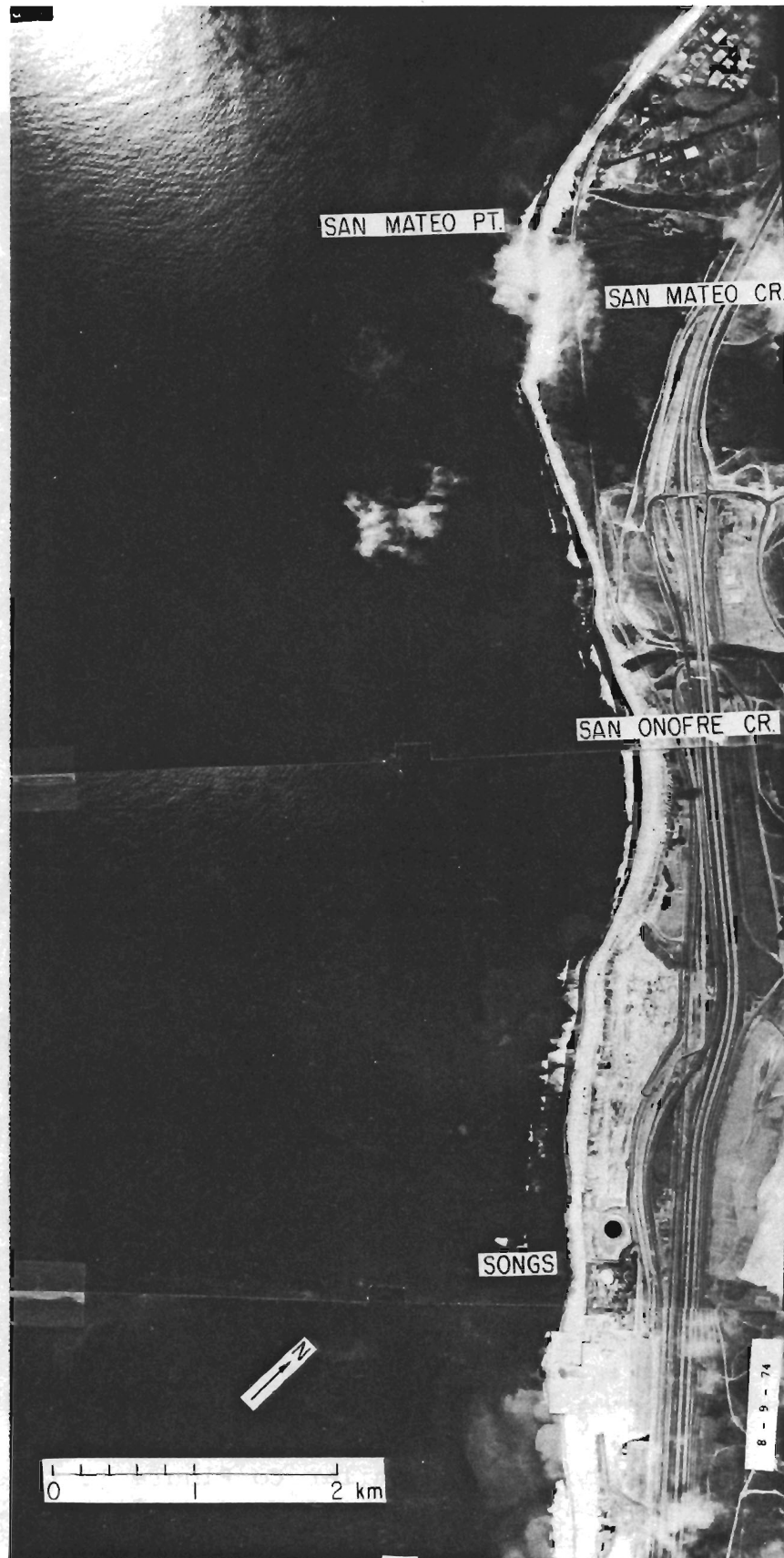


Figure 15. Aerial photograph of the reach between San Mateo Pt. and SONGS taken 9 August 1974, about 5 months after Units 2 and 3 construction began. This was a period of drought and the river mouths are closed by littoral transport. Note the indented coastline at the mouth of San Mateo Creek.

