Investigation of Thames High Watermark at London

Rick Bradford, 31/3/22

Questions to address

[1] Has the rising of mean sea levels had a significant effect on the highest Thames levels to-date?

[2] What is the likely impact of rising mean sea levels on the highest Thames levels for the rest of the century?

Basics of Mean Sea Level Rise

- Global Mean Sea Level (GMSL) has been rising for 20,000 years, over most of that period at far faster rates than at present. (Hence, there are more mechanisms at work than human induced climate change, and no reason at all to assume these other mechanisms have ceased, though they have slowed over this long time-frame).

- Global data was reviewed in Ref.[1]. Ref.[2] derives the linear trend from 1900 to 2009 to have been 1.7 ± 0.2 mm per year, or, since 1961, a trend of 1.9 ± 0.4 mm per year. There has been an acceleration in GMSL rise rate since 1880 of 0.009 mm $year^{-2}$.

- The rate of increase of the GMSL in 1880 cannot be attributed to CO_2-driven increases in atmospheric average temperature, so the maximum possible effect of the latter on the GMSL is measured by its acceleration (i.e., the increase in the GMSL rate of rise since 1880).

- The increase in the rise rate of GMSL ***potentially*** (but not definitely) attributable to increases in atmospheric average temperature between 1880 and 2022 is thus estimated to be 142 x 0.009 = 1.28 mm/yr by now (2022).

- The current rate of increase of GMSL is around 3mm/yr (i.e., the 1.7mm/yr persisting prior to the 20^{th} century, plus the 1.28 mm/yr increase potentially attributable to recent “global atmospheric warming” to 2022).

- Far faster GMSL rise rates are postulated in the IPCC reports, but it is important to appreciate that these have no empirical basis. They are purely theoretical predictions based on severe scenarios which postulate that, not only is the rise rate accelerating but the rate of acceleration is also increasing. There is no evidence for this in the existing data. Based on the January 2020 UNEP Adaptation Gap report, Ref.[3] states, “*the world is heading for a 3°C temperature rise this century… A 1.15 metre rise in sea level between 1990 and 2100 is within the range of possible outcomes*”.

Table 1: GMSL Increases, observed and predicted

Period	Total Rise (metres)	Maximum feasibly due to GAAT global warming
1900 – 2022	0.253	0.046
2022 – 2100 (best estimate)	0.261	0.128
1900 – 2100 (best estimate)	0.514	0.174
1900 – 2100 (IPCC bound)	1.150	0.810

Mean Sea Level Rise at the Mouth of the Thames

Ref.[3] tells us that, at Southend-on-Sea,

- Sea level rose by about 1.4 mm per year (on average) between 1911 and 2018, relative to land level versus 3.6 mm per year between 1990 and 2018
- These rates of sea level rise are similar to the IPCC's 'very likely' range of global mean sea level rise

…and broadly compatible with my observations on the GMSL rise rate, above.

The Thames at London Basics

- The Thames has been flooding at London regularly since Roman times (and, presumably, before).
- The Thames is normally taken to be tidal as far as Teddington lock (so 99 miles of the river's 215 mile length are tidal).
- The high-water mark in central London is very variable because of (i) seasonal variations in the natural tide, (ii) storm surges (driven from the North Sea), and, (iii) highly variable fluvial (river) flow. Coincidence of two or more of these factors could lead to a flooding risk in the absence of the barrier.
- The Thames Barrier was built to protect central London from exceptional tides driven by storm surges. It was designed against the 10^{-3} pyr storm tide. It was largely a response to the great flood of 1953 and became operational in 1982.
- As of February 2022 there have been 206 closures of the barrier: 115 attributed to the tide alone and 91 attributed to the additional influence of a high fluvial flow. Hence fluvial flows are significant, not just sea tides or sea surges.
- Ref.[3] notes that, "to date, there has been no statistically significant increase in annual closure numbers of the Thames Barrier". (This is noteworthy because there are many newspaper reports which state the opposite).
- The latter observation implies that global warming has not, as yet, had an identifiable effect on the highest water observed in the Thames (noting that roughly half of global atmospheric warming has occurred since the barrier became operational in 1982).
- This suggests that GMSL rise is (so far) negligible in comparison with the three factors listed above, i.e., seasonal variations in tide, storm surges, and fluvial flows. This will be confirmed by the quantitative analysis below.

Global Average Atmospheric Temperature Increases

It is worth bearing in mind the big picture regarding Global Average Atmospheric Temperatures (GAAT). Ref.[4] compiles several sources which together provide this picture,

- 1910 was a minimum in GAAT (cooler than in, say, 1880) so it is conservative to use 1910 as a time datum;
- Between 1910 and 1940 GAAT increased, by perhaps 0.4 to 0.5^{o}C;

- Between 1940 and 1970 GAAT was roughly unchanging;
- Between 1970 and ~2020 GAAT increased, by perhaps 0.8 to 0.9^{o}C.
- Total GAAT increase 1910 to present was thus roughly 1.2 to 1.4^{o}C. (Referenced to 1880 this rise would be closer to the oft-cited 1^{o}C).

