Understanding tides

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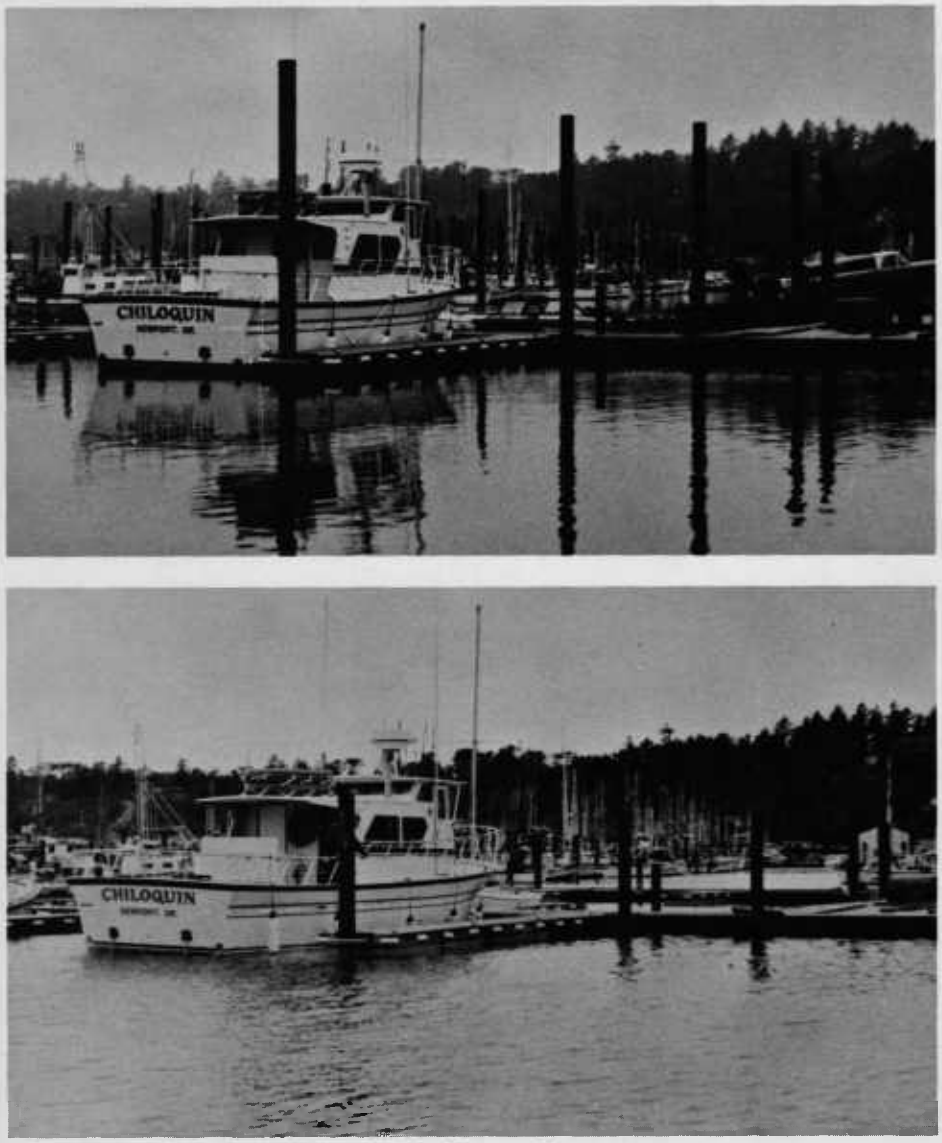

Figure 1.—*The Moon's and the Sun's gravitational tugs on the Earth cause the oceans to bulge in two places. As the Earth turns on its axis, the ocean bulges and lows rise and fall along coastlines as daily tides. In these two views of the Newport, Oregon, harbor (photographed seven hours apart on the same day), the fall and rise of the tide show in the relative heights between the floating boats and docks against the fixed pilings and shore objects.*

Another title in the series

Learning about the ocean

The tide is the periodic daily or semidaily fluctuation of the sea surface. Ocean tides occur worldwide, but the degree of fluctuation varies from imperceptible to many meters.

The first documented reference to tides was in the fifth century B.C. by the Greek historian, Herodotus, who observed characteristics of the tide in the Red Sea. In the next century, Pytheas noted that the motion of the Moon and the rise and fall of the tide were related. Apparently this observation was an outgrowth of his travels to the British Isles, where the range of tide is many times that of his native Greece.

As human horizons expanded, knowledge of physical sciences and, thus, understanding of tides also increased. From the first, tides have been considered important to navigation. Knowledge of tides was essential for growth and development of coastal communities that flourished as a result of early commerce. Wharves, buildings, and other structures had to be constructed with the ever-changing water level in mind (figure 1).

Today, it is even more important that complicated but rhythmic tidal motions and their associated forces be understood as we build closer to the waterfront or shore. Bridges and pipelines connect points of land once considered inaccessible. Bays and harbors have to be protected from the forces of the sea, of which the tide is a major contributor. Supertankers, no longer able to enter many existing ports, have to be handled on the continental shelf, requiring deepwater loading facilities in exposed areas. Consequently, we need to understand not only tides in coastal areas, but also those of the open ocean.

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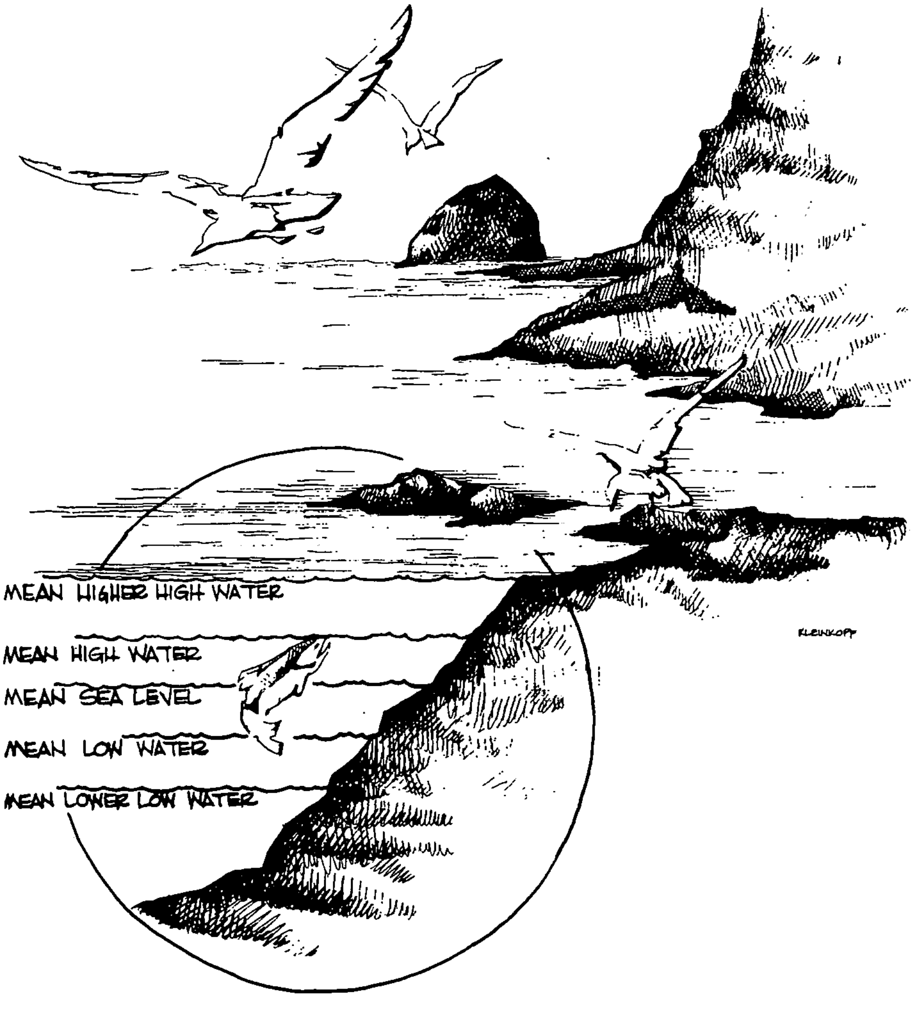

