CITY OF LOS ANGELES
COASTAL ISSUES RELATED TO FUTURE MEAN SEA LEVEL RISE

Prepared for the
CITY OF LOS ANGELES
Los Angeles, California

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1 INTRODUCTION

The City of Los Angeles (LA) expects to face numerous planning challenges due to climate change, including from impacts related to increasing sea levels. The City manages critical and valuable infrastructure along the coast, including two sewage treatment plants, two power plants, the Port of Los Angeles, Marina Del Rey small craft harbor, and sandy beaches in Venice and the Marina Peninsula. In addition, critical transportation and utility corridor infrastructure is vulnerable to erosion and flooding damage at Pacific Palisades, and cliff erosion threatens parts of San Pedro. Moreover, there is the threat of saltwater intrusion into the City's groundwater supplies, potentially diminishing already low levels of potable water.

2 CITY OF LOS ANGELES COAST OVERVIEW

Inspection of a map of the Los Angeles city boundaries (Figure 1) shows four distinct coastal regions of the city that are partly separated by other jurisdictions. These are: 1) Pacific Palisades; 2) Venice-Marina Peninsula-Playa Del Rey-LAX; 3) San Pedro (exposed coast); and 4) San Pedro (sheltered)-Wilmington-Terminal Island-LA Harbor. Each region has a unique coastal setting and ocean exposure, and a different history of development and human intervention. For these reasons, each area has a different suite of current coastal problems. Similarly, each area is expected to have dissimilar sensitivity to the effects of future mean sea level rise (MSLR) and so will require different adaptation strategies to remain viable.

Pacific Palisades is a relatively high-relief shoreline with a critical coastal transportation and utility corridor. The viability of Pacific Coast Highway (PCH) is certainly the main concern. The expansive beach area from Venice to the foot of Los Angeles International Airport (LAX) is a low-relief and important recreational and storm-wave protection resource that has been highly modified by human activities since the early 20th century. The ocean-front exposed shore of San Pedro has urban development, and is once again high-relief with unprotected sea cliffs subject to geotechnical instabilities. The sheltered harbor-side of San Pedro with Wilmington and Terminal Island form the Port of LA. It is one of the largest and most important ports in the world that serves critical local, regional, and national ocean shipping needs and provides large economic benefits. The area is protected by the LA-Long Beach outer breakwater, which has its root at Cabrillo Point. Detailed descriptions of LA shoreline segments are given by Orme (2005) and Sherman and Pipkin (2005).

3 MEAN AND EXTREME SEA LEVEL

Mean sea level (MSL) has risen globally and along the California coast by about 18 cm (0.6 ft, or 7 inches) during the 20th Century. This 1.8 mm/year rise was caused by a combination of ocean volume expansion and addition of fresh water from continental ice melt in response to gradual global warming. The rate of MSL rise (MSLR) has apparently increased to about 3 mm/year since about 1990 owing to greater rates of ice melt. MSL is expected to rise from 0.5-2 m (1.6-6.6 ft) by 2100, which presents a large range of uncertainty (Nicholls *et al.*, 2011; NRC 2012). Interestingly, while global MSLR has accelerated, it has been suppressed along the California coast due to changes in wind patterns over the Pacific Ocean (Bromirski *et al*., 2011). No net increase in sea level has occurred off California since about 1980. However, these wind patterns are expected to reverse over the coming decades and bring a resumption of MSLR in California to at least the global rate (Bromirski *et al.*, 2012). This means that any coastal flooding or erosion over the past 30 years has occurred with a backdrop of essentially no sea level rise, and that these problems can be expected to worsen once MSLR resumes.

On the open coast, beach erosion, structure damages, and facilities flooding are mainly caused by waves and wave-driven runup and overtopping, especially when these coincide with high tides. Storm surges, seasonal sea level cycles, and prolonged, several-year long elevated sea levels related to El Niño conditions are relatively less important, but can nevertheless add up to 0.5 m (1.6 ft) to total water level. On this coast, the extreme tide range is almost 3 m (10 ft) or nearly 1.5 m (4.9 ft) above and below MSL. Large storm waves reaching 8-10 m (26-33 ft) offshore can produce shoreline runup reaching about 1-2 m (3-6 ft) in vertical elevation on the beach. Large runup together with an extreme tide, storm surge, and El Niño conditions can potentially produce maximum total water levels at the shoreline of up to 4 m (13 ft) above ambient MSL under rare conditions.

It is the recurrence of extreme total water levels that dictates the vulnerability of the coast to erosion and flooding, and their consequent damages. The main effect of future MSLR on the

California coast will be to shorten the average interval between given extreme total water levels over time. For example, a total high water level of 3 m (10 ft) that may occur only once every 50-100 years at current MSL will occur more and more frequently as MSL goes up. Eventually, this same total high water level could occur on average every 20 years, then 10 years, then every year, *etc*. depending on ultimate MSL elevation. Sometimes this is called "return-period creep." While waves and wave runup are what actually cause flooding, damage, and erosion, especially during high tides, inundation from MSLR gradually brings those same conditions higher and farther landward over time.[1]

4 SHORELINE EROSION

One of the most noticeable long-term effects of MSLR is to shift the shoreline on sandy beaches upward and landward. Essentially, this occurs as nature's way of keeping constant the relative geometry of the beach profile and MSL for any given set of wave conditions. In other words, 18,000 years ago when sea level was 120 m (390 ft) lower than it is today, the beaches presumably looked the same except for being lower and some distance offshore (assuming the wave climate was the same, and there was sufficient sand to form beaches in the first place). The beaches gradually prograded landward and upward as MSLR proceeded over the last 18 millennia and erosion removed the land. This process can be described by the "Bruun Rule" (Bruun, 1962), which provides compelling quantitative, albeit as yet poorly documented guidance for estimating long-term shoreline retreat as a function of MSLR rates.

