

## Understanding The Tides By Geoff Wilson

The regular rising and falling of the Earth's oceans we call the tides is caused by three main factors:

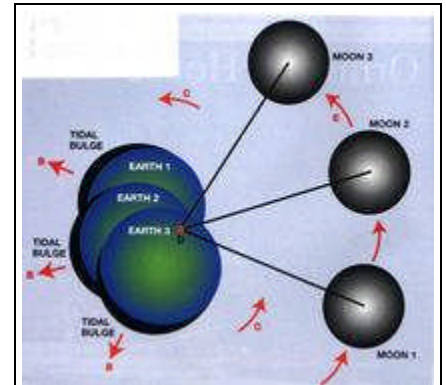
- The gravitational pull of the moon.
- The centrifugal force acting on the oceans as the Earth and moon revolve together around a common centre of gravity.
- To a lesser extent, by the gravitational pull of the sun which has much less effect than the moon because it is so far away.

As the moon revolves around the Earth, or to be more accurate, as the Earth and moon revolve together around a common centre of mass or gravity which actually lies within the Earth (because the earth has far the greater mass) the moon's gravity draws the ocean nearest it away from the Earth so that it bulges very slightly toward the moon.

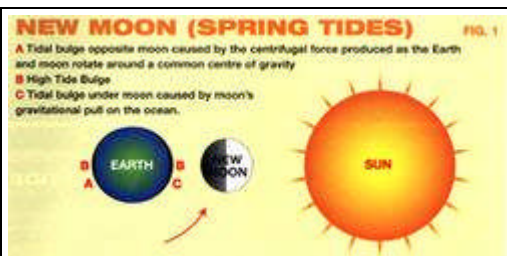
At the same time, the centrifugal force generated as the Earth and moon revolve around their common centre of gravity, causes a bulge in the ocean on the opposite side of the earth to the moon.

So, as the Earth rotates on its axis, one tidal bulge is drawn toward the moon and another remains on the opposite side of the Earth. This has the effect of bringing two high tides, and - because of the corresponding, right angle, depressions - two low tides to most places on Earth's oceans every 24 hours.

At different times of the lunar month there are three relative positions governing the ocean's tides. These are:



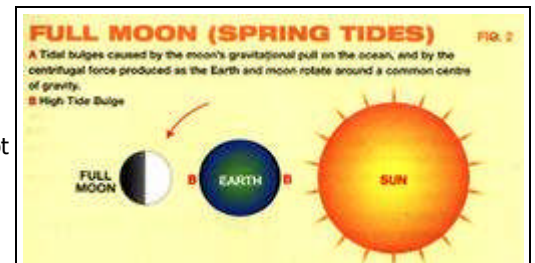
E and C: Earth and Moon revolve around a common centre of gravity, which is within the Earth, D, causing the tidal bulge opposite the Moon, B.



**New Moon**  
 A : Tidal bulge on the opposite side of the Earth to the Moon.  
 B : Tidal bulge caused by the Moon and Sun pulling in conjunction.  
 C : Tidal bulge on the same side of Earth as the Moon.

### Sun and Moon Pulling in Conjunction

This is the period of the new moon. When this occurs, the moon is underfoot in the middle of the night and overhead in the middle of the day; the new moon is rarely visible.



**Full Moon**  
 Sun and Moon pulling in opposition during the Full Moon produce the same or very similar tidal sequences as the New Moon.

### Sun and Moon pulling in Opposition

This is the period of the full moon. When it occurs the moon is highest in the middle of the night and underfoot during the day. The full moon is highly visible at night as an illuminated disc. It may be visible at dawn and dusk as well.



First and Last Quarters of the Moon are produced when the Sun and Moon are pulling in Quadrature:  
 A : Moon's First Quarter  
 B : Low Tidal Bulge  
 C : Moon's Last Quarter

### Sun and Moon pulling in Quadrature

The extremes of quadrature are known as the first and last quarters of the moon: The first quarter of the moon rises in the middle of the day and sets in the middle of the night. The last quarter of the moon rises in the middle of the night and sets in the middle of the day. The moon's quarters each appear as half of an illuminated disc.