Historic Data on Thames Tide Heights and Ranges, 1911 – 1981

Data is taken from Ref.[5]. This source looks at several different locations on the Thames. Here I shall concentrate for simplicity on one location in central London, namely London Bridge. All the data below relate to that.

The data tables in Ref.[5] record the highest and the lowest tide points – and so generally two of each reading every 24 hours. Every day is covered, with only the occasional missing data, from May 1911 to December 1995. However, I use the data here only to December 1981, because the Thames barrier came into use in 1982 and this makes the data from central London non-indicative of the highest tidal conditions from 1982 onwards.

Figures A.1 to A.4 of Appendix A illustrate what the twice-daily data typical look like (these graphs illustrate using the period 1911 to 1919).

By averaging the twice-daily high watermark the mean high tide for each year can be calculated. Figure 1 plots these annual mean heights for years 1912 to 1981. Also shown is the best fit straight line (dashed). There is a very clear upward trend with a mean slope of 3.3 mm/year.

Tidal ranges are defined as the range between consecutive low and high tides. By averaging the twice-daily ranges the mean tidal range for each year can be calculated. Figure 2 plots these annual mean tidal ranges for years 1912 to 1981. There is a clear upward trend with a mean slope of 3.9 mm/year.

Figures 3 and 4 reproduce the same data as Figures 1 and 2 but with fits (dashed curves) defined by the best straight line plus a sinusoidal variation with periodic time 18.6 years. This is the known period of the Moon's nodal precession. (The angle between the plane of the Moon's orbit around the Earth and the plane of the ecliptic varies with this period, thus causing variations in the strength of the tides). An amplitude of 0.125 metres was found, by eye, to give an improved fit compared to a simple straight line. There is no doubt that the tidal data is responding to these variations in natural gravitational effects.

However, the upward trend of the mean of these oscillations, obvious in all of Figures 1 to 4, is, as yet, unexplained and will be discussed below.