The ability of beaches to remain intact as they retreat in response to MSLR depends on the erodibility of the backshore. On sandy coasts, or ones with relatively weak cliffs, and for sufficiently slow rates of MSLR, erosion proceeds and the beach reforms from the eroded material pushed onshore and upward during periods of mild waves. The shoreline rises, and both the shoreline and backshore essentially retreat landward more or less together in response to MSLR.

However, when the rate of MSLR is too large, or the backshore is structurally hardened or naturally resistant for erosion to occur rapidly enough to provide sufficient sand, beaches narrow and eventually drown. This process is called "passive erosion." This occurred under natural conditions at hard, rocky headlands such as Palos Verdes, where sand supply and accumulation are minimal and sizable beaches do not generally form.

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[1] See Flick *et al.* (2012) for a discussion of the useful distinction between "flooding" and "inundation."

Currently, passive erosion is increasingly related to the hardening protection of many beaches that have revetments and seawalls at their back. Shore armoring is especially and increasingly prevalent in southern California, including many areas in the City of LA. In this case, the backshore essentially cannot erode, which eventually leads to a sand shortage on the beach as the shoreline retreats. As the shoreline gradually moves upward and landward in response to MSLR, the hardened backshore can only remain fixed. Therefore, the beach width decreases and eventually disappears when the shoreline intersects the backshore. This sand shortage can be expressed as a certain volume per unit time (cubic meters or yards per year) over a given length of shoreline. In turn, this can be used to estimate the cost of stabilizing the shoreline position or the price of inaction.

Sand from an outside source placed on the beach at the proper rate can remedy this shortage and mitigate the shoreline retreat and beach width loss. This illustrates the basis for future beach nourishment activity that will undoubtedly be necessary if there is desire and support to maintain beach widths at anything like their current dimensions. Flick and Ewing (2009) used the Bruun Rule to make rough estimates of the range of sand volumes that would be needed in southern California to “keep up” with shoreline retreat from a range of MSLR scenarios. They concluded that the (current dollar) average cost of $19-$48 million per year for the lower-range (0.5 m or 1.6 ft by 2100) of future MSLR scenarios was surprisingly small compared with the dollar value of coastal-dependent economic activity, estimated at about $14 billion per year.

Beach sand nourishment can and has been done as projects for their own sake, or as a consequence of other coastal construction activities where “opportunistic” sand is produced as a byproduct. In southern California, most beach sand nourishment has occurred as a byproduct of coastal construction, as summarized below. Where dedicated sand replenishment projects have been carried out, these have been sponsored by some combination of federal, state, and local funding. The U.S. Army Corps of Engineers and the California Department of Boating and Waterways (DBW)[2] are (respectively) the federal and state agencies responsible for beach sand nourishment projects, while the cities are generally the local sponsors. In all cases, funds must be appropriated in federal, state, and local budgets. A unique privately-funded sand replenishment project is being planned at Broad Beach in Malibu, California (The Malibu Times, 2012).

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[2] Division of Boating and Waterways in the California Department of Parks and Recreation as of July 1, 2013.

5 SHORELINE CHANGE MODELING

Shoreline change modeling may be useful in the LA beach areas to provide the ranges of expected long-term projected shoreline retreat as a function of future MSLR. While many coastal change computer numerical models exist, there are as yet no proven models that can be used to reliably accomplish this task. Nonetheless, experimental data-based models of shoreline retreat in two southern California military installations (Naval Base Coronado and Marine Corps Base Camp Pendleton) have been developed (Chadwick *et al.*, 2011).

These models seek to mimic two processes that affect beach width at different time scales. First, the day-to-day and seasonal erosion and accretion cycles are modeled using the equilibrium method of Yates *et al.* (2009). This is a crude, but proven model for these wave-driven changes. Historical beach width information and hindcast six-hourly wave height and period were used to calibrate the model (Figure 2A). Projected ocean wave conditions for 2000-2100 derived for the IPCC (2007) A2 climate change scenario were then used to estimate coastal wave conditions (O'Reilly and Guza, 1991) at the military bases and the resulting future beach fluctuations. Finally, the long-term and much slower erosion of beach width was estimated using the Bruun Rule for four MSLR scenarios of 0.5 m, 1.0 m, 1.5 m, and 2.0 m (1.6-6.6 ft) and combined with the wave-driven fluctuations.

Figure 2B shows the results of these calculations for 2050-2100 at a relatively wide beach in Coronado, California. Regular, seasonal fluctuations in beach width range up to about 50 m (160 ft). However, sharp decreases up to 150 m (490 ft) occur during periods of very high wave energy, but rapid recovery is also projected. The slow trends of beach width downward are evident for the four MSLR scenarios used as shown by the green, black, aqua, and red curves, respectively. Beach width loss between 2000 and 2050 (not shown) is only about 5-25 m (15-80 ft), depending on the MSLR scenario, but accelerates later in the century as projected MSLR rates increase. By 2100, 20-80 m (65-260 ft) of net decrease in beach width can be expected from MSLR alone.

It is important to recognize the limitations of this experimental composite model. These include the fact that no tide or explicit runup information is used in the Yates *et al.* (2009) formulation; that the interconnection of rapid and slow beach width change are not explicitly modeled; that the Bruun Rule approach has not been proven on decadal time scales; and that there is no account of sand budget deficits or surpluses, although these could be included if they were known; among others.

Nonetheless, results are useful for illustrating beach width scenarios from which various trajectories, summaries, and statistics about possible future average and minimum beach width can be estimated. For example, it is clear that the number of days that the beach width falls below a given minimum value increases over time. The reliability of these kinds of models can only be improved with measurements. This underscores the critical need to monitor regional beach width going forward. Without continuing measurements, future assessments and projections will be no more reliable than today's.

6 CITY OF LOS ANGELES COAST

6.1 Pacific Palisades (LA City-County Line to Santa Monica)

This coastal area is southwest-facing extending approximately from the LA City-County line at Topanga Canyon Blvd (Hwy 27) east of Topanga Beach to Montana Avenue at Santa Monica (Figure 3). PCH sits on a bench cut between the retreating low sea cliff and another cliff on the north (landward) side.