Figure 2.—*The height of the ocean's surface rises and falls with predictable regularity. The means of these periodic high- and low-water conditions are defined as tidal datums. The tidal datums are relative (that is, related to one another) and identified as shown above.*

As people seek to better manage the wastes they dump into streams, rivers, and estuaries, they are calling on oceanographers for more information concerning estuarine and coastal circulation. This is essential for establishing intelligent but practical waste management procedures. Tides play an important role in determining rates of dilution, mixing, and flushing of these coastal waters.

Defining seaward boundaries is another issue with relevance for tide knowledge. In the offshore oil industry, for example, state-Federal boundaries must be precisely defined for determining which jurisdiction may claim taxable revenue. Similarly, as in past years along the Oregon coast, private-state boundaries are becoming critical issues. Since the coastline is not static and instead is constantly undergoing change, boundaries are difficult to demarcate. As a result, boundaries are defined in relation to mean tide elevations.

To help keep track of these mean tide elevations and use them, certain standard references have been established. The most effective references are the *tidal datums*, which are simply fixed references from which we reckon heights or depths. There are a variety of such datums, called by different names, such as *mean low water, mean lower low water, mean high water, mean higher high water*, and *mean sea level.* Each of these tidal datums may be determined in relation to a time period of a specified length, called a *tidal epoch.* These tidal datums can be located on the ground and mapped (figure 2).

Elementary tidal theory—the equilibrium tide

The cause-and-effect relationship between the Moon and tides remained a mystery until 1687, when Isaac Newton published his classic book, *Philosophiae naturalis principia mathematica,* which stated his laws of gravity. Newton's work, along with that of Daniel Bernoulli in 1740, led to the *equilibrium theory of tides*—a basis for understanding simple tidal generation.

The Moon as primary force. Although a number of forces act to produce tides, for the moment we will consider only the forces caused by the Moon. Newton's law of gravitation states that two bodies are attracted toward each other. The strength of this attraction depends on the mass of the bodies and the distance between them. (Two bodies are attracted directly proportional to the products of their masses and inversely proportional to the square of the distance between them.) In the case of the Earth and the Moon, the gravitational attraction between the two is balanced by an additional force. The balancing force is the centrifugal force caused by the rotation of the Earth and the Moon about the center of mass of the Earth-Moon system.

On the side of the Earth nearer the Moon, the gravitational attraction between the Earth and the Moon is greater than the centrifugal force. On the side of the Earth farther from the Moon, the centrifugal force is greater than the gravitational attraction between Earth and Moon.

Thus, the tide-generating forces try to create two tidal "bulges" on opposite sides of the Earth along a line connecting the Earth's center and the Moon's center. Because there are two bulges, there are generally two tides per lunar day (figure 3).

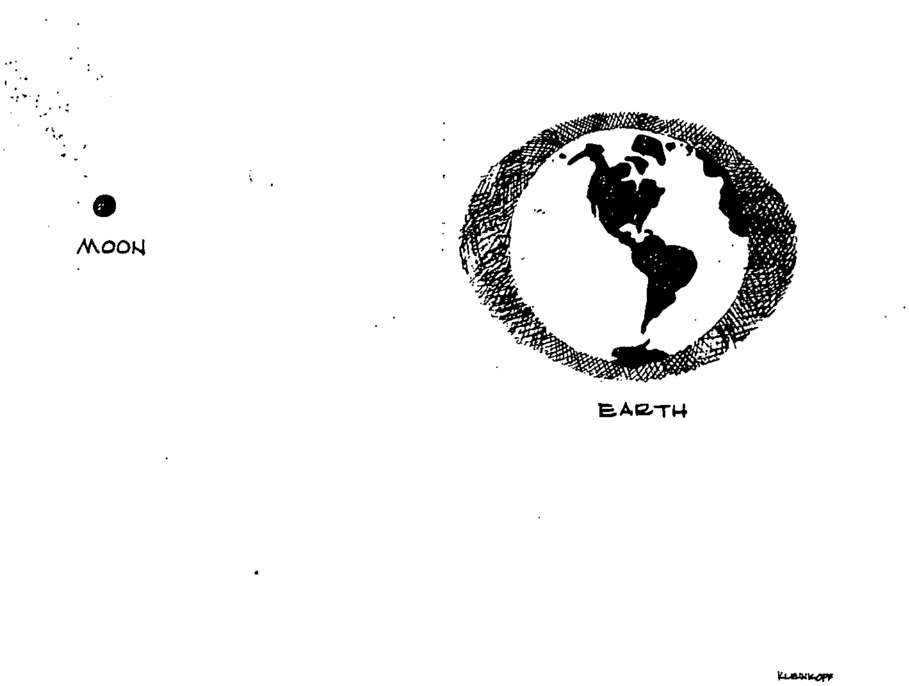

Figure 3.—*Two tidal "bulges" are present on opposite sides of the Earth, formed by the difference between the gravitational forces and the centrifugal force caused by the Earth's revolution around the center of mass of the Earth-Moon system. The Earth makes one complete rotation relative to the moon every 24 hours and 50 minutes. Thus, a location on a coast moves through each of the ocean bulges in a lunar day, and there are two tides a day along most coasts.*

The Sun as secondary tidal force. Heavenly bodies other than the Moon cause tide-generating forces, but the only other body of significance is the Sun. Although it has far greater mass than the Moon, the Sun is much farther from the Earth than the Moon. Consequently, the Sun's tide-generating force on Earth is only about 46 percent as great as that of the Moon.