### Spring Tides

The term spring here means welling up. Spring tides, or those tides with the greatest rise and fall, are caused by either the sun and moon pulling in conjunction, as is the case with the new moon, or by the sun and moon pulling in opposition, as is the case with the full moon. The tidal effects are greatest beneath the orbital path of the moon and on the other side of the Earth directly opposite the moon's orbital path.

Although spring tides occur twice every month, either during - or within two or three days of - both the new and full moon, one spring tide is always greater than the other. Sometimes this is the spring tide caused by the full moon, at other times it is the spring tide caused by the new moon. This happens because the orbit of the moon around the Earth, like that of the Earth around the sun is elliptical, not circular.

As the moon orbits the Earth, the ellipticity of its orbit sees it alternate between perigee (closest point to the Earth - about 362,000 km - where it will affect the tides more), and apogee (furthest point from the Earth - about 412,400 km - where it will have less effect on the tides).

The moon takes 27.55 days to go from perigee to perigee, and 29.52 days to go through the lunar cycle from one new moon to the next. For this reason, both the full moon and the new moon will alternate from perigee to apogee, and vice versa, during the course of a year.

The ellipticity of the Earth's orbit around the sun also produces a periodicity in the tides which is less obvious: The Earth's furthest distance to the sun in its elliptical orbit is some 149 million km. This occurs around July 2 and is known as aphelion. At this point the sun's contribution to the tidal effect is least.

The Earth's closest distance to the sun in its elliptical orbit is some 154 million km. This occurs around January 2 and is known as perihelion. At this point, the sun's contribution to the tidal effect is greatest.

So theoretically at least, a new or full moon at this time, coupled with the moon closest position to the Earth (perigee) should produce the largest tidal range for the year in those locations directly beneath the orbital path of the moon, but not necessarily elsewhere.

## Neap Tides

The word "neap" comes from an ancient Greek word for scanty or scarce. Neap tides are caused by the sun and moon pulling in quadrature during the first and last quarters of the moon. This produces the lowest of the high tides and the highest of the low tides.

At such times, narrow lagoon entrances and the channels between headlands and islands will flow more gently than they do at other times because the rise and fall of the oceans is greatly reduced during neap tides.

## Why the tides become later each day

The moon revolves around the Earth in the same direction as the Earth revolves around its own axis. However, while the Earth completes a full rotation of 360 degrees once every 24 hours, the moon - in respect to its elliptical orbit - advances, on average, some 12.2 degrees each day. Therefore, the Earth would have to rotate some 372.2 degrees to keep up with the moon on a day to day basis.

Because 15 degrees of rotation on the Earth takes one hour, the 12.2 degrees required to catch up with the moon each day represents some 50 minutes: A mean tidal day on Earth is therefore 24 hours and 50 minutes.

## West Coast Tides

Our planet Earth rotates on its axis every 24 hours so that both sun and moon appear first on the eastern horizon and traverse our skies to the west. Likewise, the tidal bulge caused by the moon, and modified by the gravitational pull of the sun, also travels from east to west like a wave: A tidal wave if you like, but not to be confused with tsunamis which are sometimes erroneously referred to as tidal waves by uninformed sources.

For this reason, tides on the east coast of our continent behave more or less as expected, rising and falling twice every 24 hours and progressing, on average, some fifty minutes a day.

In contrast to this, tides on the west coast of our continent, and indeed tides which occur on the west side of significant promontories and land masses, behave differently. After all, coastlines with a westerly aspect are in the wake of the tidal wave, and as such are subject to complex aberrations and turbulence not encountered by coastlines facing east.

## Dodge Tides

West coast tidal sequences include the phenomena known as "dodge tides". Dodge tide is the name given to a diminished tidal sequence, usually producing only one low tide and one high tide in a 24 hour period. Dodge tides occur over periods of three or more days, often, but not always, following the first and last quarters of the moon.

Also, west coast tides may not advance at anything like 50 minutes a day. While they may advance more or less normally through part of the tide cycle, this advance may decline to only a few minutes each day until one tide drops out altogether in a typical dodge tide sequence. Then, with the passing of the dodge tide, a fairly normal advance begins once more. There are many tidal variants among west coast tidal systems, far too many to discuss here.

