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Sea Level Dynamics

As discussed in the Preface, one of the more complex aspects of water boundaries is the dynamic nature of the land/water interface. A major cause of that variation is constantly changing water level. That fluctuation is due to a variety of causes including the tides, metrological conditions, and global sea level changes. Traditionally, sea level variations are classified by the period of variation, ranging from *surface gravity waves* with periods varying from 1 to 20 seconds; to *seiches* and *tsunamis* with periods of up to an hour; to *astronomic tides* with dominant periods of one-half and one lunar day; to *storm surges* with periods ranging from a few hours to several days; to *long term, apparently nonperiodic trends* caused by geological and climatological effects with periods of thousands of years.

In addition to varying periods, sea level variations also vary considerably in amplitude. Variations range from those associated with seiches and surface waves with amplitudes as small as a few centimeters to tsunamis with amplitudes in the tens of meters.

1.1 Short-Term Sea Level Variation (Other than Tides)

1.1.1 Surface Gravity Waves

Possibly the most noticeable sea level variations are *surface gravity waves* (Figure 1.1), which are generally called either wind waves or swell. *Wind waves* are the effect of wind on water and always travel in the same direction that the wind is blowing. Wind waves continuing for longer than a few hours gain sufficient energy to take on a distinct character known as *swell*, which move across open areas of water even though not under the influence of the wind. Wind waves generally have periods from 1 to 15 seconds. Swell has longer periods,

Sea Levels and Coastal Boundaries, First Edition. George M. Cole.

Figure 1.1 Surface Gravity Waves.

generally between 12 and 25 seconds, and appears less steep than wind waves. Also, swell will not normally break in open water, while wind waves will often break.

The height of waves is usually expressed as the vertical distance from peak to trough. Since there can be considerable differences in height between individual waves in an area, another measurement used to describe heights is the *significant wave height*. That measure is the average height of the highest one-third of waves over an observational period, generally about 20 minutes. Wave heights up to 30 m have been measured.

1.1.2 Seiches

Seiches are the periodic change in sea level that occur in enclosed waters and which are set in motion by some disturbance such as a strong wind, atmospheric pressure changes, or boat traffic. Basically, seiches represent water sloshing back and forth within an enclosed basin with periods ranging from a few minutes to a few hours depending upon the size of the basin. The amplitude of seiches is generally in the tenths of a foot range or less (Figure 1.2).

Knowledge of seiches is important for the design and operation of harbors and other areas where berthing of deep draft vessels occur. In addition, knowledge of

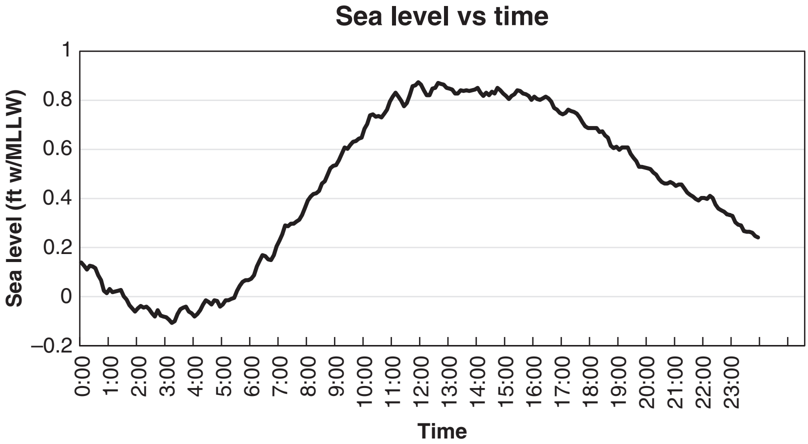

Figure 1.2 Prominent Seiche Superimposed on Tidal Variation for Typical Day, Isla Magueyes, Puerto Rico. *Source:* www.tidesandcurrents.noaa.gov/NOAA/Public Domain.

these variations is important in tidal studies since they can easily distort tidal measurements.

1.1.3 Storm Surges

As previously discussed, surface waves are created by the drag or stress of atmospheric wind on the sea surface. Changes in the level of the sea surface are also related to another atmosphere phenomenon called the *inverse barometer effect*. The combination of the effect of wind drag (which is proportional to the square of the wind speed) and effect of atmospheric pressure (which decreases sea level by one centimeter per millibar) can result in huge sea level surges being generated by storm systems, especially in shallow water bodies.

In simple terms, a mound of water can be produced by a storm moving across a water body. The storm wind moving cyclonically around the storm can push the water causing it to pile up as it approaches the shore. Since tropical storm winds have a counterclockwise motion in the northern hemisphere, the storm surge in that hemisphere is typically greatest in height to the right of an approaching storm. The height of a storm surge in a particular location depends on a number of different factors including storm intensity, forward speed, angle of approach to the coast, central pressure, and the shape and bathymetric characteristics of coastal features such as bays and estuaries, and the width and slope of the continental shelf. A shallow slope will potentially produce a greater storm surge than a steep shelf. As a result, a storm approaching an area such as

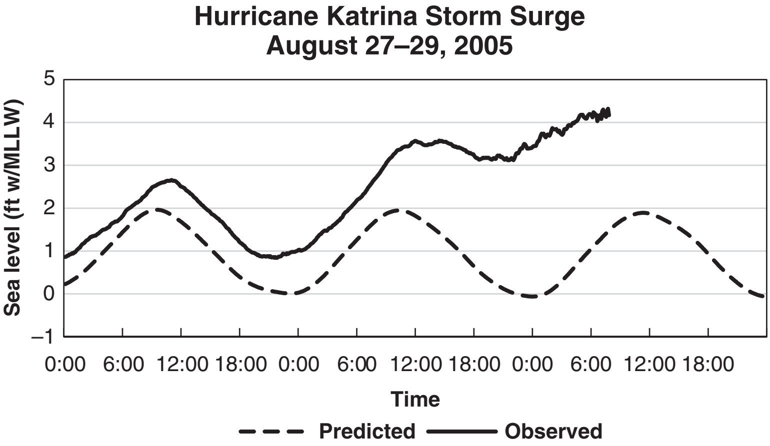

Figure 1.3 Storm Surge of Hurricane Katrina as Observed in Biloxi, MS (Note that the gauge was lost near the height of the storm surge). *Source:* NOAA/https://tidesandcurrents.noaa.gov/predma2.html, last accessed 13 November 2023.

the Louisiana coastline with a very wide and shallow continental shelf may produce a 20-ft storm surge, while the same hurricane approaching the eastern U.S. coastline with a steeper continental shelf would result in a much smaller surge. Often, storm surges cause greater damage than the winds in a storm (Figure 1.3).

1.1.4 Tsunamis

A *tsunami* is a series of waves created by a displacement of the water column caused by an undersea disturbance of some type. That disturbance may be undersea earthquakes, landslides, volcanic eruptions, or even explosions or meteorite impacts. The period of the waves varies from minutes to greater than an hour, depending on the nature of the disturbance creating the tsunami. Once generated, the waves travel rapidly across the open ocean with a speed equal to the square root of the product of the water depth and the acceleration of gravity (9.8 m/s^2), with speeds often over 620 kmph (IOC 2006). The wavelength may be as long as 80 km. At sea, the wave height may be less than a meter in height, so the waves are virtually unnoticeable at sea. Yet, as the tsunami waves approach shoaling water, the water piles up which creates waves as high as 30 m or more (Figure 1.4).