Figure 1

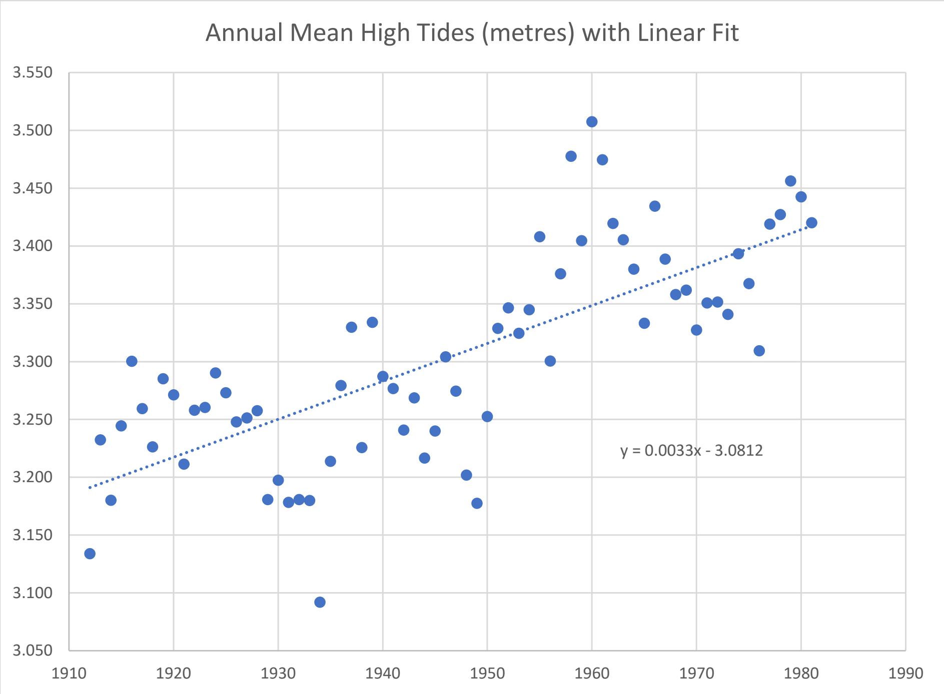


Figure 2

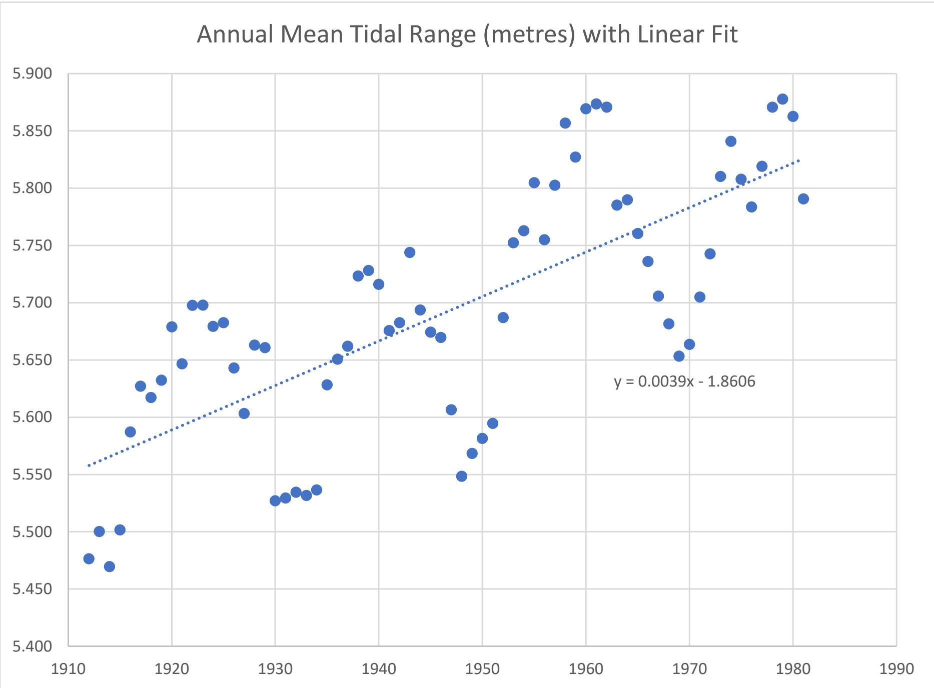


Figure 3