## The effect of Earth's tilted axis on the Tides

The Earth is tilted so that its equatorial plane makes an angle of about 23.5 degrees with the plane of its orbit. Furthermore, the plane of the moon's orbit makes an angle of 5 degrees to the plane of the Earth's orbit.

The intersection of the moon's orbital plane, and the Earth's orbital plane rotate. Because of this, the moon's maximum declination to the Earth's orbital plane reaches 28.5 degrees - 23.5 degree plus 5 degrees. At the other extreme, it is 18.5 degrees - 23.5 degrees minus 5 degrees. It takes a little over eighteen years and seven months to complete this cycle.

Because Earth's northern and southern hemispheres are not only alternately tilted toward and away from the sun, but are tilted in respect of the plane of the moon's orbit as well, a seasonal periodicity is caused in the tides.

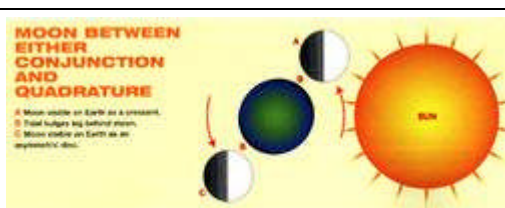
For example, an observer on the south coast of Australia might notice that of the two tides occurring each day, one is greater in range than the other. In autumn, the spring tide with the greater range will occur in the morning. In spring, the spring tide with the greater range will occur in the evening.

## Diurnal Inequality

The variation between the morning and evening tidal range is called diurnal inequality and is caused when the two opposing tidal bulges occur on different sides of the equator due to the Earth being tilted on its axis in respect to its own, and to the moon's orbital plane.

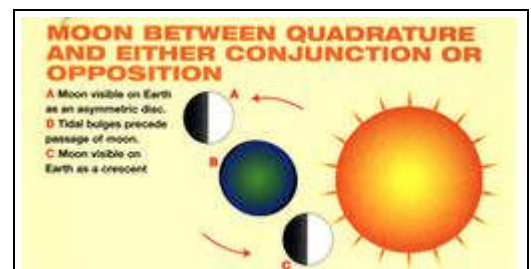
## Intervals between tides

The intervals between successive high tides on east coast locations averages out at 12 hours and 25 minutes, the high tide becoming later, on average, some by 50 minutes each day. In practice though, the interval between daily high tides varies between just over half an hour, through the first and last quarters of the moon, to over an hour through the full and new moon. Let's look at how this variation comes about.



Moon Waxing to First Quarter and Moon Waning to Last Quarter:

- A : Waxing moon is visible on Earth as a crescent.
- B : Tidal bulges lag behind Moon.
- C : Waning Moon is visible on Earth as an asymmetric disc



Moon Waning to New and Moon Waxing to Full:

- A : Waning Moon is visible on Earth as an asymmetric disc.
- B : Tidal bulges precede passage of moon.
- C : Waxing Moon is visible on Earth as a crescent.

As the moon passes through either the new or full moon position, pulling either in conjunction with, or in opposition to the sun, the tidal bulge on either side of the Earth is greatest and aligned with moon and sun.

However, as the moon leaves the position of either opposition (full moon) or conjunction (new moon), the tidal bulge on the Earth's oceans diminishes slightly. Not only does it diminish, but it begins to lag behind the moon causing the intervals between tides to shorten.

However, as the moon passes through either the first or last quarters, a curious thing happens: The lagging bulge diminishes progressively until a bulge begins to form ahead of the moon's passage, leading the moon into the next position of either opposition or conjunction and spreading out the intervals between daily high tides to an hour or more.

### **Tidal variations**

Working out the tides would be simple if the oceans covered the whole of the planet except for some conveniently marked piles protruding from the water at different latitudes from which the heights of the tides could be read. But approximately one third of the Earth's surface is land which interrupts the passage of the tides.

The land interrupts the tides in such a way that currents form where the passage of the water is restricted to flowing through channels and around capes projecting into the ocean.