To understand the variations in tides as they occur over extended periods of time, consider the constantly changing relationship of the Earth, the Moon, and the Sun. Remember that the Moon orbits about the rotating Earth, and both the Earth and the Moon orbit about the Sun. In addition, remember that they do so not in perfect circles, but in ellipses, so that distances one from the other are constantly—and predictably—changing.

Remember that the Earth's axis is tilted with respect to its orbit about the Sun, and the Moon's orbit is also at an angle to the Earth's orbit. Therefore, the angular relationships between the Earth and the Moon, and the Earth and the Sun, are constantly—and predictably—changing. Now let's look at the effects of all these dynamic relationships.

The Moon and the Sun interact. Anyone who has observed tides or studied a tide table has noted that the difference between a high tide and a low tide may be greater at one time of the month than at another. The *range of tide*, or difference between successive high and low waters, varies primarily as a result of the changing positions of the Sun and Moon with respect to the Earth.

Figure 4 reminds us that as the Moon rotates about the Earth approximately once a month, it is aligned with the Sun twice a month and it is at right angles (*quadrature*) at two other times during the month.

When the Moon is on a line connecting the Earth and the Sun, we have either a new Moon or a full Moon. At this time the attractive forces of the Sun and the Moon are aligned and reinforce each other, increasing the tidal bulge. When this occurs semimonthly, the range is increased, with the high tides being higher and low tides being lower than average. These are called *spring tides* (this name implies no reference to the season of the year).

When the Moon is at quadrature, we have either a first-quarter or a third-quarter Moon. At this time the attractive forces of the Sun and the Moon are at right angles and tend to counteract one another, resulting in a decreased tidal range: high tides are lower and low tides are higher than average. These are called *neap tides*.

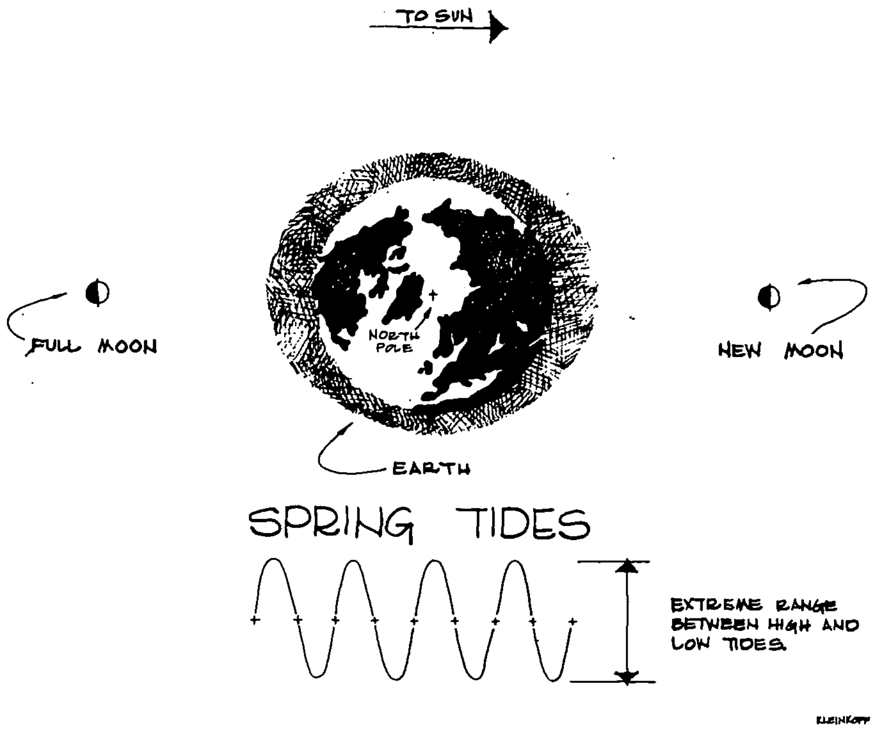

Figure 4a.—*During times of full and new Moon, the Earth, Sun, and Moon are in a line; and spring tides occur.*

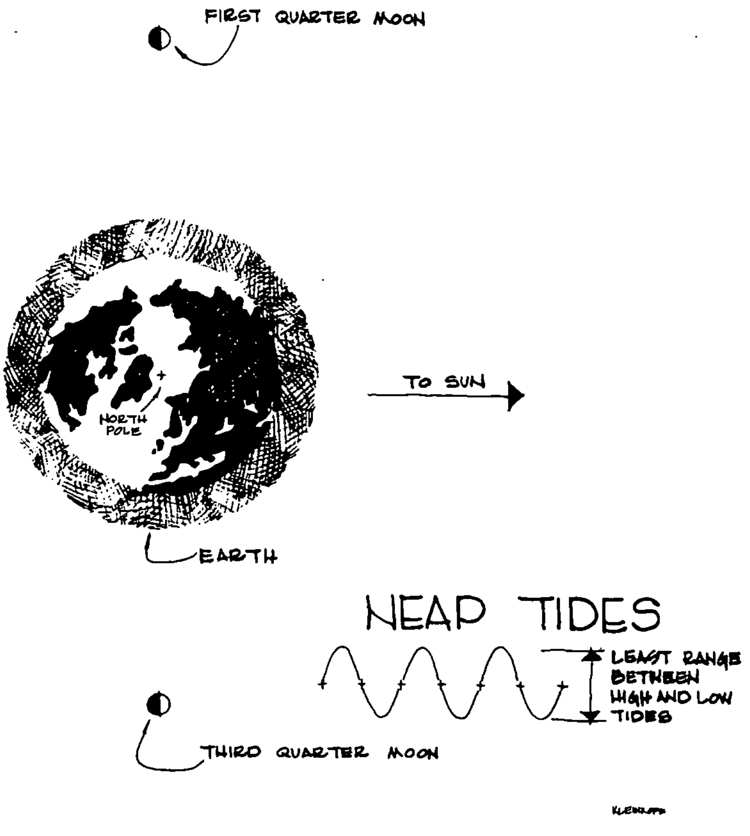

Figure 4b.—*When the Moon is at first and third quarter, the Moon and Sun form a right angle with the Earth; neap tides now occur.*

Effects of elliptical orbits. As the Moon moves through its elliptical orbit about the Earth approximately once each month, it passes through points nearest and farthest from the Earth. Figure 5 illustrates this phenomenon. The point nearest the Earth is called *perigee;* that farthest from the Earth, *apogee*. Tide range is increased when the Moon passes through perigee. The tide range is decreased at apogee.

As the Earth moves about the Sun, a similar situation occurs. The point when the Earth is nearest the Sun is *perihelion;* farthest from the Sun, *aphelion*. The effect of the Earth's passing through perihelion and aphelion is less pronounced than the counterparts of the Moon's motion but is of the same sort. And, of course, it occurs on a yearly basis instead of monthly.