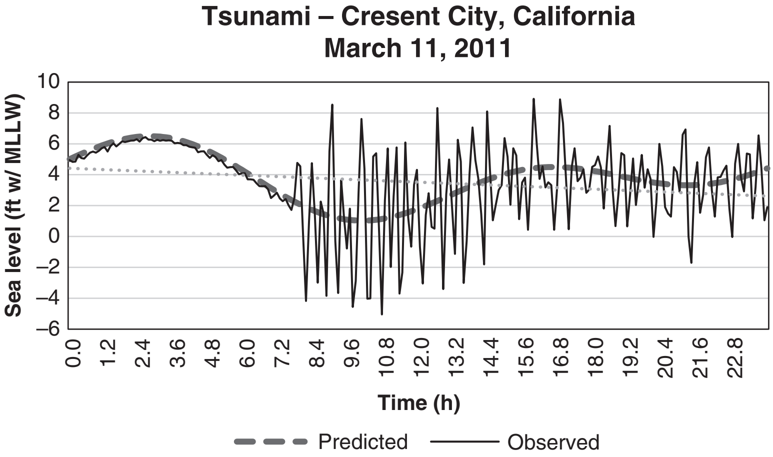

Figure 1.4 Tsunami Waves Resulting from the Japanese Earthquake of 3/10/2011, as Observed in Crescent City, California. *Source:* www.tidesandcurrents.noaa.gov/NOAA/ Public Domain.

1.2 Tidal Variation and Datum Planes

1.2.1 Tidal Cycles

Tides are sea level variations caused by the gravitational forces of the sun and moon as well as solar radiation. Tidal variations are cyclic and follow periodic patterns due to the cyclic nature of those astronomical phenomena. As a result, tides may be distinguished from other types of sea level variations.

The primary driving force of the tides is the gravitational pull of the moon as it rotates around the earth. Due to that force, there is an uplifting of the sea under the moon caused by its gravitational pull on the fluid water. On the side of the earth opposite the moon, the lesser gravitational force due to the greater distance to the moon and the centrifugal force caused by the earth's spin causes a second higher water. Although interrupted by intervening land masses, these two high water waves, with their intervening low waters, follow the moon in its revolution about the earth and represent the primary constituents of the observed tide. Since one-half of the average interval between consecutive transits of the moon is 12.42 hours, the moving high waters generally take the form of a sine wave with a period of that interval.

There is a similar, although somewhat lesser, effect on the level of the seas caused by the gravitational pull of the sun on water on the rotating earth. That wave may be represented as a sine wave with a period of 12.00 hours. Changes in sea level caused by several other relationships between the moon, sun, and earth may also be considered as sine wave constituents of the observed tide. For example, the elliptical orbit of the moon about the earth results in a constituent with a period of 27.55 days with highest water at the time of perigee (when the moon is closest to the earth) and lowest water when the moon is the greatest distance away. Also, there is a constituent period of one year associated with the declination of the sun.

When the constituent cycles associated with the cycles of the moon and sun are "in phase" (when the peaks are occurring at approximately the same time), tides with greater than normal ranges occur. Such is the case twice a month near the time of the new and full moon when the earth, moon, and sun are in a line. At those times, the constituent waves associated with the sun and moon are in phase and produce the so-called *spring tides*. Much smaller *neap tides* are those which occur at the time of the quarter or three-quarter moon when the sun and moon are at 90 degrees to each other as measured from the earth. Their respective following waves are then out of phase and result in smaller tidal ranges (Figure 1.5).

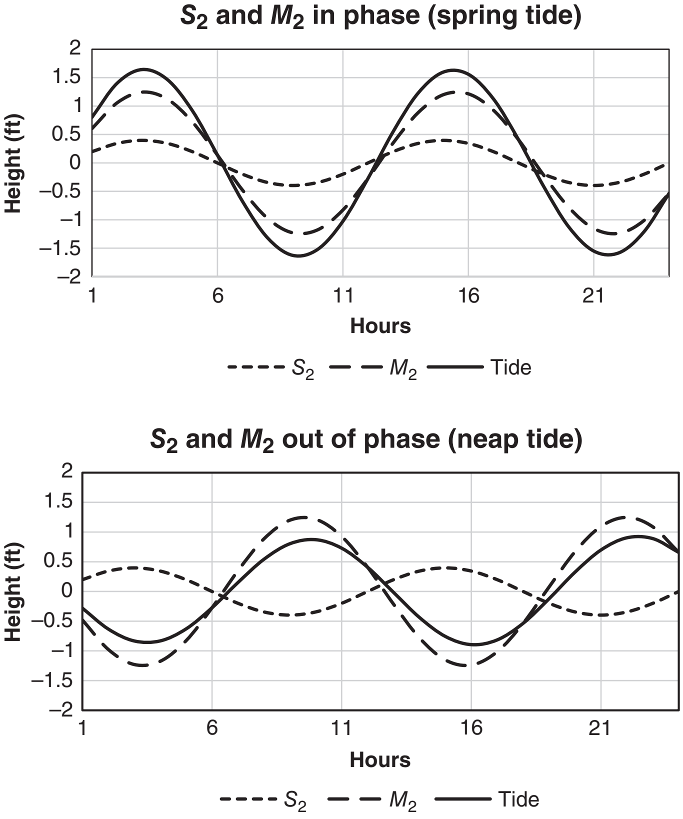

Figure 1.5 The Relationship Between the Semi-diurnal Constituents of the Moon (M_2) and Sun (S_2) for a Spring Tide and a Neap Tide Using the Amplitudes of Those Tidal Constituents for Fernandina Beach, Florida.

The observable daily tidal patterns may be classified into three categories. These are semi-diurnal, mixed, and diurnal. Semi-diurnal tidal patterns (Figure 1.6) have two cycles of nearly equal amplitude during each lunar day of 24.84 hours. Tides along the east coast of the United States are predominately semi-diurnal. Mixed tidal patterns (Figure 1.7) have two cycles which are of unequal amplitude. Tides along the west coast of Florida and the Pacific coast of the United States have predominately mixed tidal patterns. Diurnal tidal patterns (Figure 1.8) have only one tidal cycle per day and are found along the northern and western coast of the Gulf of Mexico and several other places in the world.

In addition to the daily patterns, longer-term observations allow a view of other tidal patterns. For example, a plot of hourly sea level values over a month of observations shows a pronounced pattern with a period of 27.55 days associated with the elliptical orbit of the moon about the earth (Figure 1.9). In such a plot, the spring tides associated with the new and full moons as well as the neap tides associated with the quarter moons may be observed as having greater and smaller ranges.

Similarly, an annual tidal pattern is typically visible as a trend line when the mean tide level (MTL) for each month in the year over a 19-year tidal epoch is plotted (Figure 1.10). That pattern is particularly noticeable in areas such as the northern reaches of the Gulf of Mexico where the tides tend to be considerably lower in the autumn due to prevailing northerly winds.