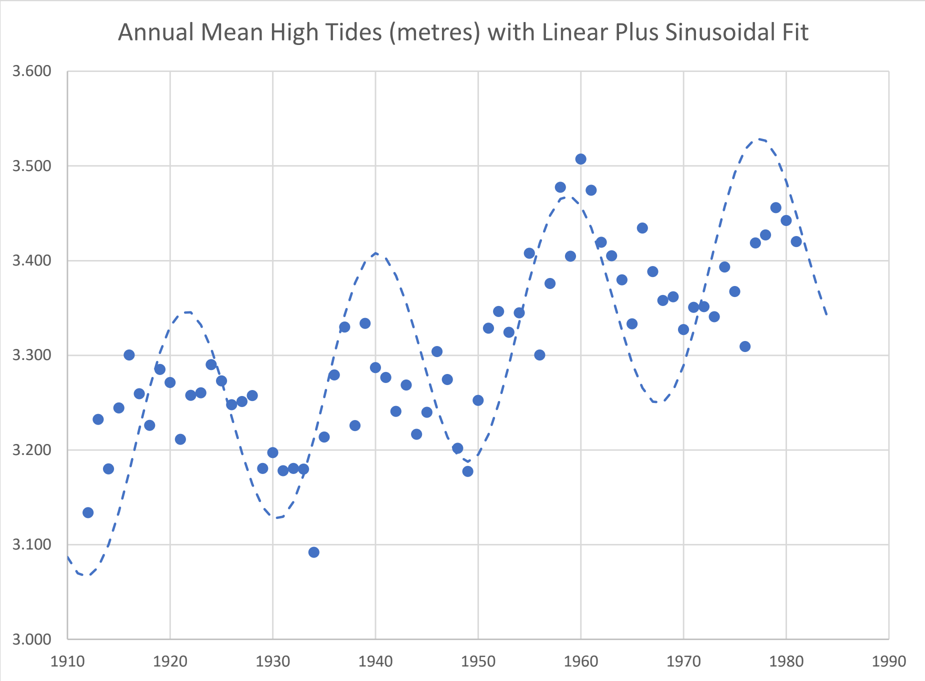


Figure 4

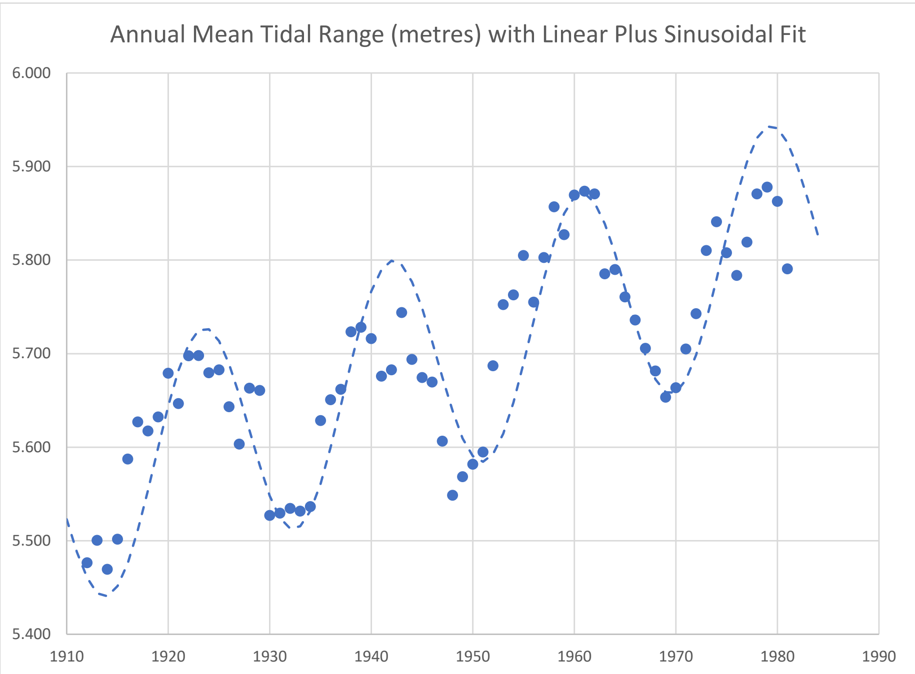
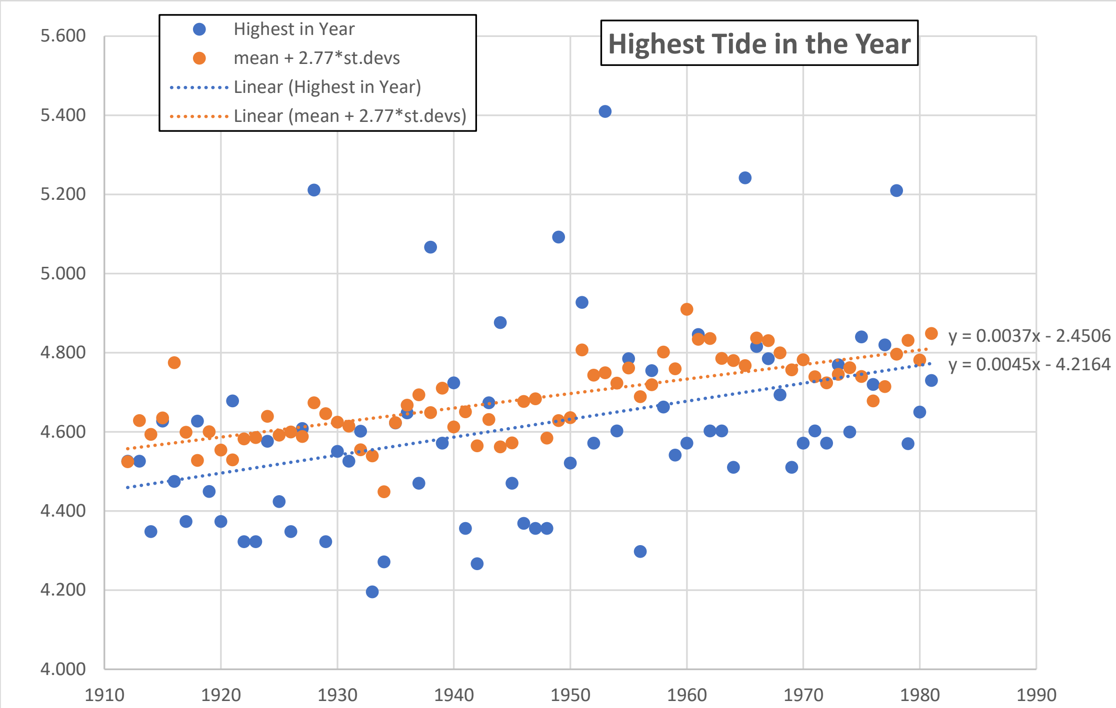