The angular relationship. As noted previously, we observe a changing angular relationship between the Earth and the Moon, and the Earth and the Sun. The angular distance north or south of the equator is called *declination*. The changing declination of the Moon and the Sun also play an important role in modifying tides.

The Moon's declination completes a full cycle approximately every 27⅓ days. In completing this cycle, it can reach maximum values of nearly 28.6° north and south of the equator.

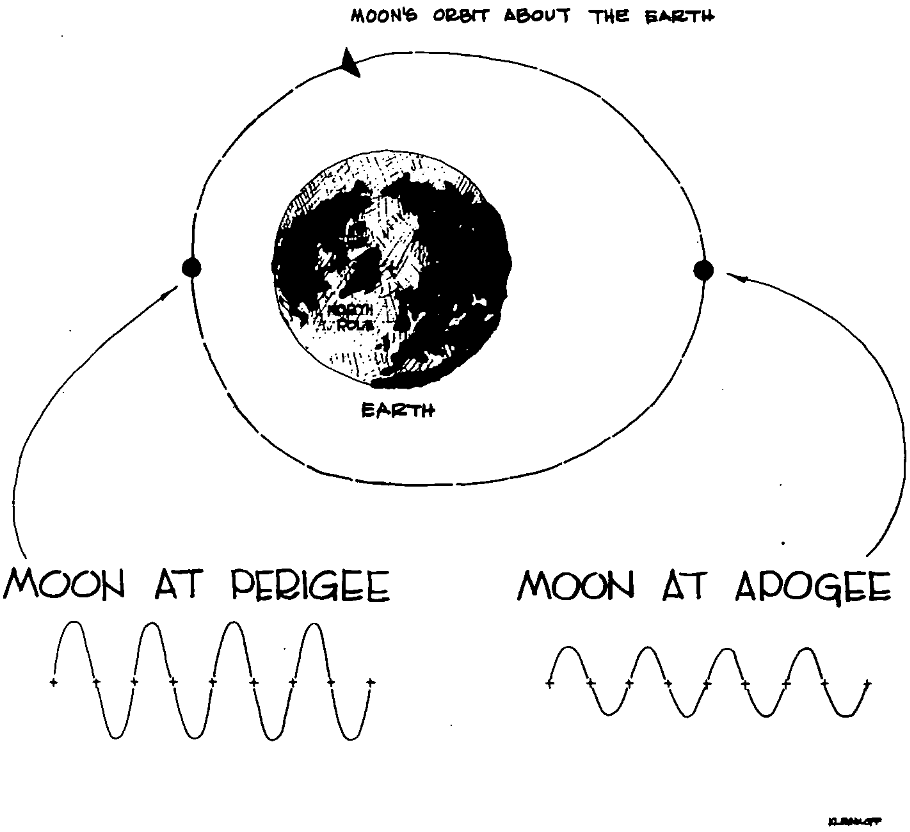

Figure 5.—*Elliptical path of the Moon orbiting the Earth. Tidal range is greater when the Moon is at perigee than when it is at apogee.*

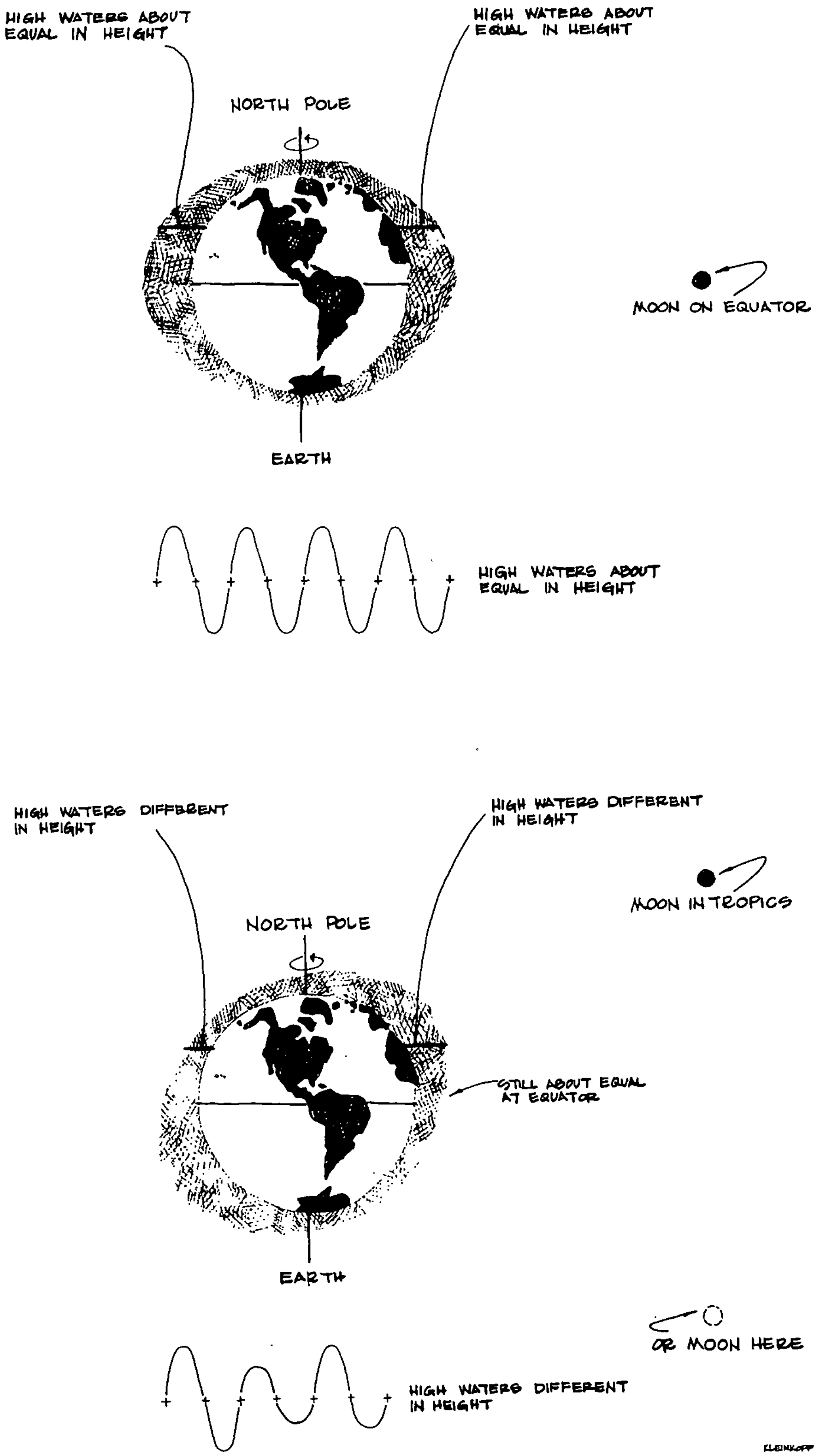

Figure 6.—*The difference in height of each day's two high waters or of its two low waters increases as the Moon moves (declines) toward the Earth's north or south pole. This difference, called diurnal inequality, is generally greatest when the Moon is at maximum declination.*

As the Moon approaches its maximum declination (once north and once south each cycle), its attractive force is unevenly distributed with respect to the equator, as shown in figure 6. The effect is to cause a difference in the heights of succeeding high waters and succeeding low waters in the same day. The difference between high waters and between low waters is known as *diurnal inequality* (diurnal means "daily").