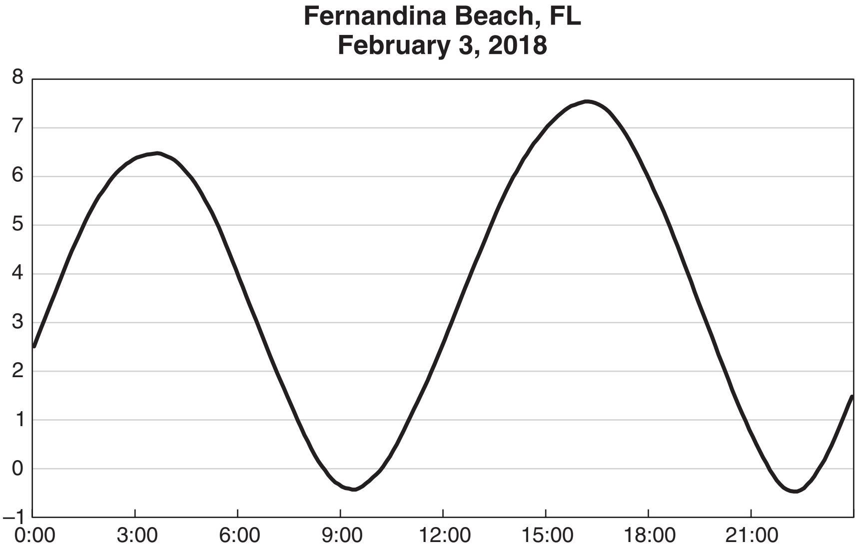

Figure 1.6 Typical Semi-Diurnal Tidal, Pattern Fernandina Beach, Florida. *Source:* www.tidesandcurrents.noaa.gov/NOAA/Public Domain.

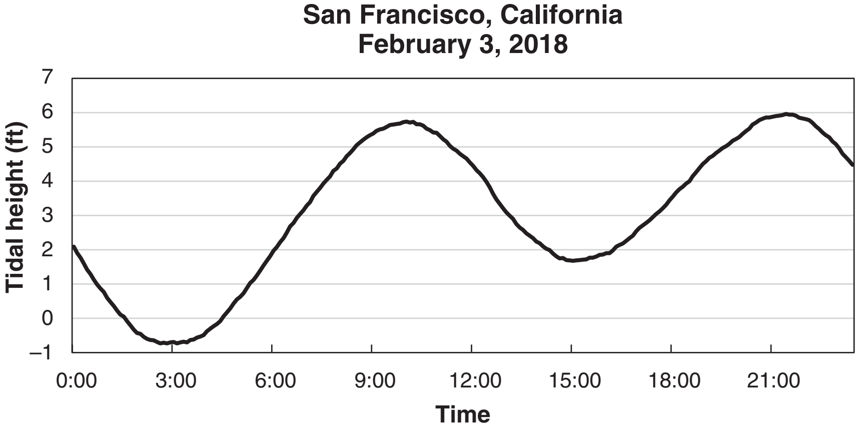

Figure 1.7 Typical Mixed Tidal Pattern, San Francisco, California.
Source: www.tidesandcurrents.noaa.gov/NOAA/Public Domain.

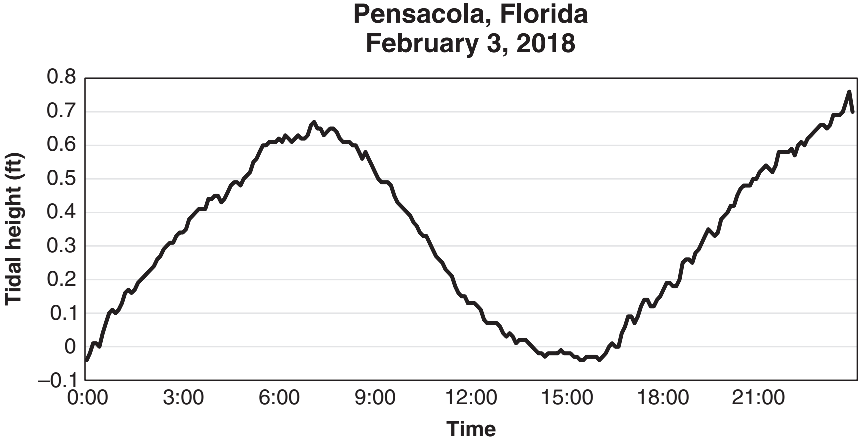

Figure 1.8 Typical Diurnal Tidal Pattern, Pensacola, Florida.
Source: www.tidesandcurrents.noaa.gov/NOAA/Public Domain.

In addition to those described and other relatively short-term constituents associated with astronomic forces, there is another sinusoidal cycle, that associated with the movement of the moon's nodes[1] with a period of 18.6 years, that affects

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[1] Movement of the moon's nodes refers to the movement of the intersection of the moon's orbital plane and the plane of the Earth's equator which completes a 360° circuit in 18.61 years.

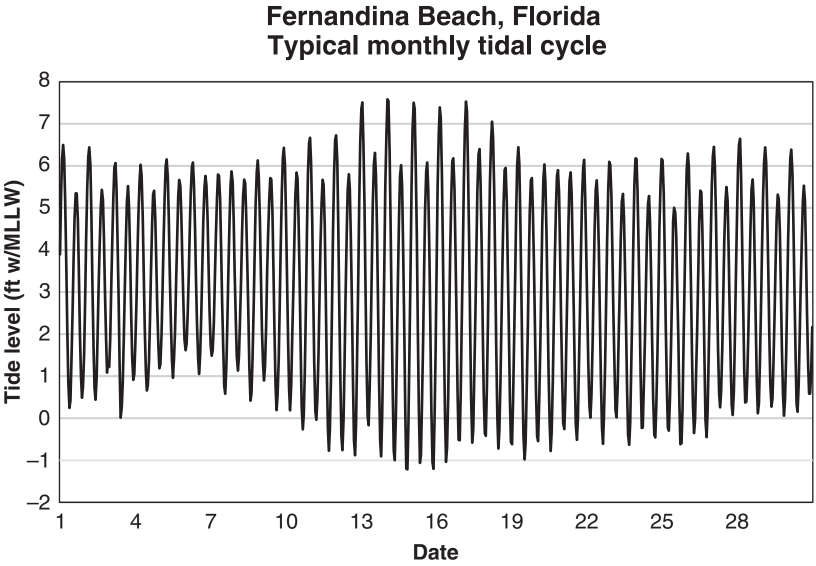

Figure 1.9 Typical Monthly Tidal Pattern – June 2018, Fernandina Beach, Florida, Florida. *Source:* www.tidesandcurrents.noaa.gov/NOAA/Public Domain.

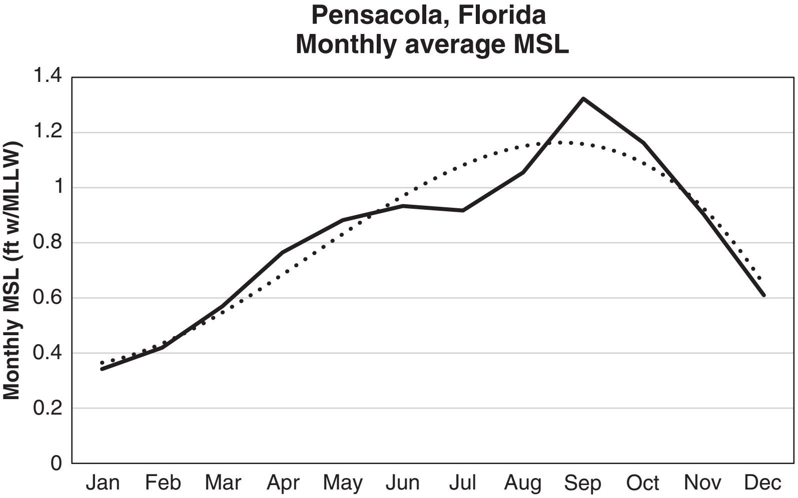

Figure 1.10 Typical Average Monthly Mean Sea Level, Pensacola, Florida – 1999–2018. *Source:* www.tidesandcurrents.noaa.gov/NOAA/Public Domain.