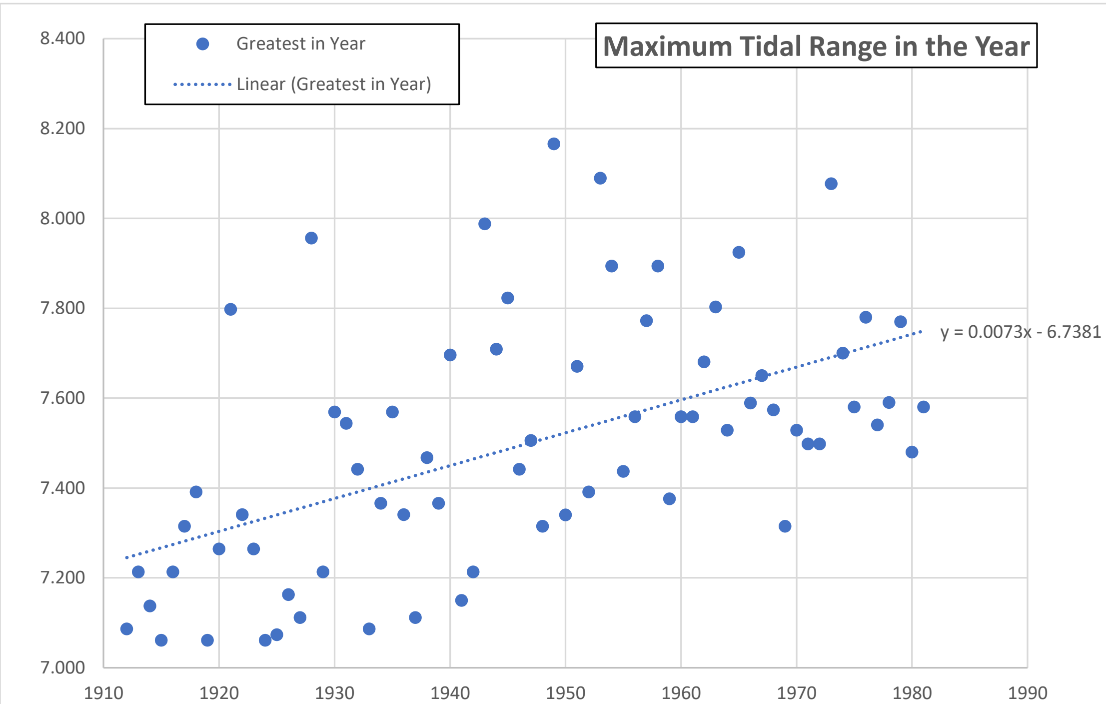
Figure 5 plots against year the highest tide which occurred in each year (blue points). Also shown for comparison are the mean tide heights for that year plus 2.77 standard deviations. This corresponds to a probability of exceedance of 1/365, and hence would be an estimate of the highest likely tide in the year if the distribution were normal. The six highest tides in the period 1912 to 1981, i.e., those over 5 metres, exceed what would be expected from the tail of the normal distribution, i.e., they are exceptional. These are the tides most likely to flood (specifically the highest of all, at over 5.4 metres was the great flood of 1953).

Figure 5



Similarly, Figure 6 plots against year the maximum tidal range which occurred in each year.

Figure 6



It's tempting to interpret the rising best-fit lines in Figures 1 and 5, i.e., the annual mean tide height and the greatest high tide in the year, as resulting from the rise in the global mean sea level (GMSL). But there are problems with this interpretation. Firstly, there is no sign of a cessation of this rising tide height between 1940 and 1970 as seen in the atmospheric temperature data (the GAAT).

A more serious problem is that the tidal ***range*** has also increased over this period, both as regards its annual mean (Figure 2) and its annual maximum (Figure 6). In fact the annual maximum has increased at about twice the rate of the high tide itself. But if an increasing GMSL were the cause it would affect both low and high tides equally and leave the tidal ***range*** unaffected. Clearly something else is going on here.

Tidal Data Before 1911?

It would be nice to have comparable, high-quality tide data covering at least part of the 19th century. Unfortunately I failed to find detailed data. In lieu of this I shall rely on the review of Ref.[6]. This was published 10 years before the Thames barrier became operational and appears to be the definitive state of knowledge at the time, and hence was presumably used in setting the design parameters of the barrier.

Ref.[6] opens with a quote from J. B. Redman (1877), Ref.[7],

> "In 1799 the range of springs at London Bridge, as ascertained by Russell and Gream for the Trinity Corporation, was only 15 feet; so that, in the last three-quarters of a century, the increased oscillation is 5 feet 9 inches. Of the increased range of 4 feet 7 inches as compared with Sheerness, 3 feet 10 inches are due to the elevation of the surface at high water, and 9 inches to the depression at low water."

Staggeringly, this suggests that in the first 78 years of the 19th century, the tidal range at London Bridge increased by an average of 22.5 mm per year. Far faster even that indicated by Figures 2 or 6 for the period 1912 – 1981.

The quote also implies that the height of the high tide increased by 46 inches more than the increase at Sheerness, i.e., 46 inches more than the adjacent sea level rise. That's an excess of an average of 15 mm per year compared with the sea level. Again this is substantially faster than the rise rate in the 20th century.

Ref.[6] also provides some valuable, if sparse, data from as early as 1835 on the tide heights during major surges, Figure 7. The highest surges appear to have increased in height by one metre in 120 years, or an average of 8.3 mm/year, broadly similar to (but slightly larger than) Figure 6 in the 20th century.

