Storm Surges in Yarmouth Harbour

October 2013 – February 2014

The UK Meteorological Office (Met Office) reported the following provisional assessment[1] of the weather experienced across the UK during the winter 2013/2014:

- "Winter 2014 was an exceptionally stormy season, with at least 12 major winter storms affecting the UK in two spells from mid-December to early January, and again from late January to mid-February…..An analysis of pressure fields by the University of East Anglia suggests that this winter had more very severe gale days than any other winter season in a series from 1871."
- "The persistent heavy rainfall through the season resulted in this being the wettest winter for the UK, England, Wales and Scotland, and the second wettest winter for Northern Ireland, in a series from 1910. It was also the wettest winter in the long running England and Wales Precipitation series from 1766."
- "Mean temperatures over the UK were well above the long term average…..with a notable absence of frosts…"

The winter was also exceptional for Yarmouth in the number of times that the sea rose above the quay, flooding neighbouring parts of the town. The frequency of major storm surges was much greater than Yarmouth had experienced before. It is important to stress that the flooding in Yarmouth was due to storm surges, driven by the patterns of wind and air pressure in the storms moving into northwest Europe from the Atlantic, and not due to the heavy rainfall which we suffered as well. [The heavy rainfall associated with these storms led to serious flooding in other parts of the country (e.g. on the Somerset Levels, in parts of the Thames valley).]

The storm surges experienced in Yarmouth covered a greater span of time than those discussed in the Met Office assessment above. The first major storm surge arrived on 28th October 2013 (associated with what has been referred to in the media as the St Jude's Day storm) and the last on 14th February 2014 (referred to as the St Valentine's Day storm). Prior to this winter's events, the last major storm surge experienced at Yarmouth occurred on 10th March 2008. That event was discussed in detail in the report "Adapting to Coastal Flooding in the Yarmouth Area in the 21st Century" produced by the Yarmouth Coastal Defence Working Group in December 2010. At the time of that report, it was thought that comparable storm surges could be expected to occur roughly every 20 years.

The height of the quay in Yarmouth is about 3.9m above Chart Datum. [This height is not as precise a level as in an architectural structure, but may fluctuate about this value by ±0.1m across the whole harbour]. If one defines a significant storm surge (for Yarmouth) as one which reaches or exceeds the height of the quay, six such events were observed between October and February, as shown in the Table 1 below.

Significant storm surges observed in Yarmouth Harbour

Date	Predicted tide[a]	Observed tide[b]	Height of storm surge
10 March 2008	Noon 3.0m	4.1m	1.1m
28 October 2013	05:23 2.6m	4.01m	1.4m
4 November 2013	10:26 3.1m	3.97m	0.9m
5 November 2013	11:02 3.1m	3.85m	0.75m
6 December 2013	00:16 3.1m	3.83m	0.7m
3 January 2014	11:18 3.1m	3.80m	0.7m
14 February 2014	22:37 2.9m	4.15m	1.25m

Notes

(a) The time and height above Chart Datum of the predicted high water is taken from the "Yarmouth Harbour Visitors' Guide & Tide Tables". This tidal information is provided by the Admiralty Hydrographic Office.

(b) With the exception of the observed tide in March 2008, where the reading was a visual observation against a tide board, the observed tides are the instrumental readings obtained by the Yarmouth Harbour Tide Gauge operated by the Environment Agency.

Table 1. Storm surge observations in Yarmouth Harbour, March 2008 and 2013/2014.

Many more, smaller storm surges were observed. There may also have been a few large storm surges, comparable to those given in the table above, but because they did not coincide with the astronomical prediction of high water were not identified at Yarmouth. [A full comparison of the observed and predicted tidal elevations at Yarmouth is beyond the scope of this report.] The persistence of storm surges through the winter along the south coast is best shown by examining the data recorded by the two nearest Class A tide gauges operated by the UK National Tide Gauge Network, which are available over the internet[2]. These are shown below. [Note that the nearest tide gauge to Yarmouth in this network, at Bournemouth, has not been fully operational since 28th October 2013.]