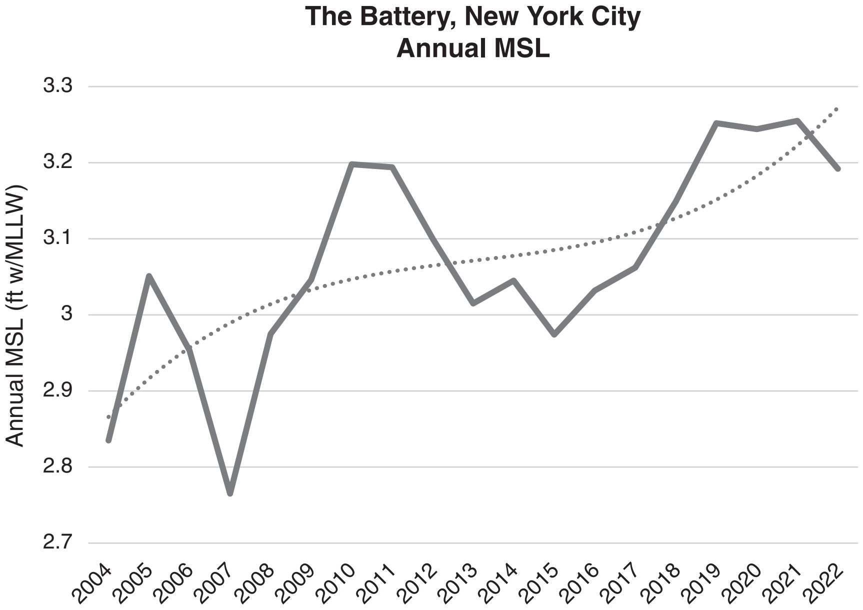

Figure 1.11 18.6 Year Tidal Cycle – 2004:2022, The Battery, New York, NY. In Addition to the Effect of the 18.6 Year Cycle, the Effect of the Upward Long-term Trend May be Seen in this Figure. *Source:* www.tidesandcurrents.noaa.gov/NOAA/Public Domain.

the water level. The effect of that cycle may be seen in Figure 1.11. There is also a long-term cycle with a period of 8.85 years due to the lunar perigee cycle, which has a prominent effect on tides in some areas (Haigh et al. 2011). It is typically apparent as a 4.4-year cycle.

Considering the periodic variations in sea level described earlier, the resultant observed tide is the composite, or algebraic sum, of all the above-mentioned constituent cycles. Although there are theoretically several hundred tidal constituents, not all are significant. Twelve of them are generally considered of primary importance in most locations within the United States (Table 1.1).

One advantage of considering the observed tide as the sum of constituent components is that it allows prediction of tides. With amplitude and phase lag of the constituents determined by tidal observations at a given location and the known constituent periods, the amplitude and time of the tidal extremes may be predicted at a location for years in advance. Lord Kelvin, who developed the tidal harmonic constituent analysis theory in 1867, also designed a tide predicting machine. That device was, in essence, a mechanical computer. It physically summed the amplitudes of the harmonic constituents over a given time and traced the resulting curve. Several similar devices were subsequently constructed

Table 1.1 Principal Tidal Constituents.

Symbol	Period (h)	Description
Semi-diurnal		
M_2	12.42	Principal lunar
S_2	12.00	Principal solar
N_2	12.66	Larger elliptical lunar
K_2	11.97	Lunar – solar semi-diurnal
Diurnal		
K_1	23.93	Luni-solar diurnal
O_1	25.82	Principal lunar diurnal
P_1	24.07	Principal solar diurnal
Q_1	26.87	Larger lunar elliptic
Long period		
M_f	1.000	Radiational
M_m	0.997	Principal lunar – solar
S_sa	0.962	Elliptical lunar
S_a	0.929	Second-order lunar

Note that the Subscripts of the Constituent Names Indicate the Frequency of the Cycles.
Source: Modified from Gill and Schultz (2001)/NOAA/Public domain.

and were widely used until well into the second half of the twentieth century. The author has a graphic memory of being introduced, as a newly commissioned officer of the U.S. Coast & Geodetic Survey (now a component of NOAA) to the tide predicting machine being used by that agency in 1961 (Figure 1.12). Tide prediction is now easily accomplished on a desktop computer with far greater precision.

1.2.2 Tidal Datum Planes

A *tidal datum* is a plane of reference based upon average tidal heights. To be statistically significant, all of the periodic variations in tidal height should be included in the average. As a result, a tidal datum is usually considered to be the average of all occurrences of a certain tidal extreme over a *tidal epoch* of 19 years (the period of the longest astronomic cycle affecting the tides, the motion of the moon's nodes with a period of 18.6 years, rounded to the nearest whole year for inclusion of a multiple of the annual cycle associated with the declination of the sun).

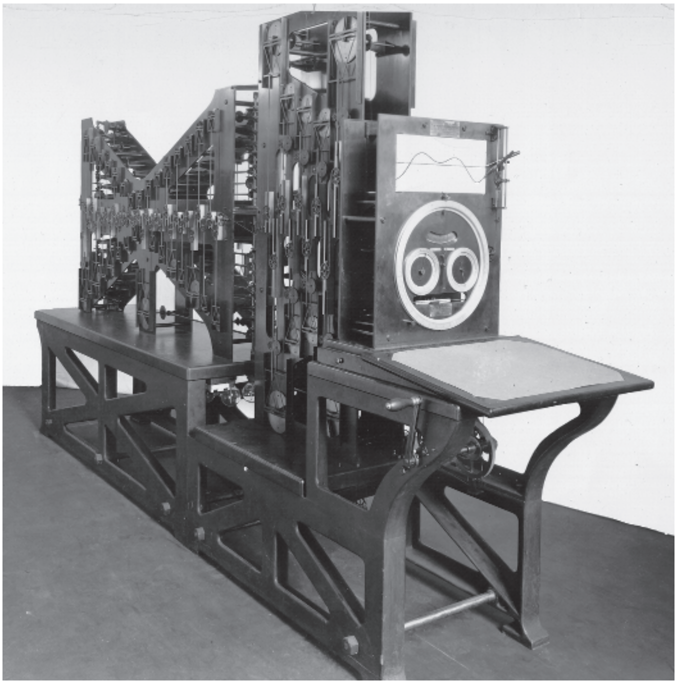

Figure 1.12 U.S. Coast and Geodetic Survey's Tide Predicting Machine No. 2. *Source:* NOAA/https://tidesandcurrents.noaa.gov/predma2.html/last accessed 13 November 2023.

Common examples of tidal datum planes include *mean high water* (MHW), defined as the average height of all the high waters occurring over a 19-year tidal epoch, and *mean low water* (MLW), defined as the average of all of the low tides over a 19-year tidal epoch. Other common tidal datums include MTL, which is the plane halfway between MHW and MLW, and *mean sea level* (MSL), which is defined as the average level of the sea over a tidal epoch. The relationship between MSL and MTL varies with location based on the phase and amplitude relationships of the various tidal constituents at those locations. Other commonly used datum planes include *mean higher high water* (MHHW), defined as the average of the higher of the high tides occurring each day over a tidal epoch, and *mean lower low water* (MLLW), which is defined as the average of the lower of the low tides occurring each day over a tidal epoch (Figure 1.13).