The crucial issue is that these rapid increases in tide height and tidal range occurred prior to increases in atmospheric temperatures (GAAT) and hence definitely unconnected with CO_2 emissions or other atmospheric temperature effects.

Bowen, Ref.[6], considers several possible causes of the increases in both tide heights and ranges, including the possibility that the land which provides the datum for tide height measurements might be sinking, though Bowen ultimately rules that out as the explanation. He notes that civil works and dredging, in deepening the river, together with embankment work over the years, has led to a reduced effective viscosity, and hence to more rapid flows which could contribute to the mysterious increases in tide heights and ranges.

Figure 7: From Ref.[6], Fig.7

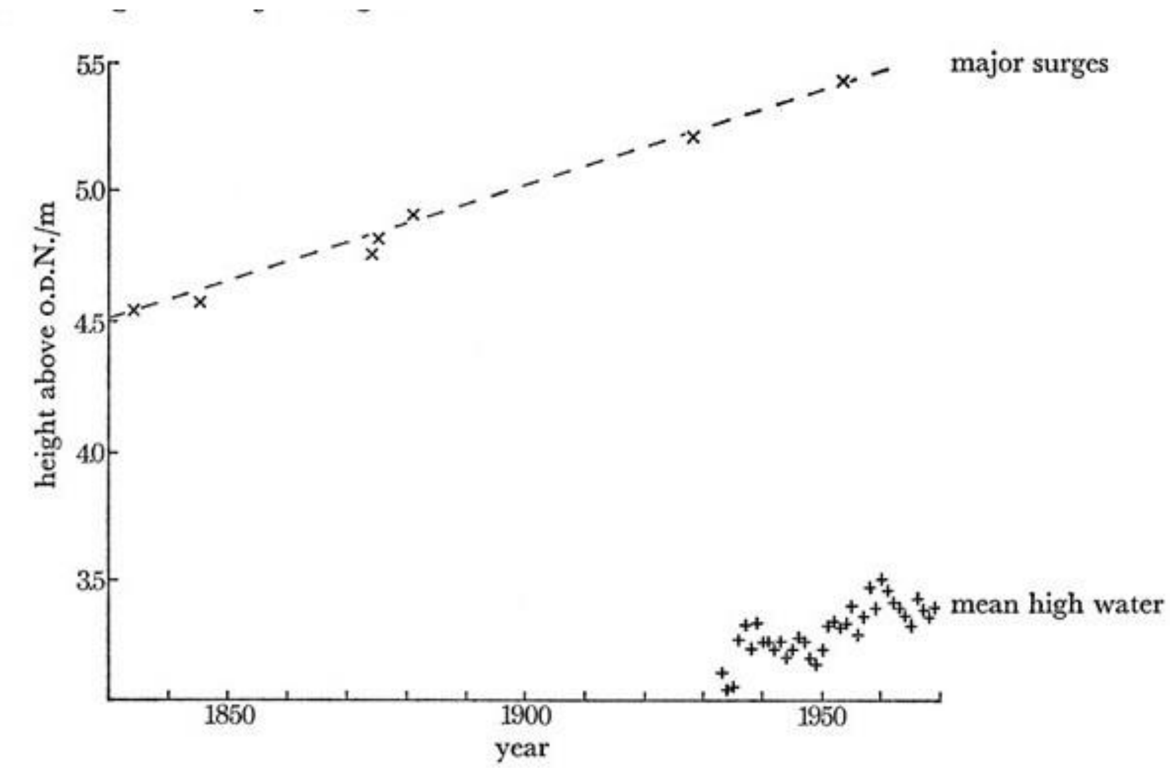


FIGURE 7. The maximum height at Tower Pier of major surges. For comparison the mean annual high-water heights are shown.

However, Bowen was ultimately of the view that the dominant factor in raising tide heights and ranges in central London relates to human responses to flooding upstream and downstream of the capital. Each time there has been flooding of the river upstream of central London the response has been to carry out works to raise embankments to prevent further flooding in that locale. Consequently, next time there was a particularly high fluvial flow, the river upstream of central London was more efficient at carrying this fresh river water into the capital without lateral losses. Whereas earlier the pressure of the fluvial flow on the capital would have been ameliorated by flooding upstream, subsequent to embankment improvements the capital became exposed to the full flood waters.

In the same manner, downstream of central London, strong storm surges would originally have moved laterally into marshes, at least in part. But each such local flooding event motivated improved sea defences. The next storm surge would then fail to be ameliorated by lateral losses exposing the capital to the full surge of tidal seawater.

In short, embankment work both upstream and downstream of central London has led to both high fluvial flows and storm surges from the sea becoming increasingly focused on raising the water level in the capital, and this occurred throughout the 19^{th} and 20^{th} centuries (at least).