6.1.1 *County Line to Gladstones*

East of the LA county line, there are three segmented beaches backed by PCH (Hwy 1), which is protected by several segments of rock revetment (Figure 4). These beaches are therefore already hindered in their ability to migrate landward by the existing revetments, or will be when erosion threatens to undermine PCH and new revetments must be built. A number of storm drains are also evident, but only two major developments exist seaward of PCH. These are the Chart House restaurant on the point just east of Hwy 27 (Figure 5A), and Gladstones Restaurant at the promontory by the foot of Sunset Blvd (Figure 5B). These beach fragments remain important recreational assets, even though parking is extremely challenging and limited to the shoulder of PCH where it is still wide enough.

The extent of existing revetments shows that this reach has and continues to experience episodic erosion that threatens to undermine PCH and shore-side developments with high economic value. Flooding under current MSL conditions seems to be mainly related to heavy rainfall. However, future MSLR will almost certainly cause decreases in the width of the existing segmented beaches, as well as eventually and occasionally threaten to overtop the revetments and flood PCH and the restaurants. This reach is particularly sensitive to waves from the south, including southern swell and potential future tropical storm waves.

As MSLR proceeds, it would be wise to initiate a storm watch and notification program that uses standard available weather and wave forecast products to provide warnings several days in advance of when dangerous wave and tide combination conditions may occur. This would facilitate traffic management, increase safety, and provide engineering data that will be useful once adaptation measures become necessary.

This reach presents mainly a major geotechnical and coastal engineering challenge, and also thorny societal and legal issues, but less of a technical or scientific problem. The inland stretch along PCH is heavily developed with few or no good options for retreat of the highway. Since PCH is not likely to be moved, continued and improved armoring seems the only realistic choice for avoiding wave-driven erosion undermining. This seems to be the most vulnerable part of the entire LA city shoreline, at least in the short to medium term of years to decades.

Heavily-used PCH has occasionally been undermined in some spots. It has required attention since it was first constructed, and will continue to do so in the future. LA City, County, and Caltrans highway engineers are undoubtedly aware of these problems, and are in the best position to suggest solutions once the future vulnerabilities are better defined. Careful quantification of the times, locations, and extent of any future overtopping and ocean flooding and erosion undermining of PCH and other infrastructure can eventually form the basis for a phased and ongoing plan to address these geotechnical and revetment needs.

The area's segmented beaches show "pocket beach" characteristics with wave-driven sand transport predominantly to the east. That is, they are narrow or non-existent upcoast (west) where headlands block the flow of sand or divert it offshore, and wider down-coast, reaching maximum width just west of the next headland. At least annual monitoring[3] of the beach widths will eventually provide the history that will be necessary to address the issues of stabilization with groins or other measures, and periodic nourishment that will almost certainly be needed in the future to maintain sandy beach.

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[3] Beach width monitoring surveys limited to once per year should be conducted in the autumn, just before the first winter-season storm, to ensure a consistent time history of maximum beach width. While minimum, spring-time beach width data are highly desirable, attempts to actually record these are almost always unsuccessful.

6.1.2 *Will Rogers State Beach*

Will Rogers State Beach extends about 3 km (nearly 2 miles) from just east of Sunset Blvd where the beach is narrow to non-existent, toward Santa Monica where it widens and blends into Santa Monica Beach (Figure 6). The area was part of Will Roger's estate that was donated to the state of California in 1944 and is currently operated by LA County. The western half is stabilized by a series of groins built prior to the 1960s. The groins are dilapidated and were slated for removal, but this would de-stabilize the beach and undoubtedly would cause it to narrow further.

This segment is highly instructive in that it illustrates successful and relatively unobtrusive groin beach width stabilization structures that will almost certainly become increasingly and widely necessary if area beaches are to be preserved in the future. Everts Coastal (2002) provides quantitative assessments of major shoreline sand retention structures and guidelines that will be helpful for engineers planning future structures. The use of sand retention structures to maintain beach stability should be considered. As with the segmented beaches to the west, at least annual systematic monitoring of beach width should be conducted.

Toward the southeast, beach width increases due to the up-coast influence of the Santa Monica breakwater located just offshore of Santa Monica pier (Figure 7). The breakwater was built in the 1930s as an unsuccessful attempt to create a small craft harbor. It did lead to an astonishing increase in beach width and equally importantly, to beach width stability. For this reason, the southern end of Will Rogers State Beach is less vulnerable to long-term erosion than most other beaches in southern California that are not stabilized. This beach configuration is also instructive, since the Santa Monica breakwater is also a relatively unobtrusive structure at the head of Santa Monica pier that provides sound property protection and recreation opportunities, and the related economic benefits.

Of course, the breakwater functions, as they all do, to trap sand by decreasing wave action. This obviously impacts surfing and swimming in the adjacent beach areas by eliminating waves or significantly changing their patterns, and by creating a water hazard. As beaches begin to narrow in response to future MSLR, the tradeoffs between beach width and stability and other recreational needs like surfing will have to be considered and evaluated. Issues like this represent some of the most difficult associated with future MSLR.

6.2 Venice-Marina Peninsula-Playa Del Rey-LAX

This reach is a central part of Santa Monica Bay’s iconic "Bay Watch" beach system (although the TV program was filmed mostly at Will Rogers State Beach) that extends from Malibu to Redondo Beach (Figure 8). It provides major economic benefits from coastal recreation and tourism, boating, and utility and facility siting. The beaches are mostly wide to very wide and were largely created by sand supplied as a by-product of coastal construction activity, including LAX, Marina Del Rey, and the Hyperion sewage treatment plant (Flick, 1993; Leidersdorf and Woodell, 1993, 1994). Between the late 1930s and 1963, over 24 million cubic meters (m^3) (32 million cubic yards [yd^3]) of sand were placed on these beaches, giving an average rate of about 800,000 cubic meters per year (m^3/year) (1 million yd^3/year). The increases in beach width are easily visible by comparing the view in Figure 8 with the one in Figure 9, which is a view north from Venice Beach circa 1930. The heavy construction of the piers appearing in Figure 9, most of which are now gone, inhibited wave-driven sand transport and trapped cusp-like features that locally increased beach width. Only Santa Monica pier (background) and a smaller Venice pier (center) remain.