Based on the above definitions, it may be seen that determination of a tidal datum involves a relatively simple determination of the arithmetic mean (average) of all the occurrences of a certain tidal extreme over a 19-year tidal epoch. Two less frequently used tidal datum planes which are typically exceptions when used include mean low water springs (MLWS) and equinoctial spring tide. MLWS

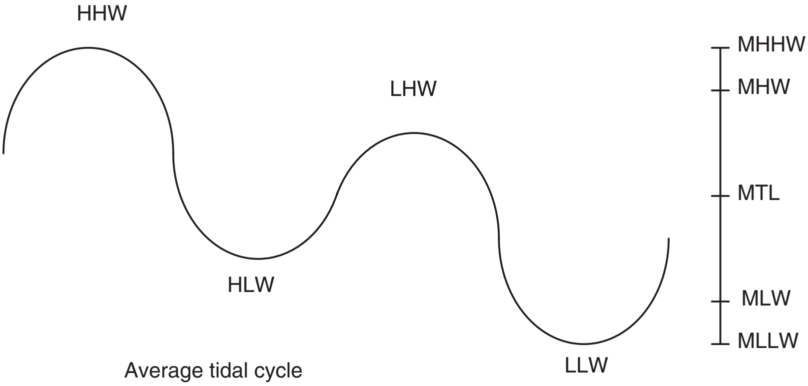

Figure 1.13 Common Tidal Datum Planes.

is the arithmetic mean of the low water heights occurring at the time of spring tides over a tidal epoch. It is usually calculated as a value one half the spring range of tide below MTL and is used in some countries as a hydrographic datum. As discussed earlier in this section, spring tides are those experienced twice a month near the time of the new and full moon when the earth, moon, and sun are in a line. Tidal ranges for spring tides are considerably greater than average tides in most areas due to the gravitational forces of the moon and sun pulling in unison. *Equinoctial spring tides* result twice annually when spring tides occur near the times of the vernal or autumnal solar equinox. At those times, the sun is over the equator, and the paths of the sun and moon are in closest alignment resulting in tidal ranges greater than average spring tides.

It should be noted that the tidal extremes used in calculation of tidal data are not necessarily the highest and lowest water that occur in a tidal cycle. In most areas, especially on the open coast, wind wave action causes a constant and frequent variation in water level. For consistency, since wind wave action is essentially unpredictable, tidal gauges measure the height of stilled water which is approximately half-way between the crest and trough of the wind waves. In areas with sizable wind waves, there can be a significant vertical distance between the crest (or trough) of the wind wave and the stilled water level of high and low water.

1.3 Long-Term Changes in Sea Level

1.3.1 Pre-Historic Trends

Sea level has been in a state of flux throughout the history of the world and continues to be so today. For at least the past half million years or so, the Earth has experienced climate cycles with periods averaging roughly 100,000 years. That period is related to the Milankovitch cycles which are the result of the eccentricity of the Earth's orbit and the tilt and precession of the Earth's axis. Each such cycle included a glacial period during which the earth experienced cooler than average temperatures resulting in the formation of many glaciers and an inter-glacial period with warmer than average temperatures during which many of the glaciers melted. This, in turn, resulted in significant changes in global sea level (Figure 1.14).

It may be seen from Figure 1.14 that the last glacial maximum ended about 15,000 years ago. At that time, the ice began melting and sea level began rising and has generally been on an upward trend since that time. Graphic evidence of the earlier stand of the Gulf of Mexico along the Big Bend area of the Florida Gulf of Mexico coastline may be seen today as a pronounced escarpment, called the Cody Scarp, lying 18 mi or so upland of the current shoreline (Figure 1.15).

As the last glacial period ended, higher temperatures resulted in melting icecaps, which led to sea level rise, increased precipitation, and greater volume of water in rivers. The scale and rate of that rise in the Gulf of Mexico has been quantified by a report published by the Florida Geological Survey (Basillie and Donaghue 2004). That report provides an analysis of 341 separate radiocarbon-dated sea level indicator points based on 23 independent field studies in the northern Gulf of Mexico. The results of that report, when plotted, provide a good overview of the trend of sea level in the northern Gulf of Mexico over the last

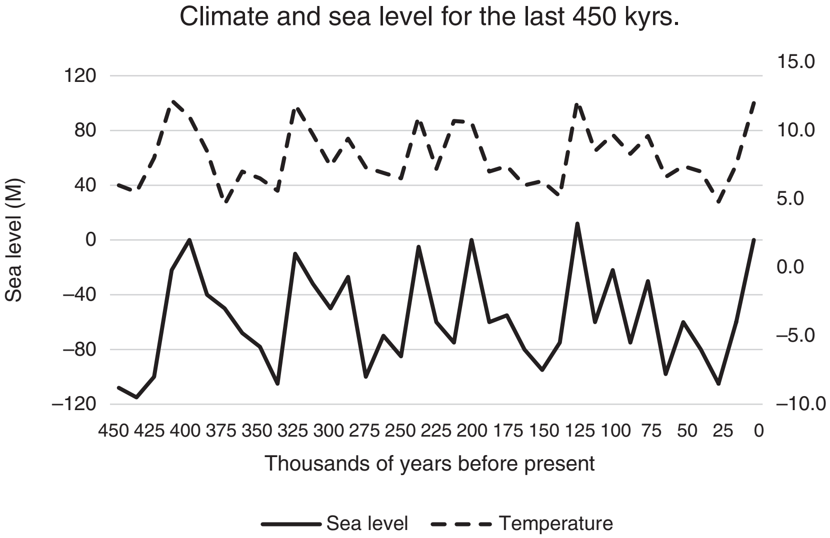

Figure 1.14 Recent Glacial/Inter-Glacial Periods. *Source:* Adapted from Carson (2011).

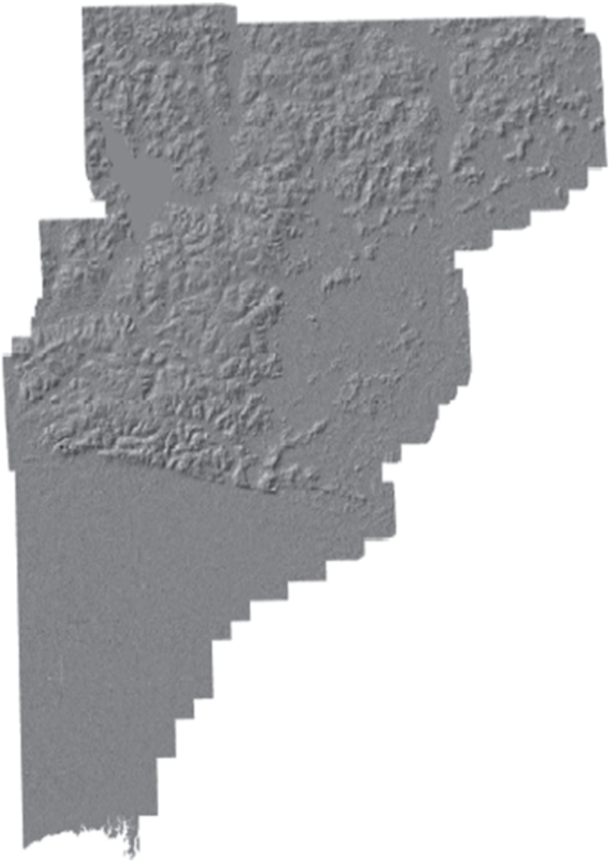

Figure 1.15 Bare-Earth LiDAR Image of Jefferson County, Florida, Showing the Cody Scarp Crossing the Southern Portion of the County.