Diurnal inequality is generally at a maximum when maximum declination occurs, producing what are called *tropic tides*. Diurnal inequality is at a minimum when the Moon is over the equator, causing *equatorial tides*. As one would expect, tropic and equatorial tides each occur twice every cycle of 27⅓ days.

Interaction. Of course, all of these astronomic movements go on simultaneously in cycles whose lengths vary one from the other. Thus, their combined effects may be to enhance or nullify one another. In a later section, we will note how all combine to affect clamming tides in Oregon.

The real tide varies from theory. In discussing equilibrium theory, we assumed the Earth was a smooth surface completely covered by a fluid in equilibrium with the tide generating forces. We ignored the effects of friction in the movement of fluid, inertia, depth of the ocean, presence of continents, and rotation of the Earth. Of course, all of these factors must be considered when we study the tides as they really are. If equilibrium assumptions were valid, tidal response would be simultaneous with the tide-producing forces.

Because this is not the case, the time of high tide varies considerably throughout the world's oceans in relation to when the Moon passes over the local meridian. (A meridian is a great circle of the Earth passing through the poles and any given point on the Earth's surface.) The height of tide also cannot be explained entirely by the simplified theory. Consequently, equilibrium theory does not fully account for the observed tidal phenomena. Instead it only gives us insight into the basic causes and fluctuations.

Predicting tides. When we deal with nature, one of our prime objectives is to predict future events. Tides are no exception. In predicting the behavior of the ocean, we generally can predict tides better than any other natural phenomenon, at least in coastal areas where knowledge of the tides is most essential.

Our ability to predict tides is good not because we understand the theory of tides better than that of other oceanic events, but because the tide is determined by the Sun and Moon, movements of which are well-ordered in time and space.

The *marigram,* or graphic record of the rise and fall of the tide, at a given location, is a continuous function that is periodic, readily lending itself to a curve-fitting procedure and thus a forecast of tidal heights.

Types of tide

A marigram is distinctive for a specific location, but there are general characteristics of the tides throughout the world that permit us to establish a classification system. Figure 7 shows examples of marigrams for *diurnal, semidiurnal,* and *mixed* types.

Diurnal. A tide is diurnal if, during the period of a lunar day (of 24 hours and 50 minutes), there occurs only one high water and one low water. Diurnal tides are primarily caused by the changing declination of the Moon and are most pronounced at the times of maximum declination (figure 6). These tides are found in the northern Gulf of Mexico and in southeast Asia.

Semidiurnal. The semidiurnal tide is that which is most commonly found throughout the world. It is characterized by two high waters and two low waters in the lunar day. The elevations of succeeding high waters and succeeding low waters are nearly the same. A semidiurnal tide is found on the East Coast of the United States, for example.

Mixed. Just as with a semidiurnal tide, the mixed tide is marked by two high waters and two low waters in a lunar day. Succeeding high waters, low waters, or both are generally different in height, however. These differences are known as diurnal inequality. Remember the inequality is caused by the changing declination of the Moon. Mixed tides are common to the West Coast of the continental United States, Alaska, and Hawaii.

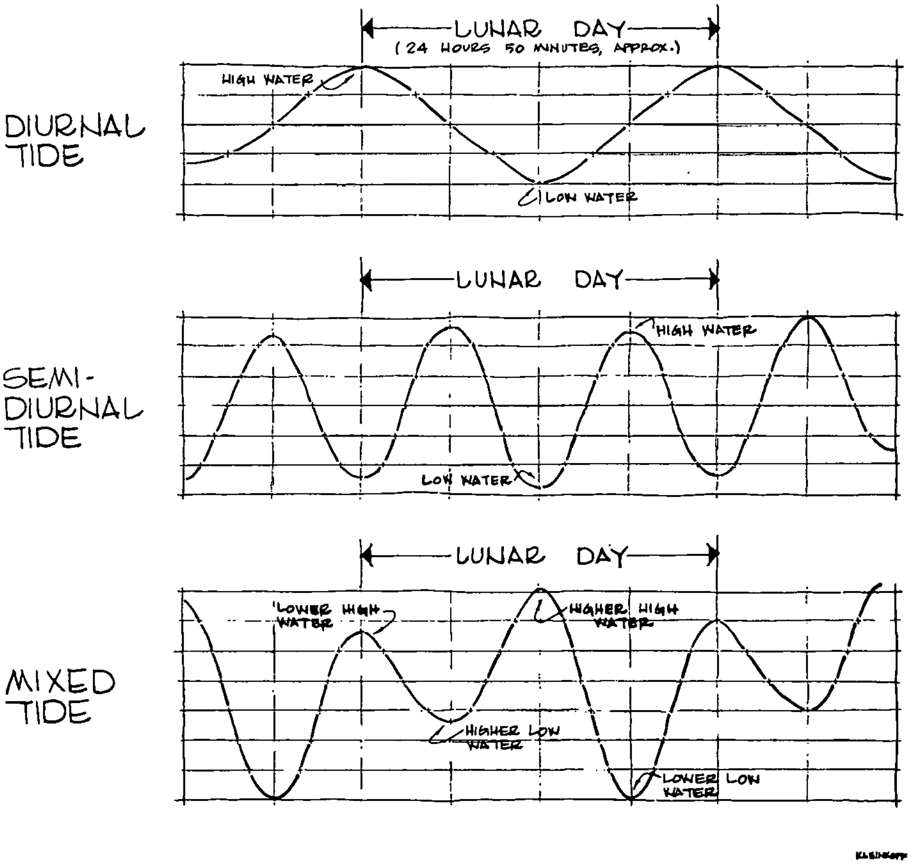

Figure 7.—*Examples of marigram types.*

Phenomena associated with tides

Marigrams may show changes in water level that are not due solely to tidal movement caused by heavenly bodies. Among these tidal phenomena are *meteorological effects.* Also, in any discussion of tides the related horizontal movement of water, or tidal currents, should be mentioned.

The meteorological effects. Water responds to external forces applied to it. Two forces always at work in varying degrees on the water surface are wind and direct barometric pressure. They combine to effect a change in the elevation of the water surface known as wind setup or *storm surge.*

In coastal areas where the water is shallow, wind interacts with water at the surface and as a result moves the water from one area to another. It is not easy to say exactly how a water body will respond because the effects are determined by wind speed, duration, and distance over which the wind blows (*fetch*), as well as by such other complicating factors as topography and stage of the tide.