This artificially wide beach configuration has continued to be stabilized by a number of large structures that provide sand-retention as a primary or secondary benefit. These include the Santa Monica and Venice breakwaters, Marina Del Rey jetties, and a number of groins south of Marina Del Rey, including El Segundo and ending at Redondo Beach (Figure 8). With completion of Marina Del Rey in 1963, the rate of sand deposition slowed to about 50,000 m^3/year (65,000 yd^3/year) (Flick, 1993). This vastly reduced amount may not be sufficient to maintain the current artificially wide beaches in the face of normal wave sand transport.

While these beaches have been wide and stable for many decades, gradual retreat is already in progress. A major concern for the future is that sand is not being provided at nearly the rate it was up to the 1960s. As MSLR resumes and likely accelerates in the future, these iconic LA beaches will undoubtedly narrow at an even faster rate. It is unlikely that any storm-wave driven flooding or property damage will occur in the foreseeable future, but if MSLR takes one of the higher trajectories, problems should become evident around mid-century.

In order to maintain the property protection and recreational benefits of these beaches, sand nourishment will undoubtedly be necessary sometime in the future. In the meantime, the City and its regional partners should continue efforts to facilitate delivery to the beach of any opportunistic sand supplies that become available. To enable sound engineering benefit/cost analysis for these inevitable projects, it will be necessary to monitor the beach width going forward in a manner similar to that discussed in the context of the beaches in the Pacific Palisades reach. The Venice-Marina Peninsula-Playa Del Rey-LAX reach is ripe for wave- and MSLR-driven beach retreat modeling, since a wealth of historical beach profile, shoreline position, and wave data exists. Such work could help to narrow the uncertainty of future rates of beach loss due to MSLR using empirical models now under development. This is of course a regional, and in fact a state-wide need, and not only a City of LA concern. However, the City can play a vital role in highlighting the need for monitoring and coordination of local, regional, state, and federal constituencies.

6.3 San Pedro – Exposed Coast

The San Pedro part of LA has a south-facing exposed open-coast portion, and an east-facing section sheltered behind the LA-Long Beach outer breakwater (Figure 10). Both sections are heavily sub-urbanized atop a flat coastal terrace that has a 35 m (115 ft) high sea cliff at its seaward edge. The geology suggests relatively resistant formations at sea level near Cabrillo Point, but more erodible material to the west toward Point Fermin. As MSLR resumes and accelerates, the weaker cliff sections will be subject to more undermining from wave action and eventual collapse than the more resistant sections. Ongoing and at least annual monitoring of cliff retreat is recommended.

Inspection of aerial photos (Google earth) shows that about 25% of the cliff edge in San Pedro is occupied by park or other open space, which minimizes the vulnerability of property loss from cliff failure (Figure 11). Cliff-top development on the other 75% of the exposed western end of San Pedro has substantial setback from the edge of the cliff. Therefore, few if any developments will be immediately threatened. However, several areas of geotechnical instability are evident, especially related to landsliding (Figure 12). Some residential development on the cliff top at the eastern end of the exposed section of San Pedro has little setback and may be threatened if cliff retreat resumes or accelerates in response to MSLR (Figure 13).

6.4 San Pedro (Sheltered)-Wilmington-Terminal Island-LA Harbor

The LA-Long Beach outer breakwater emanates from Cabrillo Beach and largely protects everything landward from wave attack (Figure 15). Of course, the harbor infrastructure and operations are vulnerable to MSLR. But, this presents mostly a series of harbor engineering challenges that will have to be addressed in stages as problems become apparent and as rebuilding opportunities arise. Anecdotal evidence suggests that the port infrastructure can accommodate even mid-to high-range MSLR scenarios by periodically being raised during major refitting projects. However, the enormous uncertainty presented by the large range of possible future MSLR (Nicholls *et al.*, 2011; NRC, 2012) presents the largest climate change-related obstacle to planning port infrastructure adaptation needs and methods.

At least one study (by the Rand Corporation) is underway to determine port vulnerabilities and possible adaptation strategies. Adaptation measures necessitated by subsidence at the Wilmington Oil Field beginning in the late 1930's should be reviewed (Mayuga and Allen, 1970), since subsidence is in many ways functionally equivalent to MSLR. Future difficulties associated with extreme high water levels should be documented to facilitate planning.

While the outer breakwater is highly effective at sheltering the harbor and adjacent coast from wave action, it is frequently overtopped during high wave events coinciding with high tides. Increased wave transmission over the breakwater and associated habitat losses nearby can be expected with MSLR. But, more frequent damage to the breakwater itself is likely only if the wave climate becomes more severe. The breakwater elevation could be increased if it does not provide sufficient protection with future higher water levels. However, this would be expensive since raising the crest would require that the entire structure be widened to maintain stability.[4]

7 RECOMMENDATIONS

1. Monitor all LA City beaches at least annually in the fall, or more frequently if possible, to provide data to establish the reliability of beach change models needed for projections of future conditions.

2. Continue to lead and promote local, regional, state, and federal efforts to monitor and model beach conditions.

3. Facilitate continued delivery of any opportunistic sand supplies that become available for area beaches.

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[4] Paragraph based on comments kindly provided by Mr. Russ Boudreau of Moffatt & Nichol Engineers.

4. Consider and plan for sand-retention structures such as the groins at Will Rogers State Beach to enhance future beach stability.

5. Initiate a storm watch for Pacific Palisades to provide weather and wave warnings to facilitate traffic management, increase safety, and provide engineering data for future adaptation measures.

6. Document times, locations, and extent of overtopping, flooding, and erosion undermining of PCH and other infrastructure at Pacific Palisades to plan geotechnical adaptations.