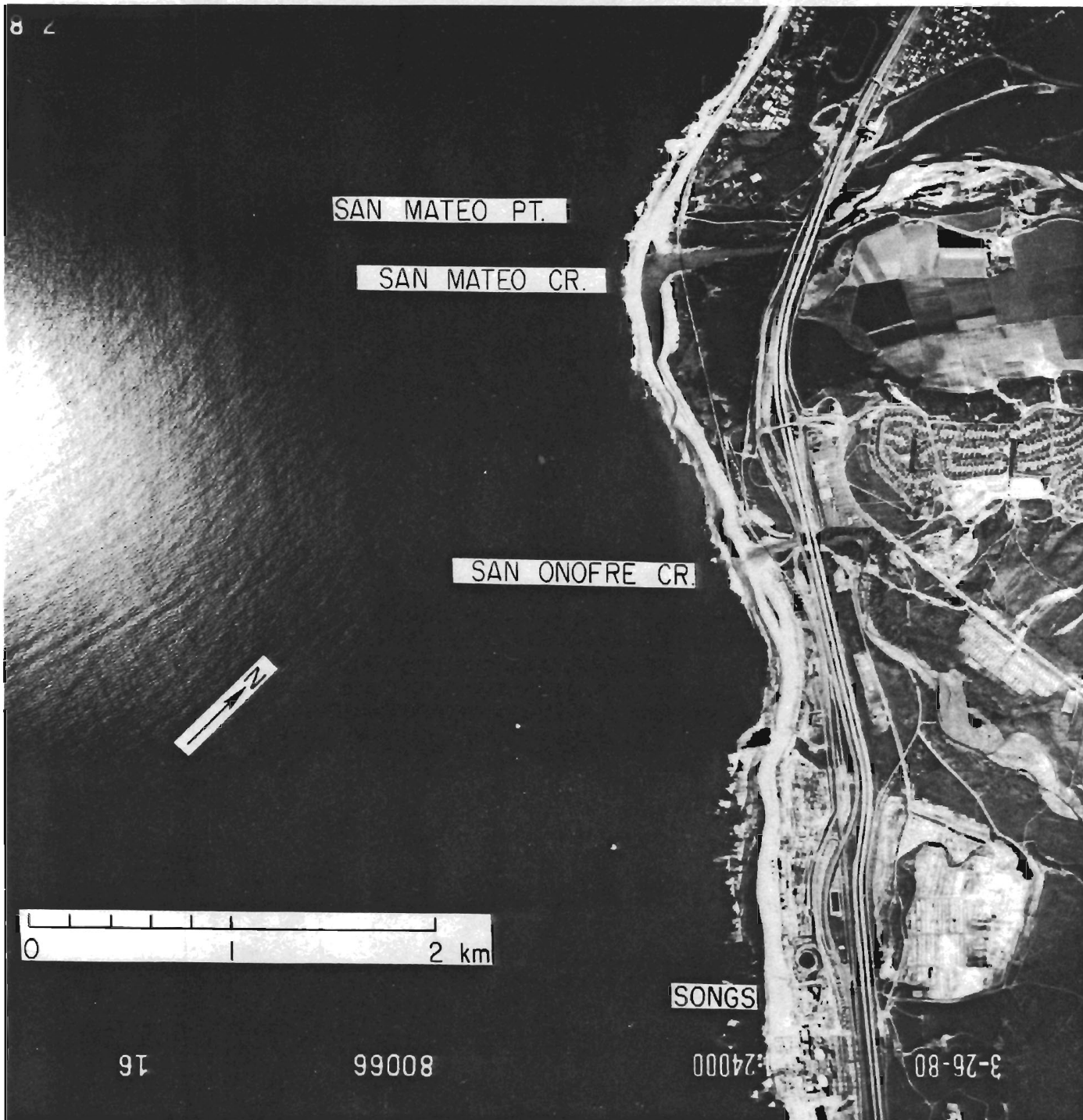


Figure 16. Aerial photograph similar to Figure 15 taken 26 March 1980, after substantial flooding occurred all over Southern California. Note the substantial sand deltas at both San Mateo and San Onofre Creeks. San Mateo Pt. is now convex, in contrast to Figure 15. Sand is now bypassing the laydown pad (bottom of picture).