It is generally true in coastal areas, however, that the water surface will respond directly to the wind. Thus, a wind blowing toward shore will tend to raise the water level on the coast and wind blowing away from shore, to decrease it.

As barometric pressure increases, the elevation of the surface of the water tends to be depressed and, conversely, as the pressure decreases, the elevation tends to be increased. As with wind, the amount of displacement is difficult to predict and depends on the intensity of the barometric disturbance and the speed with which it moves, in addition to the characteristics of the body of water.

The meteorological effects are particularly noticeable with the passage of large storms such as hurricanes. Strong winds and low pressure can raise the water level along a coast considerably. If this resultant storm surge is superimposed on an unusually high tide, occurring normally at that time, extreme flooding is often the result.

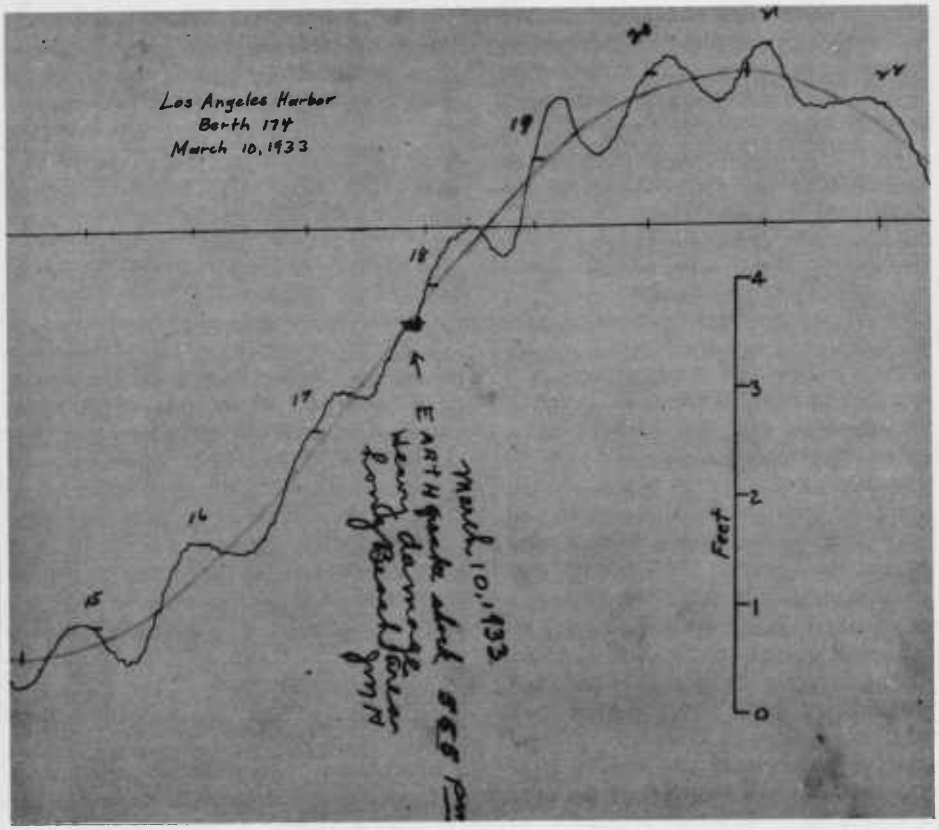

Figure 8.—*Part of the tide curve for March 10, 1933, at San Pedro, Cal. Note the small (approximately 15-centimeter) seiche having a period of about 1 hour. The Long Beach earthquake failed to materially disturb the seiche, although it shook the gauge. Courtesy C. K. Green, U.S. Coast and Geodetic Survey. Reprinted, by permission, from K. O. Emery,* The Sea Off Southern California *(New York: John Wiley and Sons, 1960).*

To some extent, the meteorological effects are predictable with change of seasons and can be estimated for predicting water level. Random disturbances raise havoc in predicting water level, however. If the astronomic tide is small, then random meteorological disturbances often represent a significant portion of the total change in water level—making accurate predictions extremely difficult.

Tide predictions generally do not include provisions for the contributions to the change in water level for other than the astronomic tide. In some cases, however, the seasonal fluctuations are included. Thus, when actual water level does not agree with predicted tide elevations, it is not the result of poor tide predictions, but rather the influence of random meteorological effects.

Seiches. A *seiche* (pronounced SAYsh) is a stationary wave oscillation the period of which depends on the dimensions of the local semienclosed body of water. You create a simple miniature seiche when you tilt a rectangular dishpan of water. The maximum change in water elevation occurs at the ends of the pan while no change in water level occurs in the middle. Figure 8 shows the oscillations of a seiche with a period of about an hour imposed on the tidal fluctuation at San Pedro, California.

A seiche is generated by an external force, often one of the same forces that generate a storm surge. After the force has been removed, the body of water responds by oscillating at its natural frequency.

As the period of the seiche approaches that of the tide, it is possible that the range of the tide can be considerably affected. Some of the great tidal ranges in the world can be attributed to this interaction of the tide of the open ocean and the seiche of a semienclosed body of water. For example, the mean range of tide at Burntcoat Head, which is in the Minas basin of the Bay of Fundy, is 11.69 meters.

Tidal currents. Oceanographers usually define *current* as a horizontal flow of water. A *tidal current* is a horizontal flow of water generated by the tide-producing forces .

Tidal currents, like the tides themselves, are periodic, and they can be analyzed and predicted. Tides, as one-dimensional phenomena, are easy to monitor. Tidal currents, on the other hand, are more complicated because they are two-dimensional (speed and direction). There are some cases, however, in which the movement of the waters is confined to one dimension, so the direction of flow reverses as the water flows alternately toward (*flood current*) and away from (*ebb current*) the land.

Oregon tides

Taking a look at tides along the Oregon coast offers an opportunity to apply our understanding of tidal phenomena.

What kind of tides does Oregon have? A look at the sample marigram for Newport, Oregon, in figure 9 reveals that there are two low waters and two high waters each day. In addition, there is an inequality both in the low waters and in the high waters. From this, we conclude that tides along Oregon are *mixed tides.*

The average difference in the elevation of the two low waters each day is 0.67 meter. The average difference in the elevation of the two high waters each day is only 0.43 meter. Thus, the low water inequality is about 1.5 times larger than the high water inequality for the Oregon coast.

What is the range of tides in Oregon? The range of tide varies along the coast, but it is generally less in the south. Table 1 shows tide ranges from 1.80 meters at Brighton and Yaquina Bay to 1.52 meters at Taft.