7. Document times, locations, and extent of cliff failures and other erosion events at San Pedro to aid in developing and planning geotechnical adaptations.

8. Review adaptation measures for past Wilmington Oil Field and port subsidence.

9. Document times, locations, and degree of difficulties from extreme high water levels to better determine port facility vulnerabilities and aid adaptation planning.

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Figure 1. Coastal segments of Los Angeles city (white) include Pacific Palisades, Venice-Marina Peninsula-Playa Del Rey-LAX, San Pedro (exposed), and San Pedro (sheltered)-Wilmington-Terminal Island-LA Harbor. Note that the LA-Long Beach Harbor outer breakwater is not shown. (Los Angeles Almanac wall map).

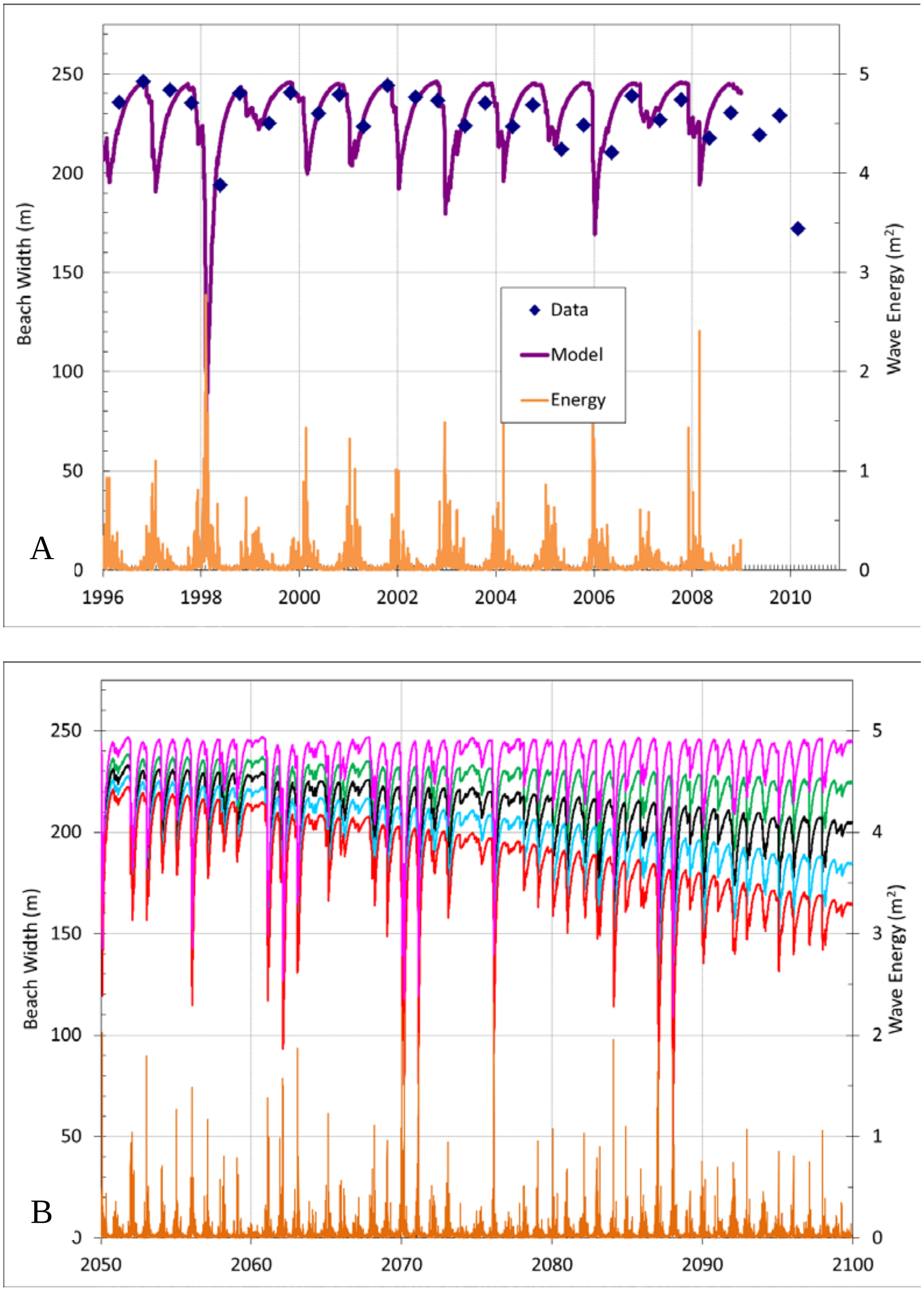

Figure 2. (A) Experimental beach width change model (violet curve) calibration at Coronado, CA, using measured beach width (blue symbols) and hindcast wave energy (orange) 1996-2009. (B) Projected beach width for projected future wave energy (orange) for waves only (pink), and waves plus four MSLR scenarios (0.5 m-green, 1 m-black, 1.5 m-aqua, 2 m-red, by 2100).

