Fremantle high tides

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The following question has arisen: what is the highest likely sea level at Fremantle in the next 20 years, and the next 50 years?

Using conservative estimates for sea level rise the highest likely sea level at Fremantle over the next 20 years is about 2.2m above datum, and 2.3m over the next 50 years.

To put this in perspective, a typical high spring tide is about 1.3m above datum, and the highest ever recorded sea level at Fremantle in the last 120 years was 1.95m, in May 2003. To give a bit more perspective, at least once in the next 20 years we can expect the main concrete jetties to go 0.28m (shin-deep) under water, with the timber jetties 0.63m under water (thigh-deep). If we project to 50 years instead of 20 years, the depths increase even more. Have we taken any of these events into account as part of our jetty repair/replacement plan?

How have these figures been derived?…...

What is "sea level"?

For the purposes of this article, sea level is the height of the water measured at the Fremantle tide gauge at any given time. This might seem absurdly simple, but there are a few traps for the wary. Firstly, the tide gauge itself is moving a bit over the years because the bit of earth on which it is mounted is moving. Geologists can explain this in more detail, but the causes range from movement of the earth's tectonic plates to local compression of the sediment due to putting more and more buildings on the Perth plain and extracting drinking water from aquifers.. To put it another way, we can ask another question: is the sea level rising, or is the earth sinking? Fortunately for this article it doesn't really matter.

Secondly, the tide gauge itself might be different in design and installation over the years. The tide gauge record for Fremantle is one of the longest in the world (120 years) and the device itself has changed over that period. Fortunately the oceanographers have allowed for most of those effects in their data processing; I shall assume they have all been taken care of.

Factors affecting sea level

Tides

This is the obvious one. Most of us know that there is one high tide a day at Fremantle and two high tides a day in the northwest. These have a harmonic period of just over 12 hrs and 24 hrs respectively, due to the earth's rotation and the moon's gravity. Spring tides are a consequence of the alignment of the sun, moon and earth, with a harmonic period of just under 28 days. That is where the knowledge of most boaters ends. What is less well known, because it is usually less important, is that there are other harmonics, some with very long periods (Hendershott, 2004). Two of particular interest are

- the 8.8 year harmonic period due to the lunar perigee rotation (variation in the moon's orbital speed) and
- the 18.6 year harmonic period due to the perihelion rotation (a particular alignment of the bodies, sometimes called the saros cycle).

In practical terms this means that we can expect some especially high tides every 8.8 years and every 18.6 years, but only if their times coincide with spring tide times.

Atmospheric pressure

Slow pressure changes

The atmosphere presses down on the ocean so if atmospheric pressure drops, sea level rises and vice versa. Every 1 hPa variation from mean atmospheric pressure (1012 hPa) will create a 10 mm change in sea level. So a typical low pressure system of 992 hPa will result in sea levels rising by 0.2 m (200–mm) whereas a typical high pressure system of 1032 hPa will cause a drop in sea level of 0.2 m.

Rapid pressure changes (meteotsunamis)

Recent research (Pattiaratchi & Wijeratne, 2015) has shown that large changes in sea level can occur when a quite small but rapid change in atmospheric pressure travels across the ocean surface. Sea level changes caused by this phenomenon are called meteotsunamis. They can occur when, for example, a thunderstorm moves fairly quickly, or a cold front approaches. They can cause sea level changes of up to 0.5 m on the WA coast, so they are one of the main sources of sea level change, and can be generated by atmospheric pressure changes as small as 2 hPa. A meteotsunami will have a period of anything from tens of minutes to a few hours (compared with tidal periods of 12 and 24 hours). Meteotsunamis have been recorded in many parts of the world. In WA they have been recorded on the west and south coasts. About 30 meteotsunamis are experienced along the west coast of WA every year, though they are often unnoticed unless their peak coincides with high tide. They have a period of about 2.7 hours all along the coast, which is governed by the fairly consistent length and depth of the continental shelf down the coast.