When do tides occur in Oregon? As a standard, the time of high water and low water for a given location is described in relation to the Moon's passage over the Greenwich (England) meridian. The time between the Moon's transit over the Greenwich meridian and the succeeding high or low water at a certain location is known as the *high water interval* or *low water interval.* Along the Oregon coast, these intervals generally increase from south to north, with the time of both high water and low water occurring about an hour sooner in the south than in the north.

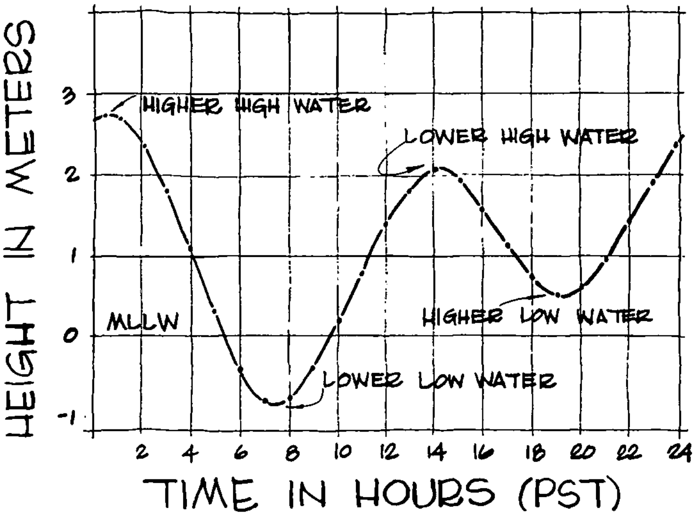

Figure 9.—*Marigram obtained at the pier of the Oregon State University Marine Science Center, Newport, May 13, 1964. Note the "clamming" tide in the morning.*

When do Oregon's highest and lowest tides occur? Each year, the largest diurnal inequality (see page 6 for review) occurs in June and July, and in December and January. These times are associated with solstices in June and December. (A solstice is either of the two times a year when the Sun is at its greatest distance from the equator: about June 21, when the Sun reaches its northernmost point on the celestial sphere, or about December 22, when it reaches its southernmost point.) Mean sea level, which varies annually because of the meteorological effects and runoff from winter rains and lower water temperatures, reaches its highest level in December on the Oregon coast.

As a consequence of the greater diurnal inequality and high sea level, the highest predicted tide usually occurs during December or January. Often winter storms further raise the water level above the normal winter high tides, resulting in local flooding.

Table 1.—*Mean range of tide at selected locations along the Oregon coast*

Location	Mean range (meters)
Columbia River entrance (N. jetty)	1.70
Brighton	1.80
Barview	1.74
Taft	1.52
Yaquina Bay entrance	1.80
Waldport	1.77
Umpqua River jetty	1.55
Coos Bay entrance	1.58
Bandon	1.58
Port Orford	1.61
Brookings	1.55

The lowest tides of the year generally occur in summer as a result of the increased inequality in the low waters combined with the lowered sea level.

Why are good clam tides in the evening in December and in the morning in June? This is a result of the concurrence of extreme astronomical phenomena:

In December
- —when there is a full Moon, resulting in spring tides,
- —the Moon is near north declination, increasing diurnal inequality.

In June
- —when there is a new Moon, resulting in spring tides,
- —the Moon is near north declination, increasing diurnal inequality.

The *times* of the lows are related to the passage of the Moon over the Oregon coast. Full Moon crosses overhead at midnight, while new Moon crosses overhead at noon. The difference in time between transit of the Moon over the Oregon coastal area and the following lower low water is about 18 hours (Low water interval, LWI, for Oregon referred to Greenwich meridian is about two hours. The Moon passed over Oregon's local meridian some 16 hours earlier, however; 16 hours plus 2 hours makes the difference, 18 hours.) Thus, the good clamming tides follow the transit of the full Moon in December by 18 hours, and occur at about 6 p.m., and in June by about 18 hours after the transit of the new Moon, or near 6 a.m.

How do tides vary in the estuaries? The time and range of tide in the estuaries vary considerably from the time and range of tide along the coast. Each estuary has its own individual characteristics. In the case of the Columbia River, the periodic tide can be detected up to Bonneville Dam. The tide progresses up the river so that the mean range decreases to only 0.3 meter at Ellsworth, Washington, 182 kilometers from the river's mouth. At Ellsworth, high water occurs about six hours after that at Astoria; low water, nearly eight hours after that at Astoria.