22,000 years (Figure 1.16). A least squares regression through those points suggests an average rise of 6.0 mm/yr over the last 22,000 years, and 2.3 mm/yr over the last 10,000 years. Those changes are considered to be associated with melting of grounded ice, thermal expansion, and redistribution of water mass, all associated with the long-term climate change that has taken place during the last 25,000 years or so.

The above cited trends reflect averages over thousands of years. Within those periods, there were numerous short-term trends with periods of a few hundred years or so, with sea level trends considerably different from the average over the entire period. As an example, the downward trend in sea level between 12,835 and

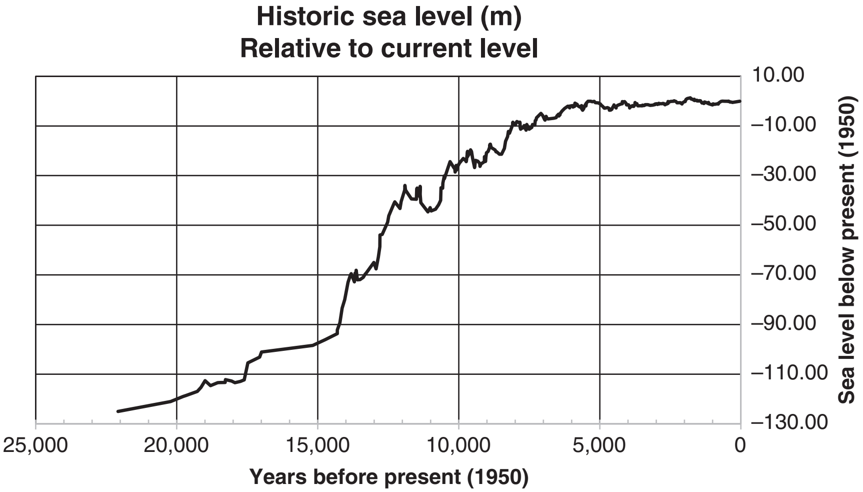

Figure 1.16 Estimated Sea Level Change Over Previous 22,000 Years, Based on Data from Basillie and Donaghue (2004), Average Rise Over Last 25,000 years: 6.0 mm/yr, Average Rise Over Last 10,000 years: 2.3 mm/yr.

11,735 before present[2] has been associated with a sudden cooling of the earth believed to be triggered by the impact of an asteroid with earth. That period has been associated with the sudden extinction of the mammoths and a decline of the Clovis culture in North America.

Another period of sea level decline began about 1800 years before present (150 AD) when the sea level was more than a meter above current levels. After that period, the data suggest a falling sea level trend of −3.0 mm/yr for several centuries followed by a generally rising trend. Within the last 1000 years, the data suggest a subperiod of rapid rise between 1000 and 700 years before present (950–1250 AD) during the so-called "medieval warm period" and another of rapid decline during the "little ice age" from 650 to 300 years before present (1300–1650 AD) when much of the world was subjected to cooler winters (Figure 1.17).

Despite the various previously described exceptions, the overall trend in sea level, based on geologic data, has been upward since the last glacial maximum, some 15,000 years ago. The result of that trend has been a gradual retreat of the shoreline. As an example, along the Big Bend area of the Florida's northern gulf coast, the shoreline is believed to be as much as 90 mi landward of its location at the beginning of that retreat. Submerged paleo-channels of rivers that led to the

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[2] For the referenced study, "present" was defined as 1950.

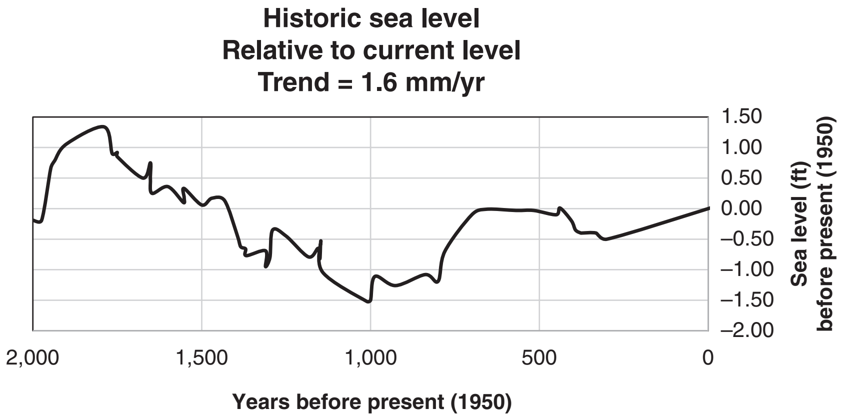

Figure 1.17 Estimated Sea Level Change Over Previous 2000 Years, Based on Data from Basillie and Donaghue (2004), (Enlargement of Portion of Figure 1.16).

shoreline at the beginning of that retreat as well as evidence of pre-historic human settlement are still clearly visible, many miles off the current shoreline (Cole et al. 2017). Therefore, pre-historic geologic data clearly suggest a constantly moving boundary between the oceans and the upland.

1.3.2 Contemporary Trends

In the last 200 years, records from sea level gauges are available that allow direct observation of the rate of sea level changes (Cole 1997), as opposed to reliance on the geologic coastline indicators. Even though more precise that the rates suggested by geologic evidence covered in the last section, the periods covered are much shorter duration. The longest operating of such stations worldwide (Figure 1.18) is in Brest, France, where sea levels have been recorded since 1807. The data from that station indicate a rising trend of 1.1 mm/yr over the entire period of observation although there is an apparent change in trend about 1890. From that point to current, the data suggest a rising trend of 1.6 mm/yr.

The tide station with the longest record of continuous operation in the United States is located in San Francisco, California. It was established by the U.S. Coast & Geodetic Survey in 1854. The records from that station indicate an average rise of 1.96 mm/yr (Figure 1.19) from an apparent datum shift in 1895 through 2018. As may be seen, the data for that station records reflect a relatively constant slope over that period.

Although the sea level change trend indicated by the San Francisco gauge is relatively close to the reported current global rate of sea level rise (1.7 ± 0.5 mm/yr) in

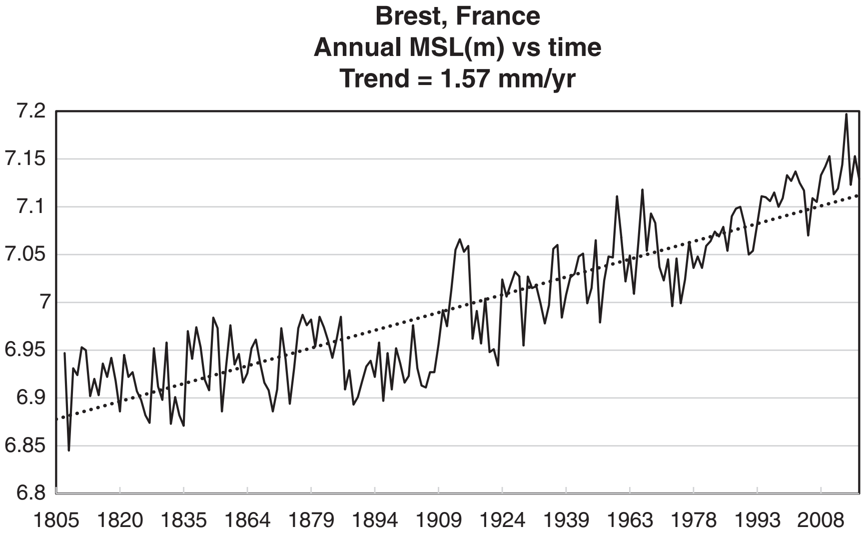

Figure 1.18 Sea Level Trend at Brest, France *Source:* Adapted from www.tidesandcurrents.noaa.gov.

