BOX 1

Short-term increases in sea level

Although long-term mean sea-level rise by itself will provoke increasing occurrences of nuisance flooding, over the next several decades it is highly likely that short-term increases in sea level will continue to be the driver of most of the strongest impacts to infrastructure and coastal development along the coast of California. Short-term processes, including Pacific Basin climate fluctuations (Pacific Decadal Oscillation, El Niño Southern Oscillation, and North Pacific Gyre Oscillation), King tides (perigean high tides), seasonal cycles, and winter storms, will produce significantly higher water levels than sea-level rise alone, and will present greater risks to coastal development.

El Niño associated flooding

Over the recorded era of the 20th and early 21st centuries, most of the significant storm damage to California's coastline has occurred during major El Niño events, when elevated sea levels coincided with storm waves and high tides [29]. The record from the San Francisco tide gauge, the longest continuously running gauge along California's coast, reveals several years when seasonal anomalies rose above the long-term trend of 1.9 mm/year (0.07 inches/year). The most prominent of those cases were major El Niño events, for example, 1940-41, 1982-83, and 1997-98, when sea levels were elevated 8-12 inches (20-30 cm) for several months at a time (Figure 2).

Adding these weather and short-period climate events to the more gradual, incremental global rise in mean sea level will present increasing risks for low-lying coastal infrastructure and development. The latest generation of climate model simulations suggests that North Pacific storminess will remain at about the same level of activity as seen in the 20th and early 21st century but that the frequency of extreme El Niño events may increase under a warmer climate [30]. Given the strong association between El Niño, large winter North Pacific storms, and anomalously high sea levels and storm surge [31], occasional large sea level events in future decades must be considered in future scenario planning.

King tides

High tides along the California coast occur twice daily, typically of uneven amplitude, and are caused predominantly by the gravitational attraction of the moon and the sun on the Earth's oceans. Extreme tides, called spring tides, occur in multi-day clusters twice monthly at times of the full and new moon. Additionally, even higher tides occur several times a year and are designated as perigean high tides, or more popularly "King tides". These events are now recognized as producing significant coastal flooding in some well-known areas such as the Embarcadero in San Francisco, where King tides are already washing onto the sidewalks. The Earth-moon-sun orbital cycles also amplify tidal ranges every 4.4 and 18.6 years, producing peaks in the monthly high tide that are about 6 inches (15 cm) and 3 inches (8 cm) respectively, higher than in the intervening years.

Storm surges

Storm surges, created when strong onshore winds combined with low barometric pressure force seawater onto the shoreline, also temporarily elevate sea levels. While storm surge along the coast of California is considerably less than that experienced during severe hurricanes and nor'easters along the Gulf and Atlantic Coasts of the United States, the storm surge during major winter storms here can reach as much as 3 feet above predicted sea levels.

Wave-driven water level increase

Large ocean waves can transport significant volumes of water up onto the shoreline as they break, causing temporary increases in sea level through two related processes. Wave run-up describes the process of an individual breaking wave washing up the beach face to an elevation as much as 6 feet above sea level. Wave set-up results from a set of large waves breaking in rapid succession, which can elevate the overall water level along the shoreline as much as 4 or 5 feet for a few minutes at a time. Because many beaches have shallow slopes, extremely high waves and resulting set-up and run-up events can have enormous impacts in causing erosion and damage to coastal infrastructure. Short-term elevated sea levels from any of these processes can not only cause flooding in low-lying coastal areas but can also exacerbate flooding along stream or river courses when runoff is temporarily obstructed by an elevated ocean or high tides, thereby leading to enhanced inland flooding.

Implications of short-term increases in sea level

The historic records and measurements (from tide gauges) of short-term elevated sea levels, whether due to El Niño events, King tides, storm surges, or a combination of these (as dramatically occurred during the 1982-83 El Niño), provide useful indicators for understanding future total water levels. These short-term elevated sea levels need to be added to projected future sea levels to obtain future total water levels.