Wind

When a strong wind is blowing towards the shore it will have a tendency to push water along, piling it up and increasing the sea level. This increased sea level can last from hours to days and is properly called storm surge. The effect is complicated firstly because the amount of pile-up depends on the geometry of the local coastline, and secondly because the piled-up water will tend to run back again. The combination of these two factors can lead to a sloshing effect called seiching, similar to the water in a bath rising and falling at each end but staying constant in the middle. An example is Cockburn Sound off Fremantle. In a NW winter storm the water will tend to pile up at the southern end of the sound, but will also tend to slosh back and forth, with a period of typically 2-3 hours. The sea level height variation due to storm surge is typically 0.2–0.3 m (Molloy, 2001).

Leeuwin current

The mean sea level at Fremantle is affected by the El Nino Southern Oscillation phenomenon (Bicknell, 2010) via the Leeuwin current. A positive Southern Oscillation Index results in a strong Leeuwin current, which causes a higher mean sea level.

Climate change

This is the controversial one. There should be no doubt in anyone's mind that the mean sea level is rising, and that at least some of this change is due to human activity. If you do not believe either of those statements then you might as well stop reading this article now. Fortunately to answer our question we don't have to delve much further into this extremely complicated topic. The records of the Freo tide gauge show that the mean sea level has been rising on average by 1.5mm per year over the last 120 years (Bureau of Meteorology, 2019). If that were the end of the story then we would not need to investigate any further for the purposes of 20-50 year prediction of sea level height. The problem is, the rate of increase 120 years ago was much less than it is today (about 5mm per year); so what is it going to be in 20 years' time? If things stay the same, the sea level will rise by 0.1m over the next 20 years, or 0.25m over the next 50 years. It would be utterly reckless to ignore increases of this magnitude. Moreover, things are definitely not staying the same. Modelling different plausible scenarios yields different results, all of them larger than the current rate of sea level rise. The WA government uses a figure of 9mm per year for coastal planning for the remainder of this century (Bicknell, 2010). That amounts to 0.18m rise over the next 20 years, or 0.45m over the next 50 years.

There is a double whammy with climate change for the question we are trying to address. Not only is global warming increasing mean sea levels, it is also increasing the number of extreme weather events. Given that we are interested in maximum sea levels, which are strongly affected by storms, we are going to end up experiencing much greater impact from climate change on peak levels than simply that due to a rise in mean sea level.

The measurements

Fremantle tide gauge

Figure 1 below shows the highest water level at Fremantle for every month over the 50 years since March 1967.