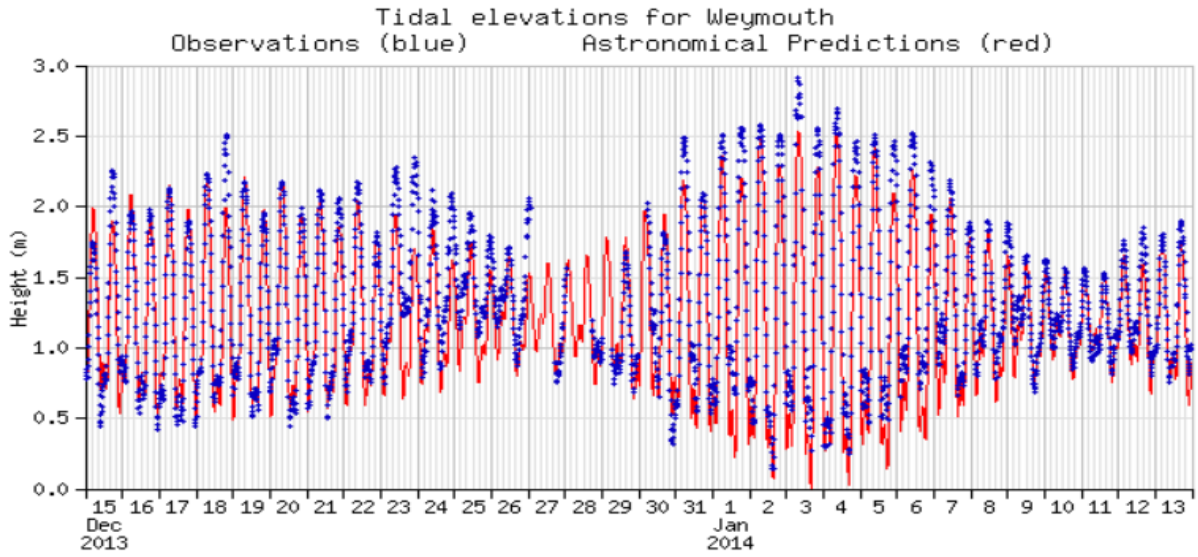

Figure 1. Tidal elevation record for Weymouth from 15th December 2013 to 13th January 2014.

The highest tidal elevation observed in this section of record was produced by the storm surge of 3rd January 2014, which was also significant at Yarmouth. However, it is apparent that larger storm surges occurred on 18th, 23rd and 26th December, but were associated with lesser astronomically-generated tides.

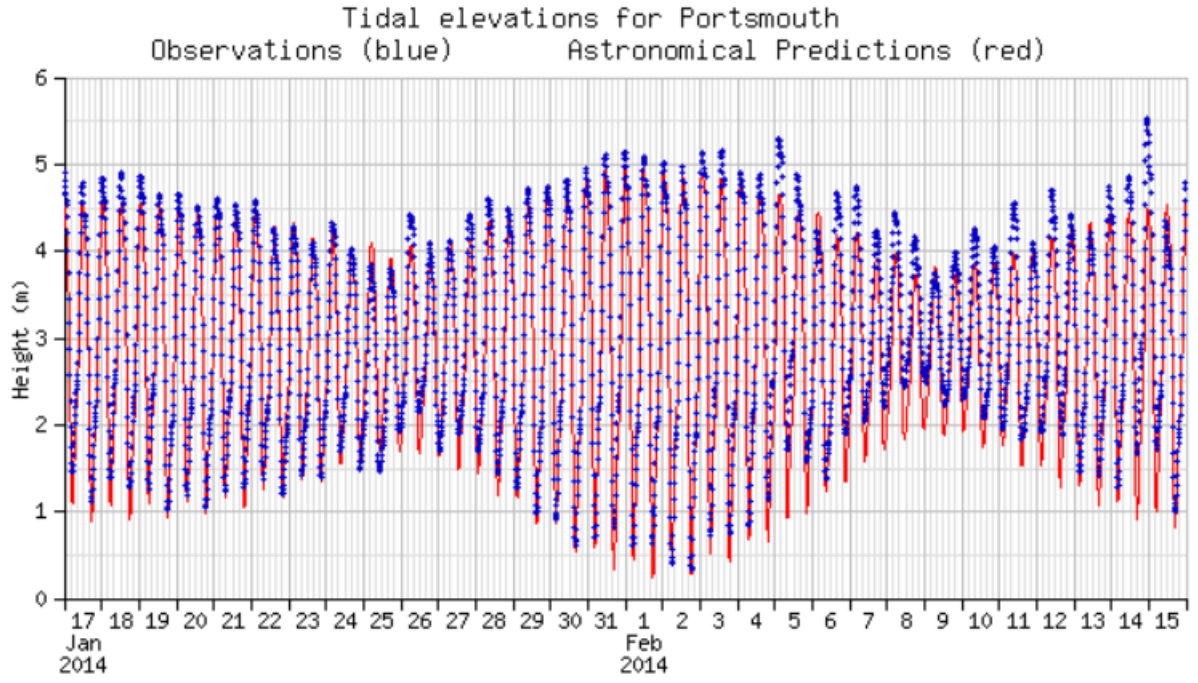

Figure 2. Tidal elevation record for Portsmouth from 17th January to 15th February 2014.