Some of these restrictions, like the narrow entrances to estuaries and tidal lagoons, cause delays and reduce the amount of water being exchanged. This in turn reduces the rise and fall of the tides within those bodies of water.

On the other hand, there are features which exaggerate the tidal range as well: The most notable of these are known as tidal bores. Possibly the best known example of a tidal bore is the Bay of Fundy in New Brunswick, Canada where the rise and fall at the wide and deep entrance is within normal limits, ranging less than three metres at the springs.

As the incoming tide progresses up the narrowing, and increasingly shallow bay, the head of water increases so much that by the time it reaches the city of St John, about two thirds the way up the bay, the tidal range may be as much as 7.5 metres at the springs, and close to double that at the head of the bay.

The funnelling effect produced by water moving up a progressively narrowing bay is a fairly obvious one. Less obvious is the phenomenon of oscillating frequency.

### **Oscillating Frequency**

Every object has a resonant or oscillating frequency at which it will vibrate given the appropriate stimulation. This can be demonstrated fairly dramatically by using a drinking glass and sound amplifier.

Once the frequency of the glass has been discovered by varying the pitch of sound higher or lower, the glass may be shattered by increasing the volume of sound to the point where the integrity of the glass is no longer sustained.

Fluids in basins, bays and other enclosures also have oscillating frequencies. This may be demonstrated on a small scale by half filling your bath with water and swishing your hand back and forth until an oscillating wave forms. Left alone, this oscillating wave will move back and forth in the bath without any assistance until it subsides.

However, by moving your hand back and forth in the water at the same rate as the wave, the oscillations will increase in size until water begins to slop over both ends of the bath.

Now just imagine that your bath is a bay open to the ocean and the speed of the incoming and outgoing tides coincide with the oscillating frequency of that body of water. Then you have the formula for grossly exaggerating the tidal range as would be the case in the Bay of Fundy.

### **A convenient comparison**

I live in central Victoria within walking distance of Corio Bay, the Geelong Arm of Port Phillip Bay. Port Phillip Bay is a shallow basin said to cover some 2000 square kilometres, but the entrance to the Ocean is less than 3 kilometres across, a factor which restricts the tidal range and delays the tide heights within the bay for an average of about three hours.

Adjacent to Port Phillip Bay, and separated by fairly narrow isthmus of land known as the Mornington peninsula, is Western Port Bay, which is less than half the size of Port Phillip.

These two bodies of water are so close together one could expect the rise and fall of the tides to be much the same. Interestingly, the tidal range inside Port Phillip is much less than in the ocean outside, and the tidal range in Western Port is much more.

Taking Thursday November 27, 2003 as an example, we found the tides outside Port Phillip Heads, and Western Port, as follows. 3.25 am high at 1.73 metres and 8.45 am low at 0.57 metres; a fall of 1.16 metres. A 3.05 pm high of 1.39 metres gave a 0.82 metre rise and at 8.45 pm low of -0.06 metres gave a fall of 1.45 metres.

At Geelong wharves, on Corio Bay, well inside Port Phillip and near the limit of tidal influence, high tide did not occur until 6.25 am and only reached 1.04 metres. Low tide was at 12.35 pm and fell to 0.43 metres, a drop of 0.61 metres just over half the fall of the tide at Port Phillip Heads.

At 5.45 pm the tide had risen to 0.94 metres at Geelong wharves, a rise of only half a metre, and by 12.35 am (next day) the tide had dropped to 0.0 metres, the greatest fall for the day but still only 0.94 metres, compared with the 1.45 metre fall at Port Phillip Heads.

Inside Western Port it was a different story altogether, instead of decreasing in range as they do inside Port Phillip, the tides inside Western Port actually increase as the following example for the same day shows:

At Stony Point, which is situated in the North Arm of Western Port, the first high tide for Thursday November 27 occurred at 4.05 am and reached 3.31 metres, almost twice the height of the tide in the ocean outside. By 10.05 am it had fallen to 0.9 metres, a drop of 2.41 metres or almost a metre more than the drop in the ocean outside.

By 3.45 pm the tide had risen to 2.72 metres, about twice the height of the ocean outside, and by 10.05 pm it had fallen almost 2.7 metres to 0.07 metres by which time the tide in the ocean had been rising for almost an hour.