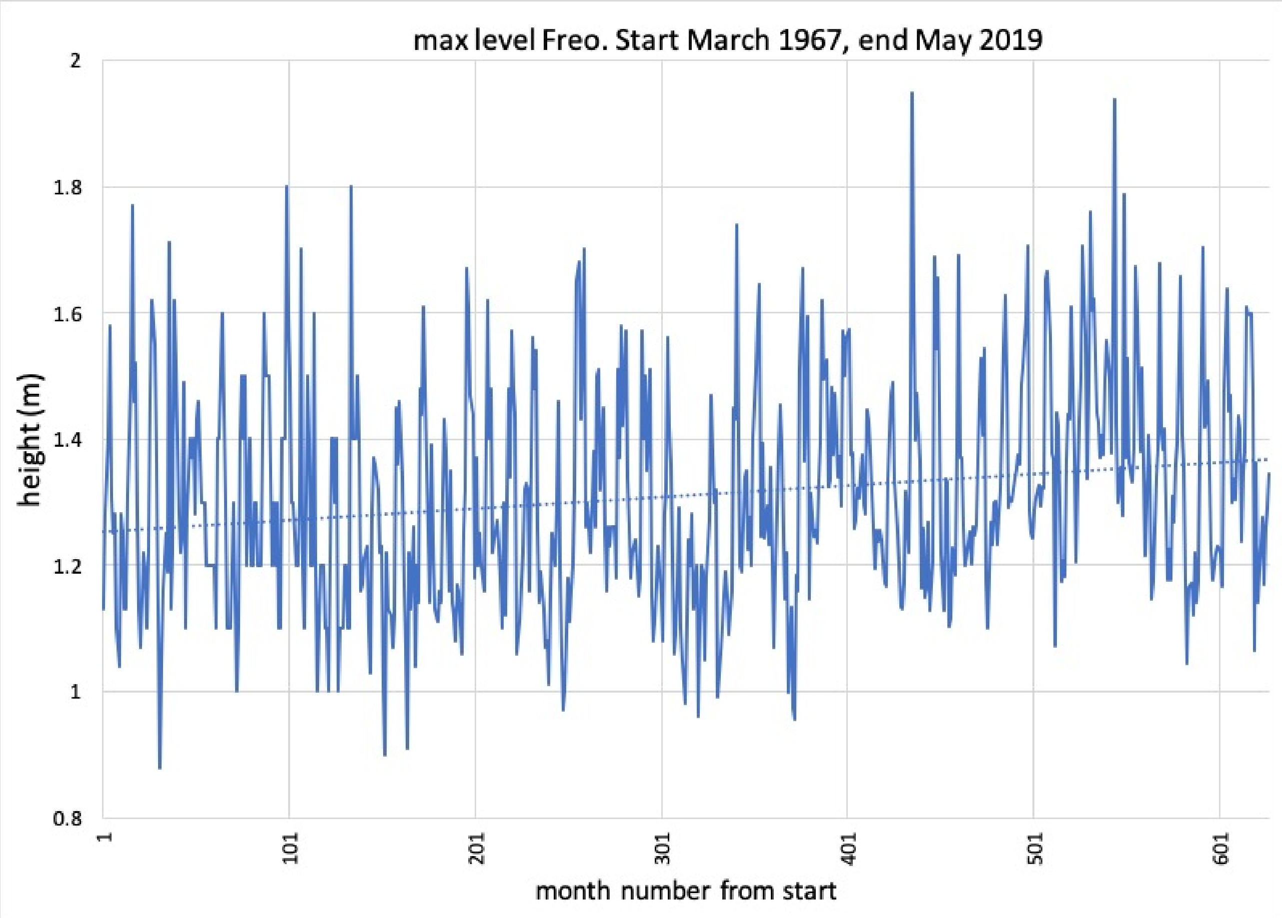

Figure 1

You can see the highest ever level of 1.95m in 2003 (about 440 months from the start of the graph) and the second highest in 2012. You can also see the trend of rising sea level, indicated by the dotted trend line, of about 2mm per year. What I cannot see, but had expected to see, was the influence of the 8.8 year and 18.6 year tidal harmonics. They might be buried in there, but I cannot see them so I sweepingly conclude they are not all that important.

Thee is an additional factor to consider; whilst the highest water level in the data set is 1.95m, Pattiaratchi (2005) states that the highest every level was 1.98m, at the same date. The difference is probably due to them having finer resolution data (e.g their data set might have recordings every minute whereas the BoM set might be averaged over a much longer time), so they would be able to pick up a brief water level rise not evident in the BoM data set. In other words, the highest level of 1.95m in the BoM data set could be 0.03m less than the actual highest level.

The next graph, figure 2 below, is a selection of the data from the first graph. I have extracted the highest water level recorded for each year since 1989 i.e. I am examining the right hand (more recent) part of the first graph, and picking out all the high points. I have also plotted what the tide tables predicted (in orange), for the 5 years I have tide tables (2014-18).