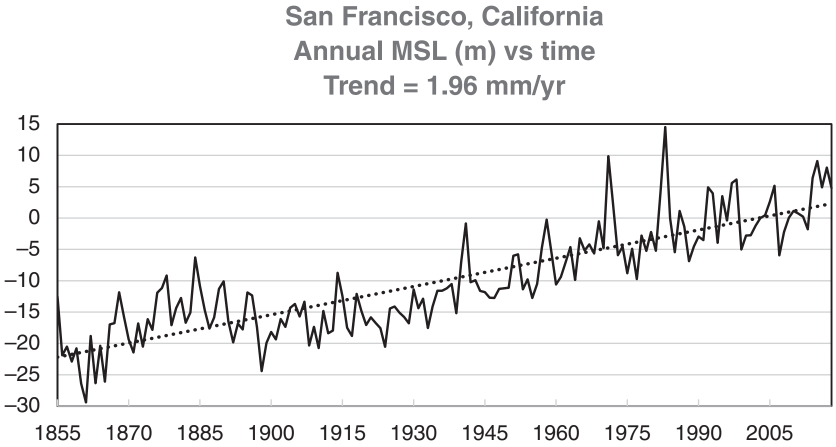

Figure 1.19 Sea Level Trend at San Francisco, California. *Source:* www.tidesandcurrents.noaa.gov/NOAA/Public Domain.

the twentieth century (NOAA 2009), there is a considerable variation of sea level trends as recorded in other tide gauges along the U.S. coastline. As an example, sea level records from a monitoring station at the Battery in New York City, with records dating back almost as long as the station in San Francisco, show higher rates of long-term rise (Figure 1.20).

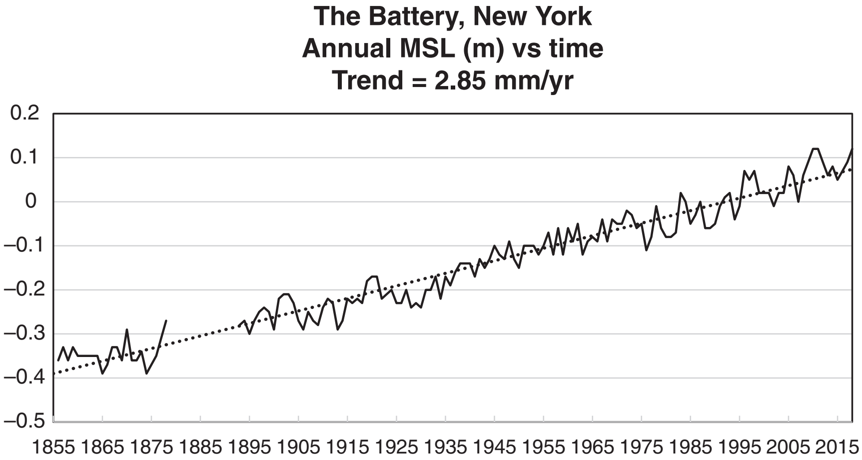

Figure 1.20 Sea Level Trend at the Battery, New York, New York.
Source: www.tidesandcurrents.noaa.gov/NOAA/Public Domain.

A graphic illustration and possible explanation of the differences in trends at various locations may be seen by examining data from a series of stations along the northern Gulf of Mexico coastline (Table 1.2). By observing gauging data at various locations along that coast, it may be readily seen that the apparent rates of sea level rise appear to vary considerably with location. The high rates appear to reach a peak in areas along the Louisiana coast where there is the highest apparent rise in the United States (e.g. 9.08 mm/yr at Grand Isle). The differing apparent rises are believed to be related to local vertical land movements. Since sea level changes are measured relative to fixed bench marks on land, measured sea level changes include both true sea level changes and vertical land movement due to various factors including earthquakes, tectonic motion, consolidation of coastal sediments, consequences of extraction of oil or water, and responses of the earth to the melting of glaciers (Pugh 2004).

The effect of local vertical land movement on apparent sea level may be graphically illustrated by comparing data for sea level change at Grand Isle, Louisiana, and for Southeast Alaska. At Grand Isle, as may be seen (Figure 1.21), there is an apparent rise in sea level of 9.08 mm/yr, while continuous GPS observations indicate that the ground there is sinking at a rate of 8.1 mm/yr (www.ags.noaa.gov). This suggests that sea level at Grand Isle is actually rising at a rate of only 1.0 mm/yr (9.1–8.1). At Juneau, Alaska, there is a **decline** in apparent MSL of 13.3 mm/yr, while GPS observations there indicate that the ground is rising, apparently due to glacial rebound, at a rate of 15.4 mm/yr. This suggests that sea level at Juneau is actually rising at a rate of only 2.1 mm/yr

Table 1.2 Sea Level Trends along the Northern Gulf Coast.

Station	Rise (mm/yr)
Cedar Key, FL	2.13
Apalachicola, FL	2.38
Panama City, FL	2.43
Pensacola, FL	2.40
Dauphine Is., AL	3.74
Bay Waveland, MS	4.64
Grand Is., LA	9.08
New Canal, LA	5.35
Eugene Is., LA	4.65
Sabine Pass, TX	5.85
Galveston Pier 21, TX	6.51
Galveston Pleasure Pier, TX	6.62
Freeport, TX	4.43
Rockport, TX	5.62
Corpus Christi, TX	4.65
Port Mansfield, TX	3.19
Padre Island, TX	3.48
Port Isabel, TX	4.00

Source: www.tidesandcurrents.noaa.gov/NOAA/Public Domain.

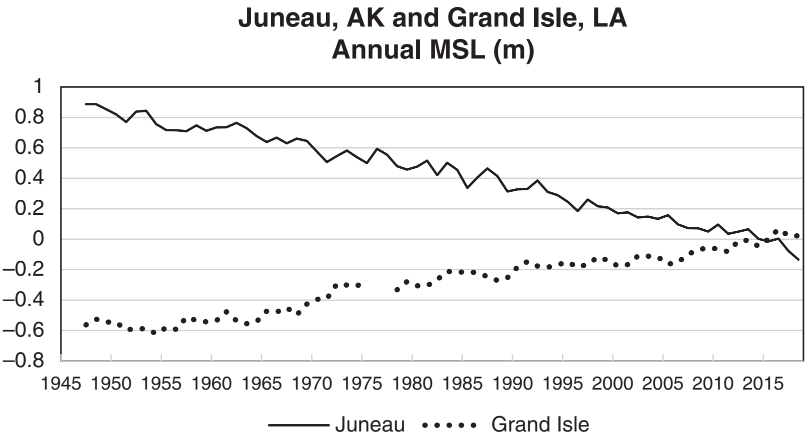

Figure 1.21 Apparent Annual Mean Sea Level, Apparent Average MSL Change: Juneau, AK: −13.3 mm/yr Grand Is., LA: +9.1 mm/yr. *Source:* www.tidesandcurrents.noaa.gov.