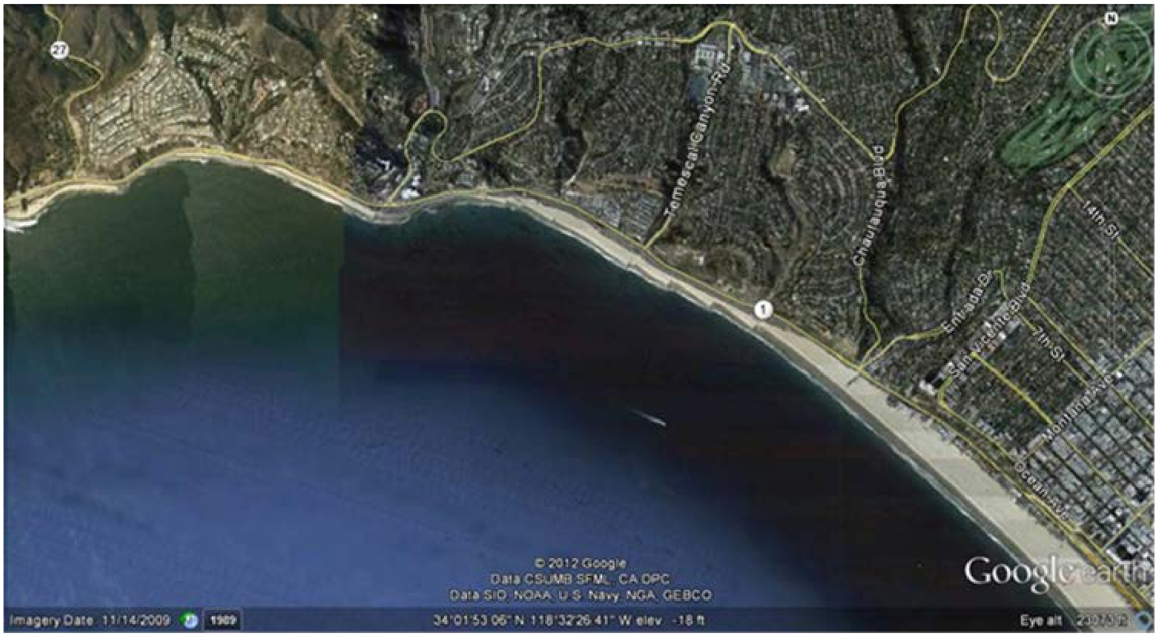

Figure 3. South-facing shore of Pacific Palisades including heavily protected Pacific Coast Highway east of Sunset Boulevard, and groins at Will Rogers State Beach (Google earth).

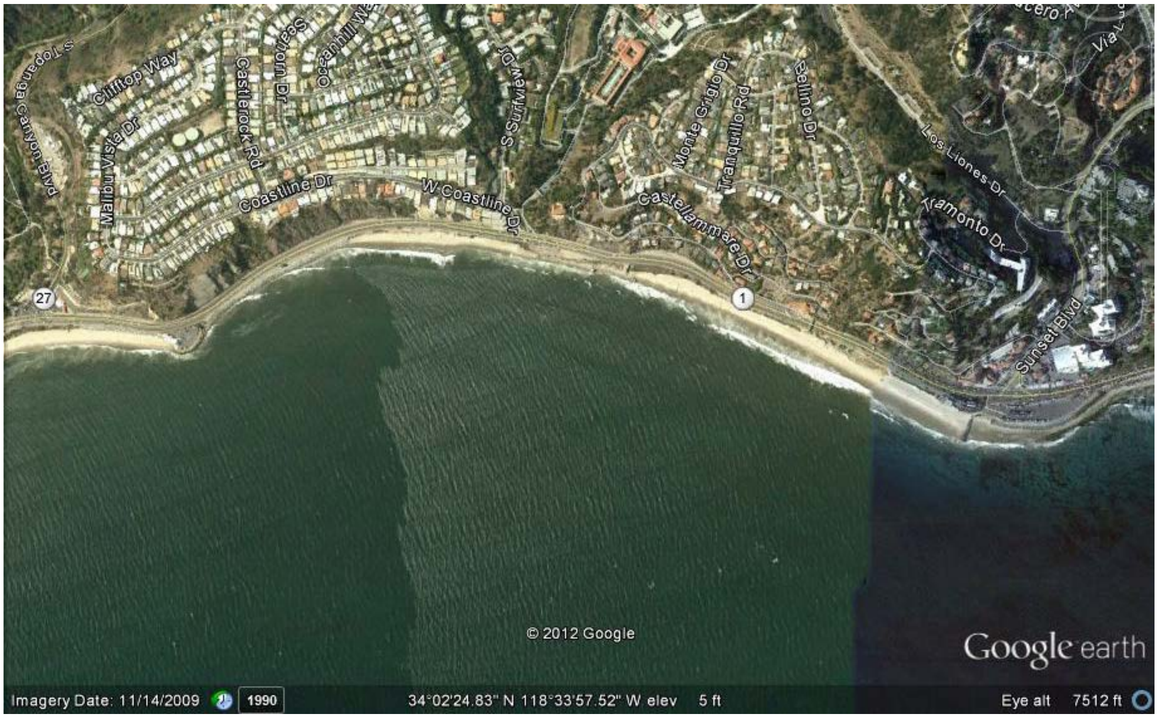

Figure 4. Reach south of Topanga Canyon Blvd (Hwy 27) to Sunset Blvd shows several segmented beaches and PCH (Hwy 1) heavily armored in places. Evidence of coastal erosion, cliff landslides, and other geotechnical instability are evident (Google earth photo).

Figure 5. (A) Point with Chart House Restaurant on PCH (Hwy 1) east of Hwy 27 showing heavy rock armoring. (B) Foot of Sunset Blvd at PCH with heavily armored Gladstones Restaurant and a terminal groin stabilizing a small beach segment (left) (Google earth photos).