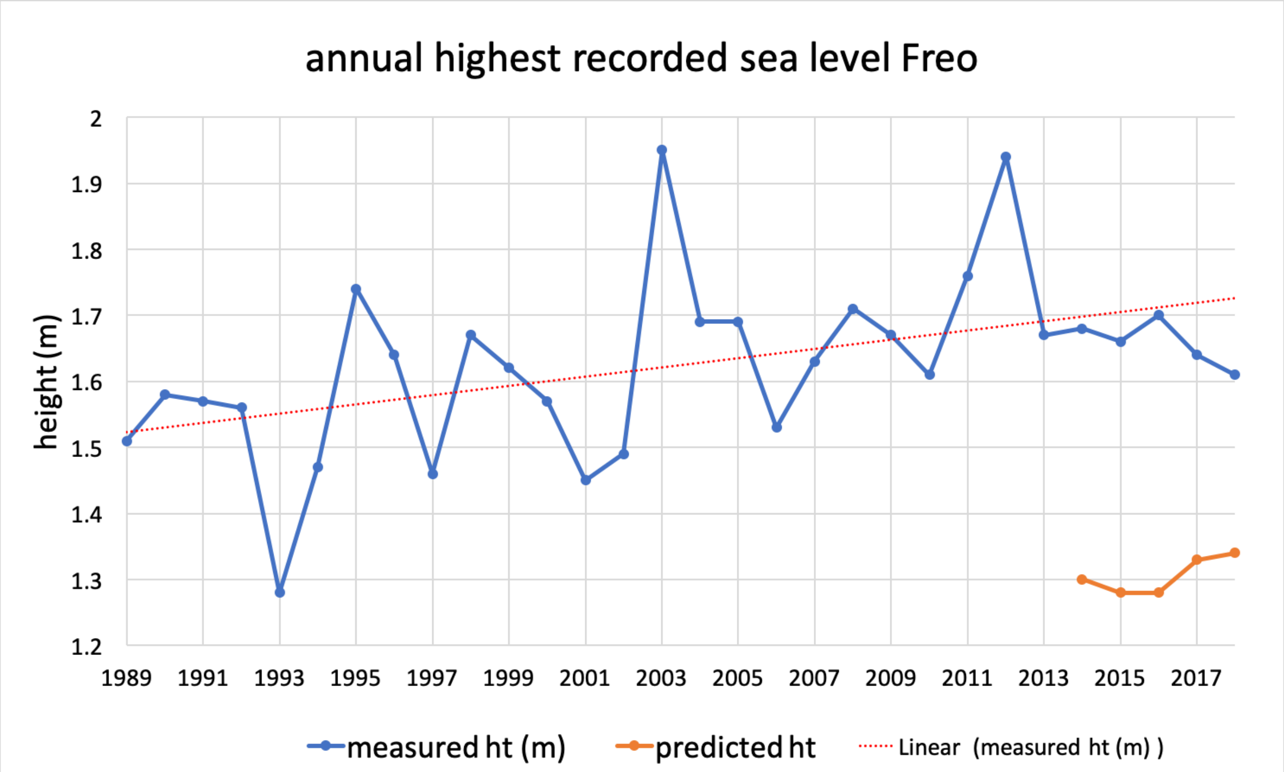

Figure 2

Again, we see the highest record of 1.95m, occurring in 2003, and the second highest in 2012.

This graph reveals two important things that are not visible in the first graph:

- Firstly, the annual highest sea level has increased 0.21m over the last 30 years by i.e. 7mm per year, much faster than the increase for the monthly peaks in figure 1.
- Secondly, the recorded highs are higher than the predicted highs (by 0.31m on average). This is the average effect of the pressure changes, meteotsunamis, wind induced sloshing etc.

There is also the hint of a repeating high roughly every 8 years. This is close to the 8.8 year tidal harmonic, but not close enough in my view to be attributed to it.

The record length of 30 years is statistically quite short. This increases the uncertainty in the estimate, though not its value. As a quick estimate of uncertainty, I have truncated the series at various years and measured the new rate of sea level increase. The results are shown in Table 1 below.

range	Sea level rise mm/year
1989-2018	7
1994-2018	5.2
1999-2018	5.2
2004-18	1.9
2009-18	-8.8
1989-2008	9.1
1989-1998	10.2
average	**4.3**

Table 1

The two 10-year truncated data sets are to short to be much use, but the roughly cancel each other out so I have included them in the average.

Something not evident from the graph is that these annual highest levels always occur in late autumn/early winter. Every data point in the graph occurs in either May, June or July. This is because the Leeuwin current is strongest at this time of year.

FSC jetty heights

I have just been down the jetties to measure how high above water they are. The wooden finger jetties vary quite a lot in height. The concrete main jetties are probably all the same height, but they might have a slight slope. I have taken the following measurements at pen B33, which is fairly typical of the pens in general. The measurements were taken to the water level, then corrected for water level above chart datum recorded at the DoT Fremantle tide gauge at the time of my measurement, published at https://www.transport.wa.gov.au/imarine/fremantle-fishing-boat-harbour-tide.asp

- The concrete surface of the main jetty is 1.92m above datum
- The jetty end of the timber finger jetty is 1.57m above datum
- The outboard end of the timber jetty is 1.62m above datum i.e. the timber jetty slopes very slightly up as you walk out.