SAN ONOFRE HISTORICAL BEACH WIDTHS 1964-1969

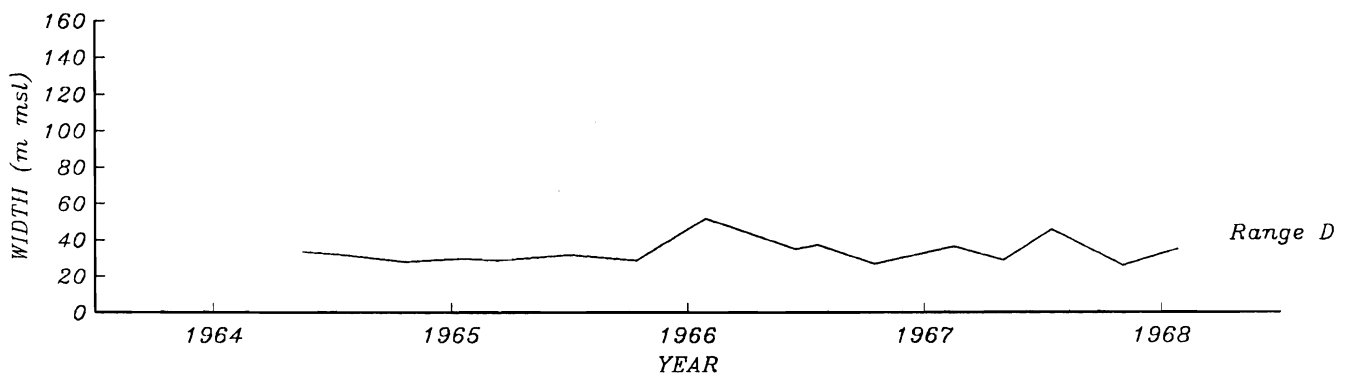