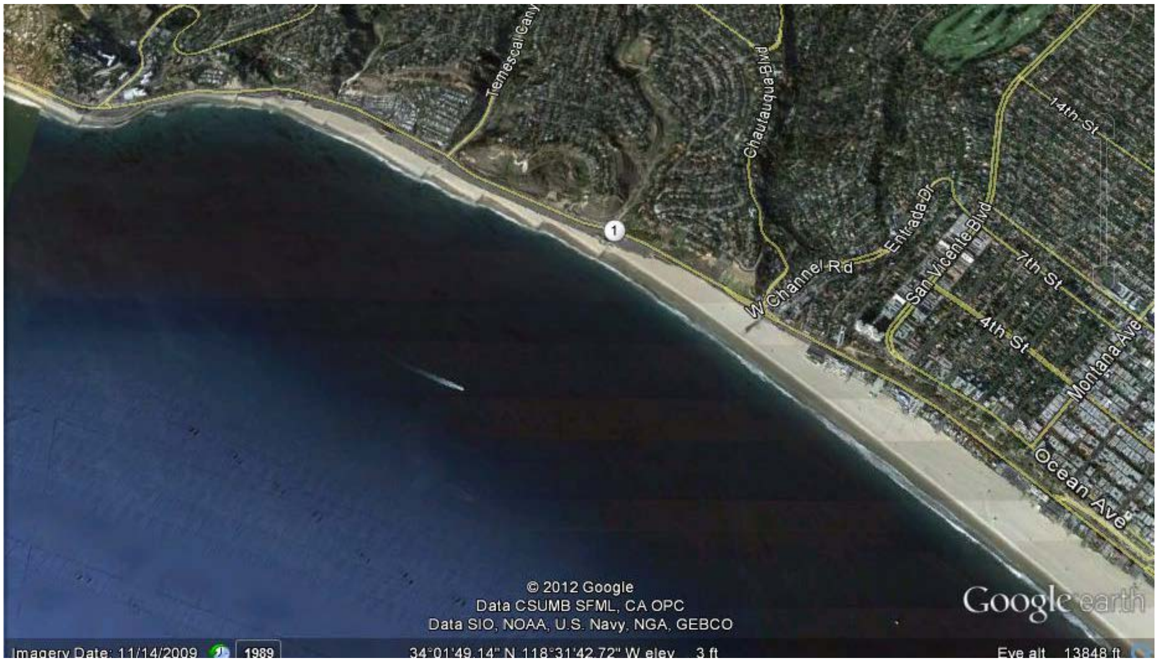

Figure 6. Will Rogers State Beach with effective groin beach sand stabilization (center left). Beach widens and blends into Santa Monica Beach to the southeast (Google earth photo).

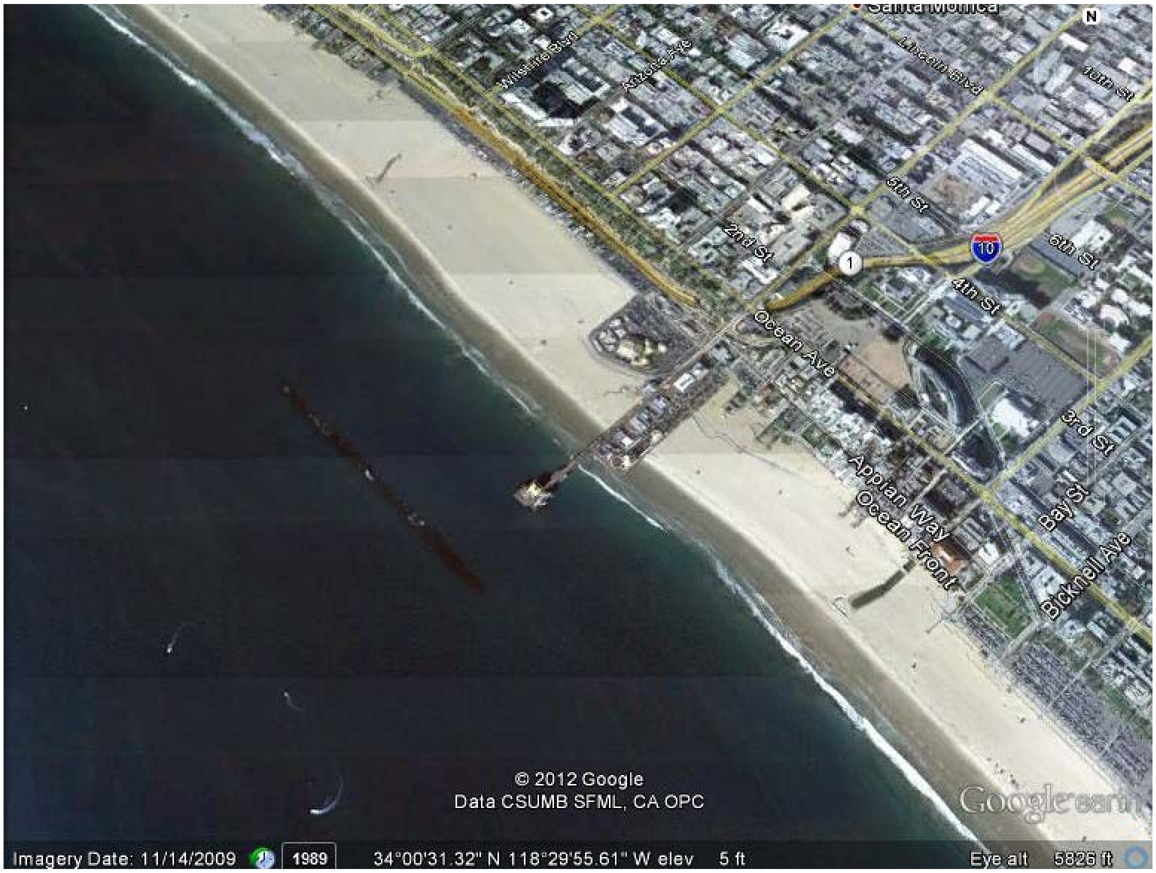

Figure 7. Santa Monica pier and offshore breakwater, which stabilizes beach width for several miles up and down-coast (Google earth photo).

Figure 8. View toward south of iconic beaches of central Santa Monica Bay: From Venice (pier, lower right) past Marina Del Rey jetties and west end of LAX runways, toward Redondo Beach (Wikimedia photo, 2007).

Figure 9. View north *circa* 1930 from Venice Beach with Sunset pier (removed *circa* 1940, foreground), old Venice pier (destroyed 1946), Ocean Park pier (removed late 1960s), Crystal pier (removed mid-1940s), and Santa Monica pier, the only one still standing. Note beach width stabilizing effects of the piers (Spence Air Photos, accessed from http://venicebeachbustours.com).