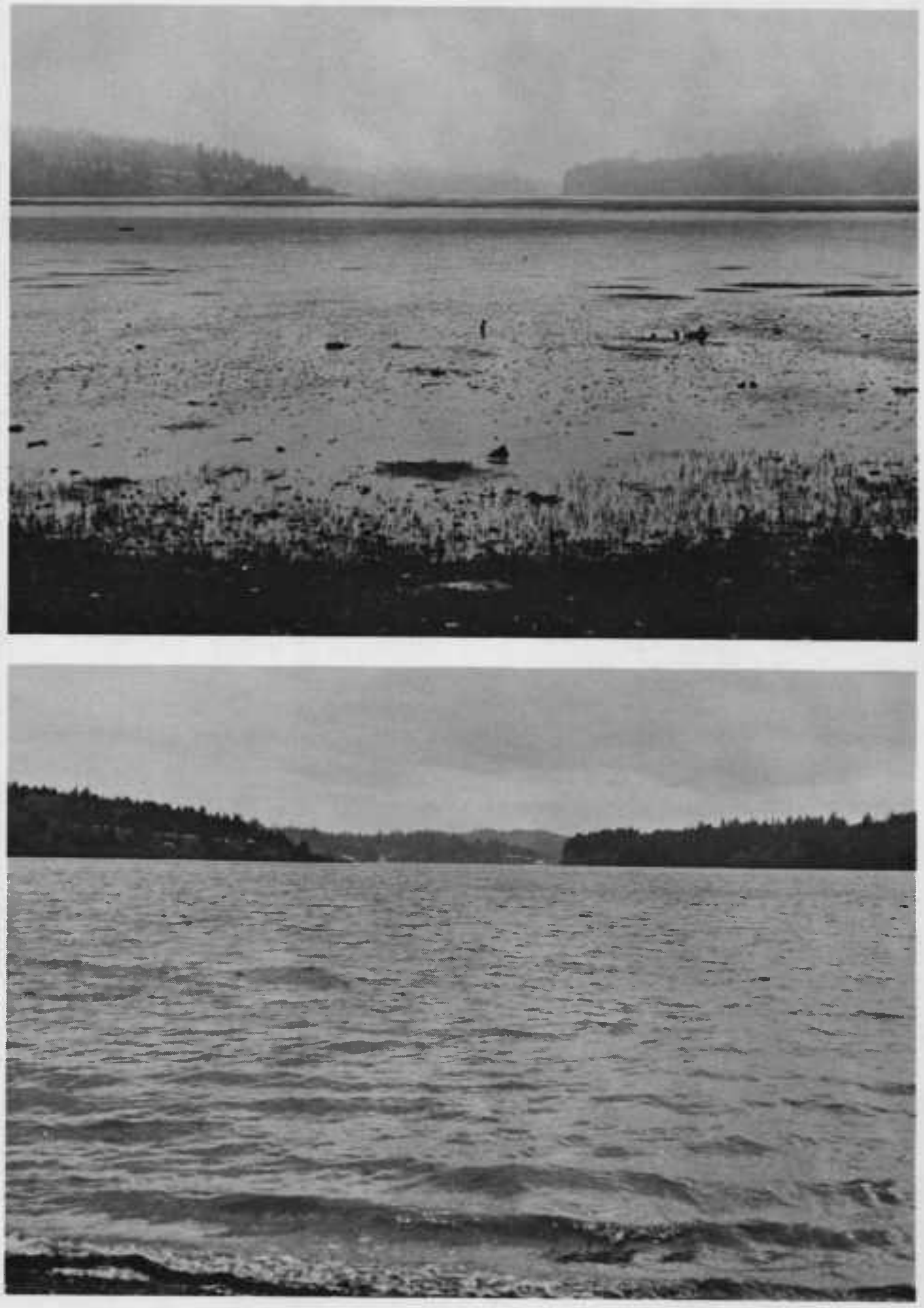

Figure 10.—*Below the high tide line, the land continues to slope downward. As tides rise and fall daily, the waters alternately advance and retreat across this sloping zone. Tidal effects reach well upstream on coastal rivers and streams. In many of the Pacific Northwest's coastal rivers, extreme low tides give recreationists access to beds of bay clams; therefore, these have come to be known as "clam tides." The advance and retreat of high and low tides in these views of Oregon's Yaquina River were photographed from the same place, seven hours apart on the same day.*

Want more information?

To obtain more information on tides, write to: Director, National Ocean Survey, 6001 Executive Blvd., Rockville, MD 20852.

Predictions of the times and heights of high and low water are prepared by the National Ocean Survey (National Oceanic and Atmospheric Administration) for a large number of stations in the United States and its possessions as well as in foreign countries and United Nations Trust Territories. These predictions are published each year (approximately six months or more in advance) in four volumes. The titles are: *Tide Tables—High and Low Water Predictions:* (1) East Coast of North and South America, Including Greenland; (2) Europe and West Coast of Africa, Including the Mediterranean Sea; (3) West Coast of North and South America, Including the Hawaiian Islands; and (4) Central and Western Pacific Ocean, and the Indian Ocean. They are available from local Nautical Chart Agencies at a nominal price.

Additional resources

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Glossary

Aphelion—The point in the Earth's orbit farthest from the Sun.

Apogee—The point in the Moon's orbit farthest from the Earth.

Current—A horizontal movement of the water. Currents may be classified as tidal and nontidal. *Tidal currents* are caused by the tide-producing forces of the Moon and the Sun and are a part of the same general movement of the sea that is manifested in the vertical rise and fall of the tides. *Nontidal currents* include the permanent currents in the general circulatory systems of the sea as well as temporary currents arising from meteorological conditions.

Declination—The angular distance of a celestial body north or south of the celestial equator.

Diurnal inequality—The difference in height of the two high waters or of the two low waters each day.

Diurnal tide—A tide having only one high water and one low water during a lunar day of 24 hours and 50 minutes.

Equatorial tides—Tides occurring semimonthly as the result of the Moon being over the equator. At these times the tendency of the Moon to produce a diurnal inequality in the tide is at a minimum.

Equilibrium theory—A hypothesis under which it is assumed that the waters covering the face of the Earth instantly respond to the tide-producing forces of the Moon and the Sun and form a surface of equilibrium under the action of these forces. The theory disregards friction and inertia and the irregular distribution of the land masses of the Earth. The theoretical tide formed under these conditions is known as the *equilibrium tide.*

High water interval (HWI)—The time interval between the Moon's transit (upper or lower) over the local or Greenwich meridian and the following high water at a specific location.

Low water interval (LWI)—The time interval between the Moon's transit (upper or lower) over the local or Greenwich meridian and the following low water at a specific location.

Marigram—A graphic record of the rise and fall of the tide. The record is in the form of a curve in which time is represented by abscissas and the height of the tide by ordinates.

Mean high water (MHW)—The average height of the high waters over a 19-year period.

Mean higher high water (MHHW)—The average height of the higher high waters over a 19-year period.

Mean low water (MLW)—The average height of the low waters over a 19-year period.

Mean lower low water (MLLW)—The average height of the lower low waters over a 19-year period.

Mean sea level (MSL)—The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings.

Mixed tide—Type of tide in which the presence of a diurnal wave is conspicuous by a large inequality in either the high or low water heights, with two high waters and two low waters usually occurring each lunar day.

Meteorological effects—Fluctuations in water level having their origin in the daily or seasonal variations in weather conditions, which may occur with some degree of periodicity.

Neap tides—Tides of decreased range occurring semimonthly as the result of the Moon being in quadrature.

Perigee—The point in the orbit of the Moon which is nearest the Earth.

Perihelion—The point in the orbit of the Earth nearest the Sun.

Quadrature of Moon—Position of the Moon when its longitude differs by 90° from the longitude of the Sun. The corresponding phases are known as first quarter and last quarter.

Range of tide—The difference in height between consecutive high and low waters. The *mean range* is the difference in height between mean high water and mean low water. The *great diurnal range* or *diurnal range* is the difference in height between mean higher high water and mean lower low water. Where the type of tide is diurnal, the *mean range* is the same as the *diurnal range.*

Seiche—A stationary wave oscillation with a period varying from a few minutes to an hour or more, but somewhat less than the tidal periods. They are usually attributed to strong winds or changes in barometric pressure and are found both in enclosed bodies of water and superimposed upon the tide waves of the open ocean.

Semidiurnal tide—A tide having two high waters and two low waters in a lunar day. The elevations of succeeding high waters and succeeding low waters are nearly equal.

Spring tides—Tides of increased range occurring semimonthly as the result of the Moon being new or full.

Storm surge—See *meteorological effects.*

Tidal current—See *current.*

Tidal datum—A base elevation defined by a certain phase of the tide, used as a reference from which to reckon heights or depths.

Tidal epoch—The 19-year period over which the various phases of the tide are averaged in order to determine a tidal datum.

Tropic tides—Tides occurring semimonthly when the effect of the Moon's maximum declination is greatest. At these times there is a tendency for an increase in the diurnal range.

Appendix.—*Metric/English conversion factors (approximate) for the units cited in this bulletin*

To convert	to	multiply by
meters	feet	3.28
feet	meters	0.30
centimeters	inches	0.39
inches	centimeters	2.54

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