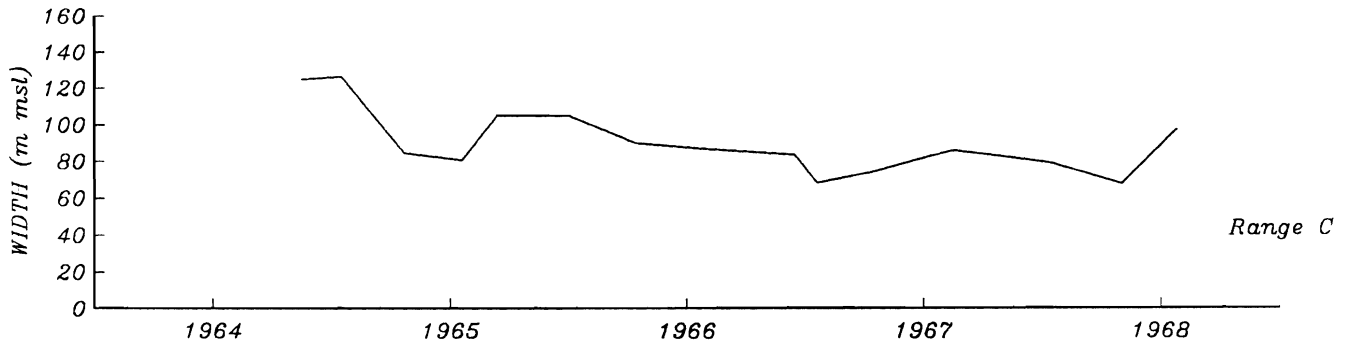
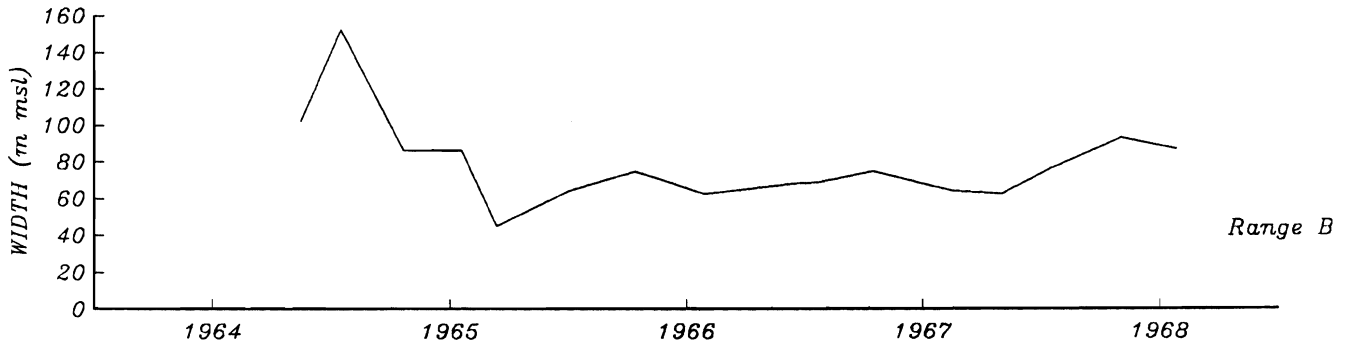
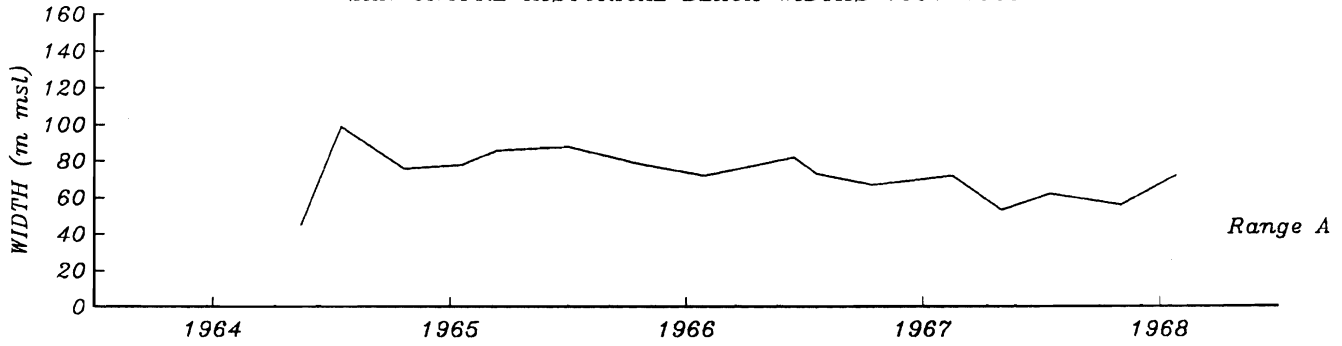