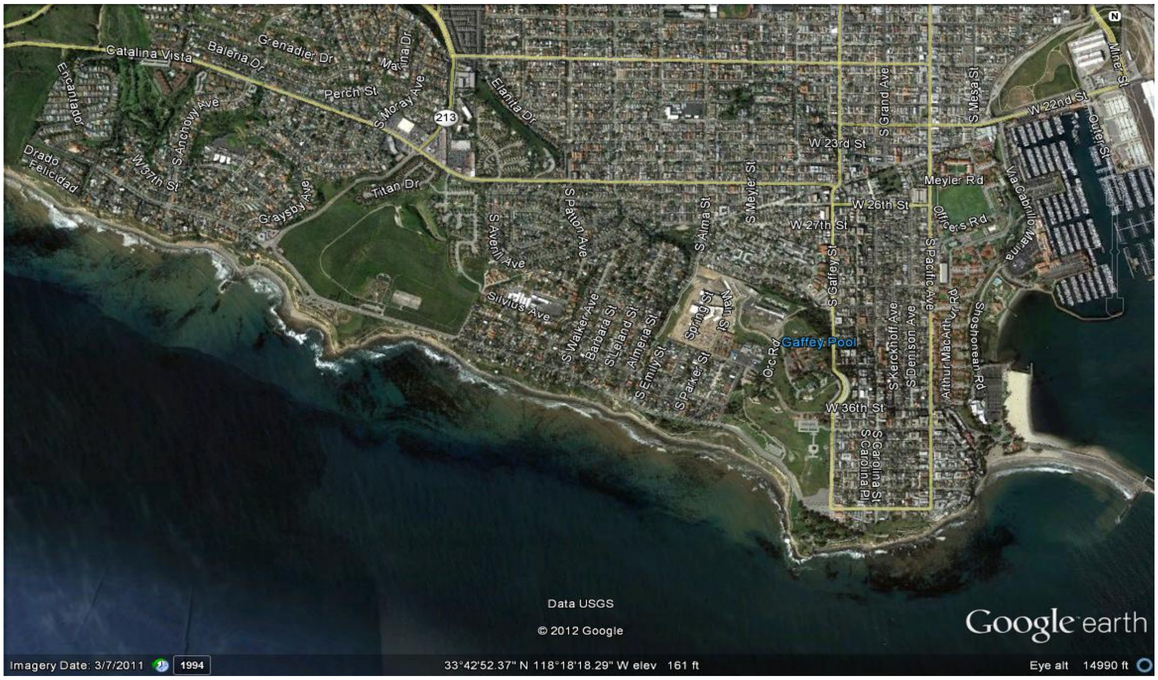

Figure 10. San Pedro reach of LA with south-facing open coast segment on the west, and east-facing portion behind LA-Long Beach outer breakwater, which starts at Cabrillo Point (lower right, Google earth photo).

Figure 11. Exposed segment of San Pedro has sizable park and other open space near the cliff edge and most suburban development has considerable setback (Google earth photo).

Figure 12. Landslides east of Point Fermin present geotechnical challenges in this segment (California Coastal Records Project Photo 201002554).

Figure 13. Eastern end of San Pedro with landslide (lower left and Figure 12) and suburban development with little setback (center right, Google earth photo).

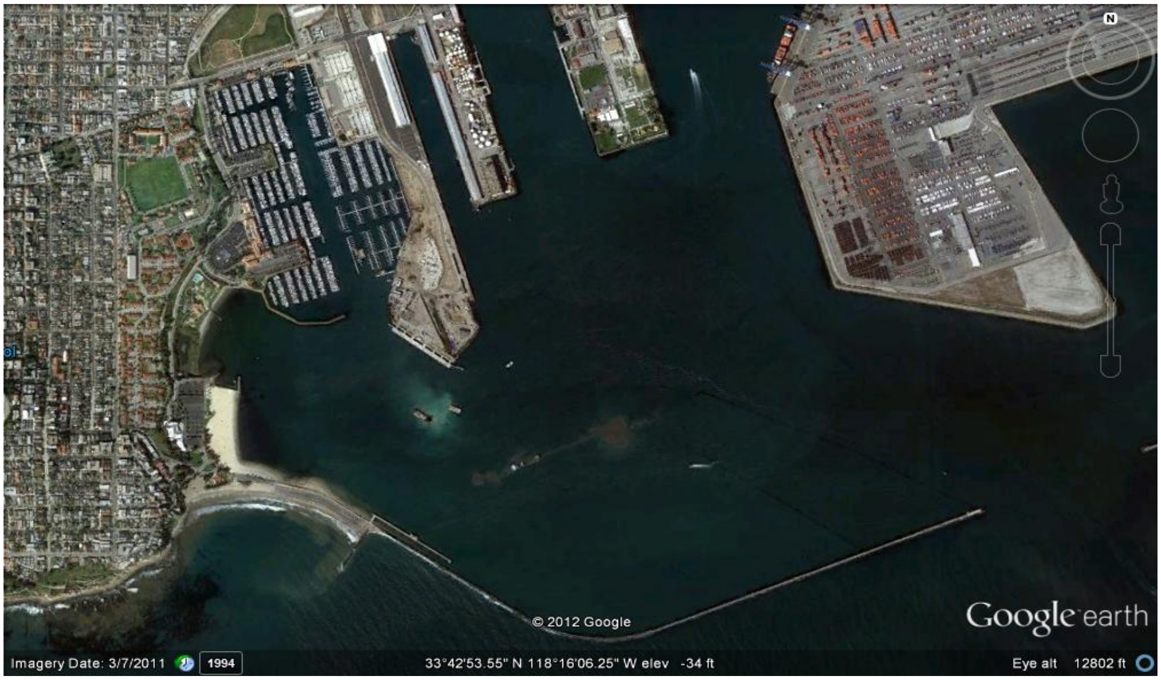

Figure 14. Eastern portion of San Pedro sheltered behind LA-Long Beach outer breakwater (lower center), with portion of Terminal Island (upper right, Google earth photo).

Figure 15. View north over LA-Long Beach outer breakwater and Angel's Gate (lower right) toward Port of Los Angeles and Terminal Island (right). Wilmington is in the distance (Port of Los Angeles photo).