Conclusions

[1] High quality data shows that mean tide heights, maximum (surge) tide heights and tidal ranges in central London all increased throughout the 20th century (specifically 1912 – 1981).

[2] Limited evidence indicates that typical tide heights, maximum (surge) tide heights and tidal ranges in central London also all increased throughout the 19th century, and at rates probably greater than those in the 20th century.

[3] Conclusion [2] implies that the dominant causes of these tide height increases do not relate to atmospheric temperature (GAAT) increases (and hence not to CO_2 emissions). This conclusion is reinforced by the increases in tidal range, which exceed the increases in tide height, and which could not be caused by increases in mean sea level.

[4] This conclusion is further reinforced by the fact that there has been no statistically significant increase in annual closure numbers of the Thames Barrier to-date.

[5] Bowen, Ref.[6], was of the view that the increases in tide height and tidal ranges in central London was due to raising embankments both upstream and downstream of central London, and other works which were carried out periodically after local flooding. The side-effect of these human interventions to prevent flooding elsewhere would be to funnel more efficiently into the capital (i) high fluvial flows of fresh water from upstream, and, (ii) storm surges of tidal sea water from downstream. The prevention of lateral losses from these flows by improving embankments simply puts more water into central London from both directions.

[6] Any effect of mean sea level rise on the Thames tide height in central London (sans barrier) is small compared to these other factors. Whether this remains the case later in the 21st century depends upon whether future sea level rises are at the best estimate level or the highly conservative level of the IPCC's upper bound. Planning, e.g., Ref.[3], rightly assumes this upper, conservative, estimate, but this does not mean that it is likely (there is currently no empirical evidence to support this upper bound).

[7] The Thames provides an excellent case study in the necessity of "Adaption" as a policy. Had there never been any CO_2 emissions from planet Earth, the requirement for human interventions to prevent flooding (embankment works and the barrier) would have been exactly the same to-date – and perhaps that will remain the case in future. "Net Zero" would be largely ineffectual in this context.

[8] Without wishing to be overly cynical, the "bigging-up" of the threat of climate change on sea level, and hence the threat to London, in policy documents such as Ref.[3] is only to be expected by any body seeking continued or increased Government funding.

References

[1] R.Bradford, Is Sea Level Rise Due to CO2?, January 2020

[2] John A. Church and Neil J. White, "Sea-Level Rise from the Late 19th to the Early 21st Century", Surv Geophys (2011) 32:585–602 DOI 10.1007/s10712-011-9119-1

[3] Thames Estuary 2100: 10-Year Review monitoring key findings - GOV.UK (www.gov.uk)

[4] R.Bradford, Global Average Temperature Data: Compilation of Sources at August 2019

[5] Haigh, I.D., et al. Historic sea level records in the Thames Estuary, UK, 1911 – 1995.

[6] A. J. Bowen (1972). The Tidal Régime of the River Thames; Long-Term Trends and their Possible Causes. Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences , May 4, 1972, Vol. 272, No. 1221, 187-199. https://www.jstor.org/stable/74029

[7] Redman, J. B. I877 Proc. Instn Civ. Engrs 49, 67

Appendix A: Illustrative Twice-Daily Data

Illustrated here for the period May 1911 to December 1919.