(15.4–13.3). This comparison graphically illustrates that in some areas, local geological mechanics are a greater factor in apparent sea level rise than actual sea level.

As may be seen from the previous two sections, sea level change is not a new phenomenon. Rather, sea level has been in a state of flux throughout the history of the world. During the last 15,000 years since the last glacial maximum, evidence suggests that sea level has generally been on a significant upward slope and continues to be so today. Further, that rise has and will continue to have an impact on vegetative and animal life, including humans. Moreover, considering the nature of modern civilization today with its more developed coastal infrastructure, changing sea level will probably have far greater impact today than earlier in the history of the earth even though the current rate is considerably less than in the earlier stage of the current rise.

One important consideration resulting from long-term sea level change is its effect on tidal datum planes. To address this in the United States, tidal datum planes, such as MHW, are calculated using a specific 19-year epoch. Periodically, a new national epoch is adopted by the National Oceanic and Atmospheric Administration (NOAA) after significant change has occurred. At the time of this writing (2015), the National Tidal Datum Epoch is 1983–2001.

1.3.3 Tidal Epochs

As mentioned previously, a tidal datum is defined as an average over a 19-year period known as a tidal epoch. Traditionally, all datum values, published by the National Ocean Service of the NOAA, are referred to a specific time period known as the **National Tidal Datum Epoch**. The policy of National Ocean Service is to consider a new national epoch every 20–25 years to consider adopting a new national epoch. When a new epoch is adopted, adjustments are made to all datum elevations for tide stations published by that agency so that all tidal data throughout the nation are based on a specific time period. The current national epoch, adopted in 2003, is for the 1983–2001 time period.

A modified policy has recently been adopted for regions where the rates of long-term land movement cause anomalously high rates of apparent sea level change. These include areas such as Juneau, Alaska, and Grand Island, Louisiana, shown as examples in the previous section. In areas such as those where the apparent sea level trend exceeds 9.0 mm/yr, a five-year computational period has been adopted to better reflect the current MSL period. Currently, tide data published for those areas are based on the 2012–2016 epoch.

1.4 Shoreline Dynamics

In addition to change in shoreline location due to sea level change, the location of shorelines also changes due to other factors. These include wave and wind action that can wear away, as well as build up the coastline, the action of currents that can erode as well as deposit material, and human activity such dredge and fill activities. The result of all of these forces is that the location of shorelines is constantly subject to change with time. As a result, where the shoreline serves as a boundary, such changes may result in changes in ownership or extent of ownership.

1.5 Variations in Nontidal Waters

Nontidal waters obviously do not demonstrate the predictable periodic variations in water level as those in waters affected by the tides. Nevertheless, variations in the level of such waters do follow certain patterns, generally due to meteorological events. The most obvious of such patterns are those relating to the immediate effect of precipitation. Typically, these are near-vertical rises in water level followed by a return to the long-term trend existing prior to the precipitation event (Figure 1.22). Most nontidal waters also demonstrate changes in water level relating to seasonal meteorological pattern, such as higher levels in the rainy season (Figure 1.23). In addition, most water bodies demonstrate trends due to long-term climate changes or water use (Figure 1.24).

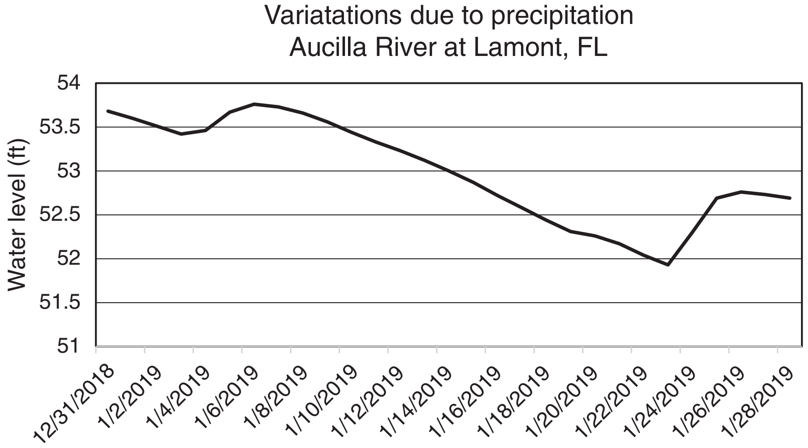

Figure 1.22 Typical Water Level Patterns Associated with Precipitation Events. *Source:* www.tidesandcurrents.noaa.gov.

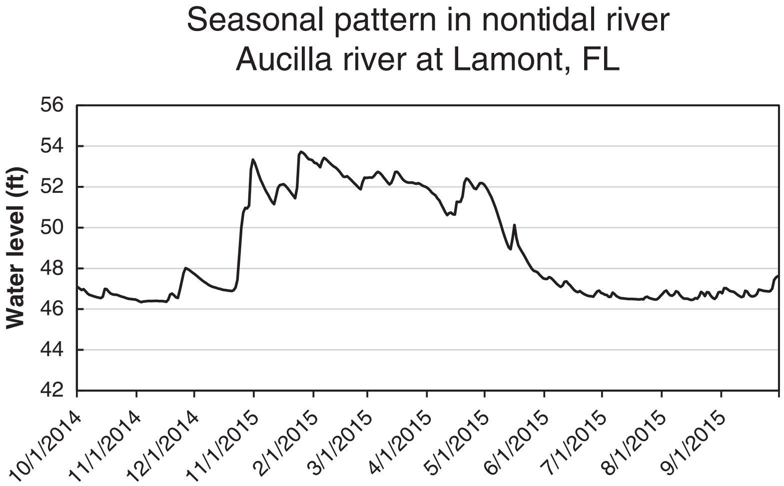

Figure 1.23 Typical Water Level Patterns Associated with Seasonal Precipitation. *Source:* www.tidesandcurrents.noaa.gov.

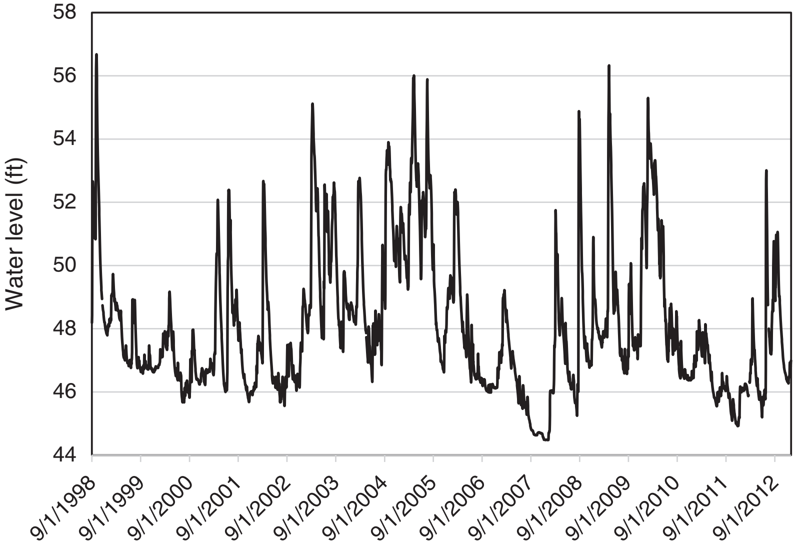

Figure 1.24 Typical Water Level Trend due to Long-Term Effects. *Source:* www.tidesandcurrents.noaa.gov.

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