Figure 17. Beach width time histories from surveys conducted around the time of Unit 1 construction. Note sharp increase in beach width at Ranges A and B due to cliff excavation, followed by gradual return to equilibrium. The remote Range D showed no effect.



Figure 18. Aerial photograph of cliff excavation early in Units 2 and 3 construction phase, 17 May 1974.



Figure 19. Aerial photograph taken 3 July 1974 and showing Units 2 and 3 laydown pad nearing completion.



SAN ONOFRE HISTORICAL BEACH WIDTHS 1974-1986

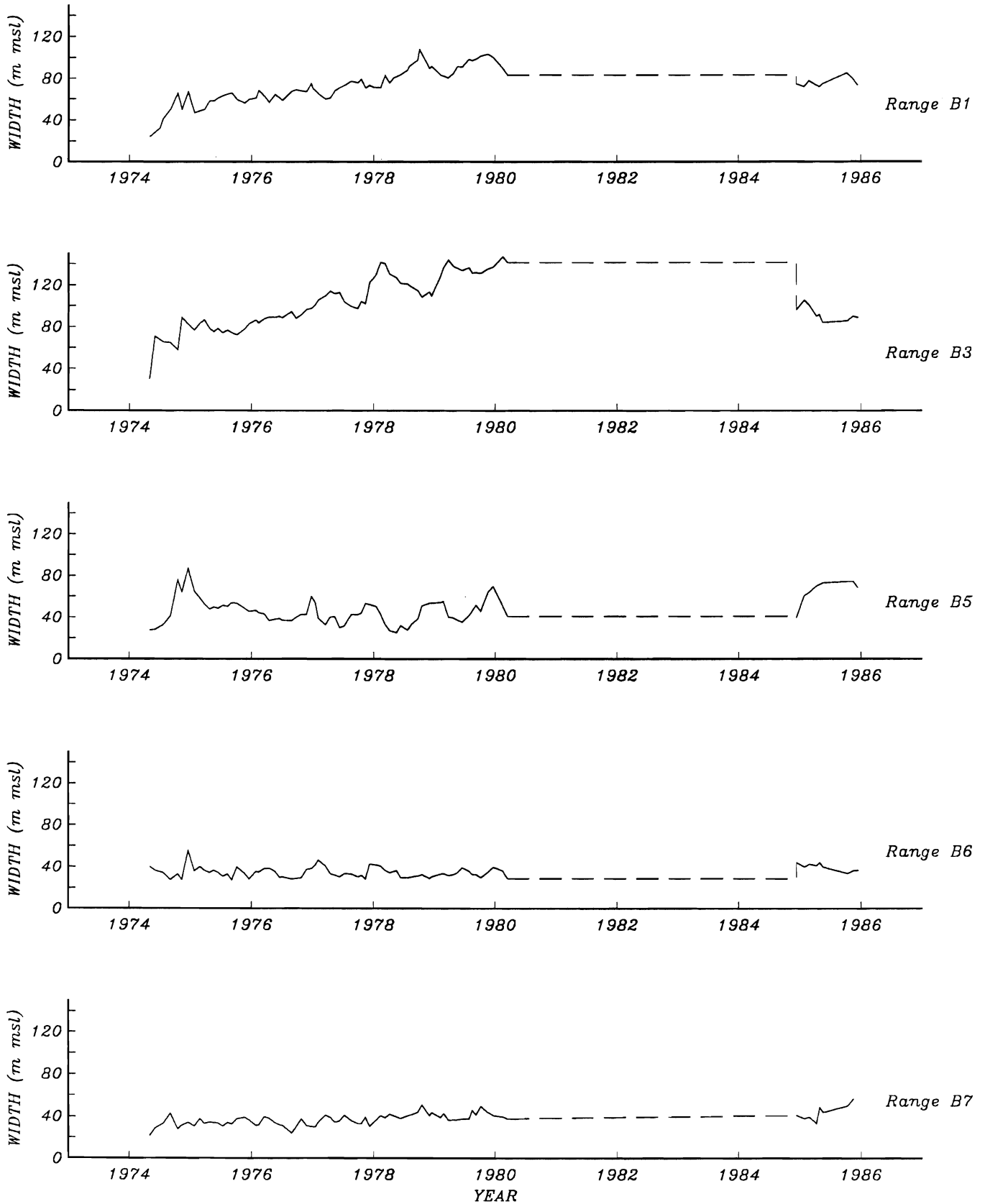


Figure 20. Beach width time histories from surveys conducted over the time span of Units 2 and 3 construction. Note widening of beach at Ranges B1 and B3 due to cliff excavation material and interruption of longshore transport of sand by the laydown pad.



Figure 21. Aerial photograph of beach trestles used to lay Units 2 and 3 cooling pipes. Photo taken 25 April 1977. Note widened fillet beach upcoast of (below) laydown pad beginning to bypass the structure.



Figure 22. Aerial photograph of reach from San Onofre Creek to south of SONGS taken 7 February 1980. Note beach in front of laydown pad suggesting active sand bypassing at this time which limited upcoast beach width as well as downcoast erosion.



Figure 23. Aerial photograph taken 21 March 1986, about one year after removal of Units 2 and 3 laydown pad.



Figure 24. Aerial photograph taken 25 January 1988. Note much reduced beach width in front of Units 2 and 3 seawall. Contrast this with Figure 23.