This means that, when the highest ever water level of 1.98m occurred (according to Pattiaratchi) in 2003, the timber jetty was shin deep underwater and the concrete jetty was not quite ankle level below water. This corresponds with my recollection of the event. The 2012 extreme level was 1.94m, so the concrete jetty would have been just awash. Those are probably the only two times the concrete jetty has been at or below the water level.

The timber jetty goes underwater almost every year, sometimes 2 or 3 times a year. This roughly corresponds with peak values of figure 2.

Predicting from the measurements

So much for what has happened in the past, what is going to happen in the future? This is the really tricky bit.

Synchronicity

I was tempted to head this section with the colloquial phrase “did all the planets line up?”, but that would be confusing as it is not just the planets that have to align to get a high sea level, it is also the weather patterns.

The various influencing factors previously identified are embedded in the data, so we don’t know how much each factor contributes to each high level (a bit like trying to unbake a cake; you cannot work backwards from the cake to the recipe). For example, for the highest level ever recorded in the monthyl data (1.95m in May 2003), did this occur at exactly the time of the highest tide of that year, or was it at a slightly lesser tide, but with an enormous wind surge on top of the tide, or at the time of an abnormally low pressure? That is an important question because, if it did not occur at the peak tide, then for the same predicted tidal height sometime in the future, we could exceed that record level if the same amount of wind surge and pressure were to coincide exactly with the high tide.

The chances are that all the factors did not coincide exactly, so I am going to suggest that a level 0.1m higher than the current highest value is quite possible. That is probably conservative.

Sea level rise

We have already identified a number of different values for the annual increase in sea level. To recap:

1. 1.5mm pa at Fremantle over the last 120 years.
2. 2mm pa for the maximum monthly levels over the last 50 years, from figure 1.
3. 9mm pa over the next 100 years used by the WA Govt.
4. 7mm is the rate for the annual maximum levels over the last 30 years, from figure 2.
5. 4.3mm is the average rate for the annual maximum levels over various portions of the last 30 years.

Option 1 is historical, things have changed a lot since those records began.

Option 2 is feasible, though 50 years back is perhaps too long to pick up the latest trends.

Option 3 is sensible for mean sea levels.

Option 4 is, worryingly, probably the most valid estimate. This is for two reasons: firstly the length of the historical data set is comparable with the duration we are wanting to forecast for. Secondly, it is measuring what were most interested in – the maximum annual levels, not the average sea level. It implicitly includes the impact of climate change on storm severity. The main argument against using option 4 is that it is quite a small data set to put a straight line through. This is illustrated in in table 1. So it has more validity but less certainty than some of the other options.

To err on the conservative side I shall use option 5 (4.3mm pa). I am not convinced this is as good an estimate as option 4, but it negates any criticism that I am scaremongering.

Putting it all together

Starting from the highest sea level recorded so far in the monthly data – 1.95m – we have to add the following to get a predicted maximum for the next 20 years:

- 0.1m for closer synchronicity
- 4.3mm pa for peak level increase. This gets added in two parts

  - firstly that record peak occurred in 2003, over 15 years ago, so we should add 0.06m to get us up to today. (There are statistical arguments against including this, but I am not convinced by them).

  - secondly, we add from today to the end of our chosen forecast period – 0.09m for 20 years ahead and 0.22m for 50 years ahead

That means the highest likely level in the next 20 years is (1.95+0.1+0.06 +0.09=) 2.2m, and in the next 50 years it will be 2.33m.

To put these predictions in perspective, we can expect the main concrete jetties to go 0.28m under water (i.e. shin-deep) at least once in the next 20 years, with the timber jetties going 0.63m under water (thigh-deep). I wonder how the electrical supply cable will cope when it is submerged with that pressure head of 0.28m? If we project to 50 years instead of 20 years, the depths increase by a further 0.13m. Bear in mind these figures have been arrived at using very conservative estimates; they could well be higher, especially if the rate of global warming increases or if we change the baseline to the highest recorded value claimed by Pattiaratchi.

Have we taken any of this science into account as part of our jetty repair/replacement plan?

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