Figure A.1: Daily Data, High Tides

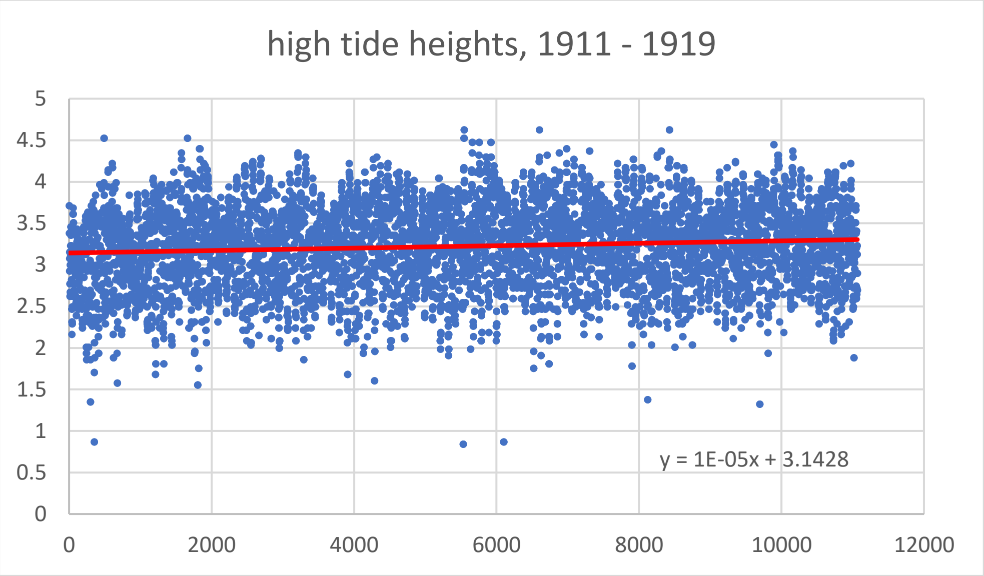


Figure A.2: Histogram of High Tides

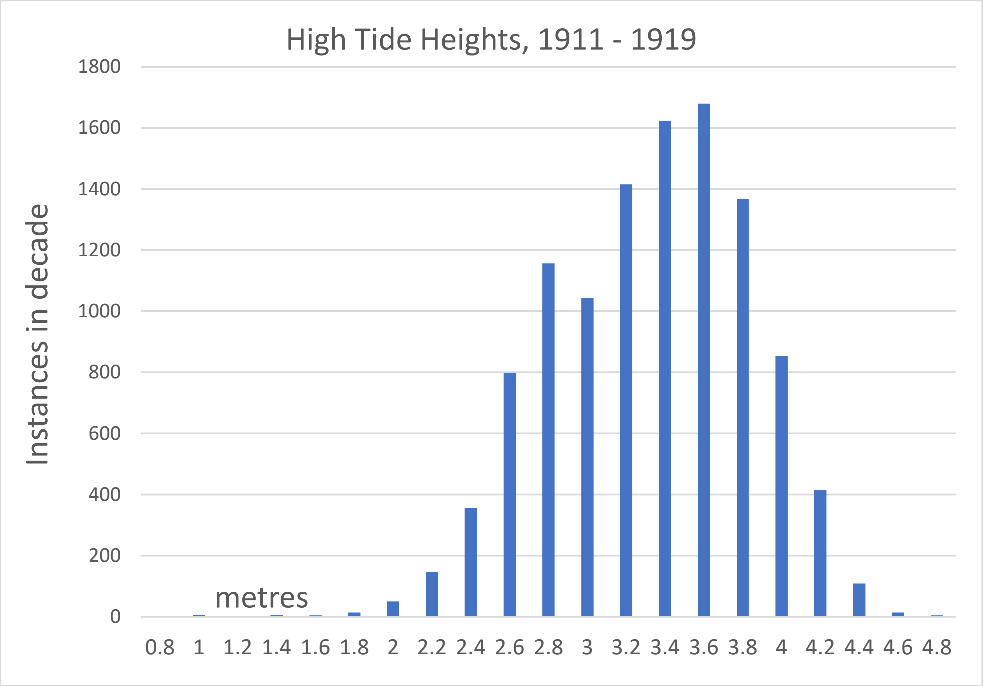


Figure A.3: Daily Data, Tidal Ranges

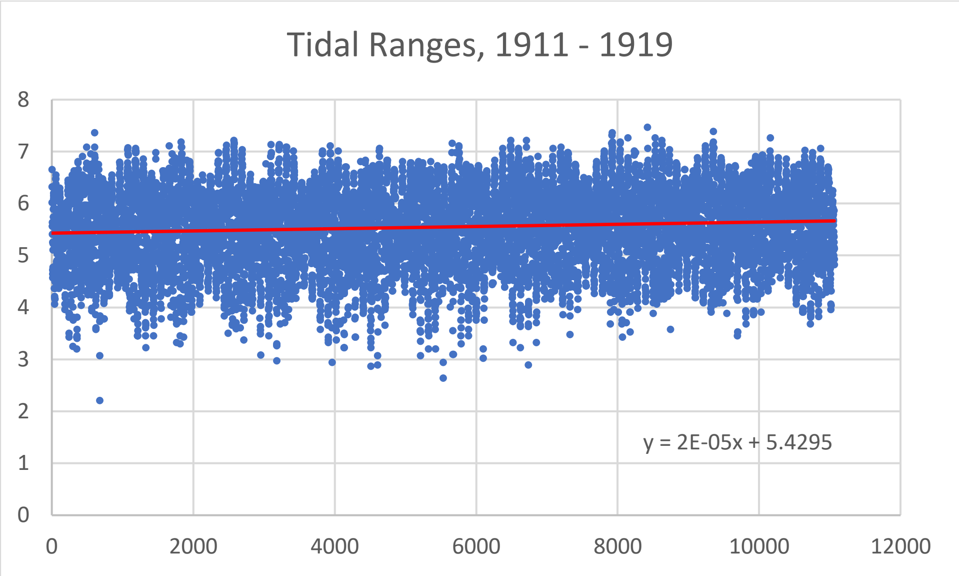


Figure A.4: Histogram of Tidal Ranges