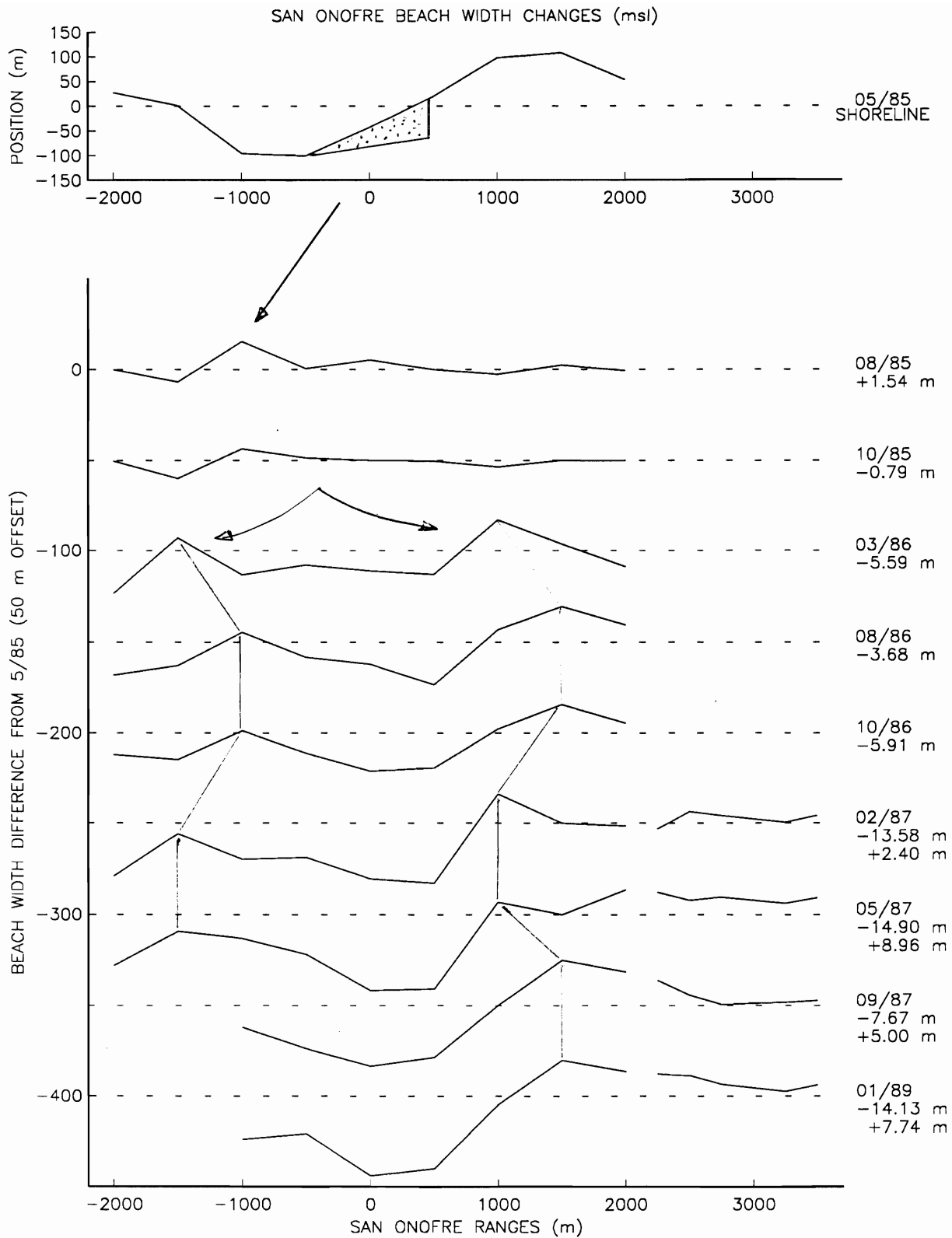


Figure 25. Time history of beach width changes in the vicinity of SONGS following removal of Units 2 and 3 laydown pad. Lower set of curves show changes of beach width, relative to May 1985 survey, on dates shown at right. Curves are offset 50 m for clarity.