### Tidal Delay

A chart of tide predictions usually gives times of high and low water only. These times of high and low tide may also coincide with periods of slack water in areas where there is a tidal stream or current ... But then again they may not.

The fact is, the highest and lowest levels reached by the tide at any given point may not coincide with periods of slack water. Let's look at one example of this:

Taking another day at random from a selection of tide predictions and selecting Saturday May 22, 2004 and the Point Lonsdale pier at the entrance to Port Phillip Bay as our point of observation.



Our tide chart indicates low tide occurred at 7.25am. We checked our watches at the but the tidal stream was still running out at several knots and didn't look like slowing down. Could our tide chart have been wrong? (22/05/04)

Our tide chart indicates low tide occurred at 7.25 am. We checked our watches at the appointed time but the tidal stream was still running out at several knots and didn't look like slowing down. Could our tide chart have been wrong?

What we didn't know, and what our tide chart didn't tell us, is - that although the tide has reached its lowest level of 0.15 metres outside The Heads - the height of the tide inside Port Phillip was still over half a metre above zero.

Although the lowest point that the tide reached on this morning at Port Phillip Heads at the appointed time was 0.15 metres, it was not until 10.25 am some three hours later, that the tide stopped running out, as indeed it should have because the rising level of water outside Port Phillip Heads, had by then reach the same level as the water inside.

Continuing our observations on that day, we found the tide began to flow in through The Heads at around 11.00 am because the water in the ocean outside The Heads was by then higher than the water inside Port Phillip Bay and rising rapidly.

Now, although the next high was at 2.45 pm, less than four hours time, we had to wait until almost 6.00 pm until the current changed direction and began to flow back out through the entrance once more.

What we have said so far is that equilibrium on both sides of the entrance to Port Phillip Bay must be reached before we can have slack water in the channel. However, on this day, high tide did not reach the furthest extremity of Port Phillip until almost 6.00 pm.

Because the tide began running out through Port Phillip Heads at about this time, and because the narrow entrance limited the flow of water, the furthest points of tidal influence did not reach anything like as high as the 1.55 metres given in the tide chart for Port Phillip Heads. On this day, Geelong wharves officially had a high tide of only .95 metres at 5.55 pm.

While the main causes of our tides are well known and easily understood, it is important to realize that there are many factors affecting the tides. We have discussed some of the more general ones but there are many more:

Barometric pressure also effects the tides. Low barometric pressure may allow high tides to rise above their predicted levels and high barometric pressure may cause low tides to recede further than predicted.

At fairly local levels, strong winds can significantly effect the tides, so much so that during prolonged or severe weather, predicted tidal ranges may become irrelevant.

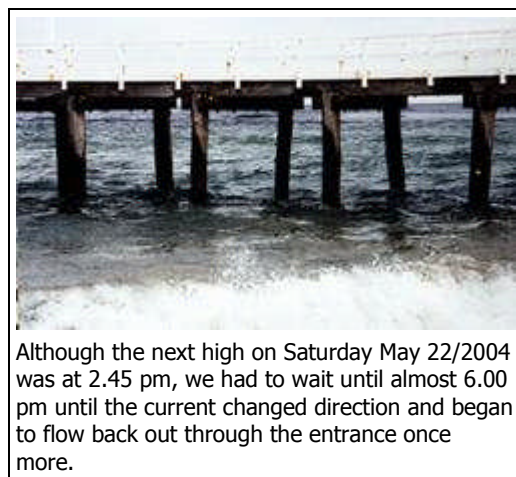
### Predicting the Tides

Because of the numerous uncertain and, even completely unknown factors affecting the tides in various localities, it is not sufficient to predict tides purely from a knowledge of the movements of the moon and sun.

Only by closely monitoring tides in any given area over the 18.7 year cycle of the combined Earth's and moon's orbital path around the sun can a reasonably accurate set of predictions be made for tidal behaviour.

### Acknowledgements and References

The Tides: Pulse of the Earth by Edward P. Clancy.  
Our Restless Tides by Steacy D. Hicks.



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