The St Valentine's Day storm produced the largest storm surge on this 30-day record and also the highest tidal elevation.

Comparison of Storm Surge Heights at Weymouth, Portsmouth and Yarmouth

Date	**Weymouth**	**Portsmouth**	**Yarmouth**
28th October 2013	0.65m	0.9m	1.4m
4th November 2013	0.3	0.5	0.9
5th November 2013	0.25	0.2	0.75
6th December 2013	0.15	0.6	0.7
3rd January 2014	0.35	0.5	0.7
14th February 2014	1.0	1.0	1.25

Table 2. Storm surge heights at Weymouth, Portsmouth and Yarmouth.

A simple comparison of the maximum heights of equivalent storm surges in Weymouth, Portsmouth and Yarmouth is shown in Table 2. The tidal elevation signal as a function of time is sometimes quite complex and differs between Weymouth and Portsmouth (See Figures 3 & 4). No attempt was been made to study this signal at Yarmouth – just the maximum tidal elevation was noted. Nevertheless, the heights of the storm surges observed in Yarmouth were consistently greater than those recorded at Weymouth and Portsmouth. Presumably this amplification of the signal in Yarmouth is related to tidal processes in the Solent.

28th October Storm Surge

The largest storm surge observed in Yarmouth from October 2013 to February 2014 occurred on 28th October 2013. Scientists at the University of Southampton were particularly interested in this event, identifying a seiche in which the seawater oscillates back and forth across the Channel[3]. Wells et al (2005) have shown that severe storms can induce such transverse oscillations of sea level in the English Channel with a period of 2 – 6 hours[4].

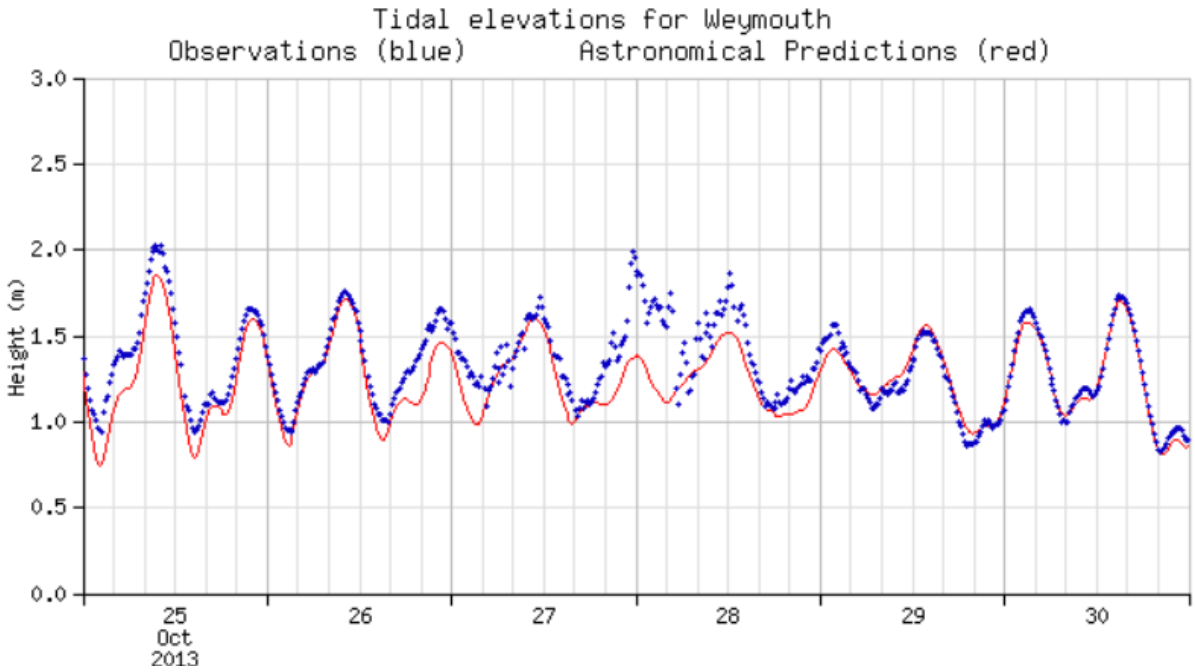

Figure 3. Tidal elevation record for Weymouth from 25th October to 30th October 2013[2].

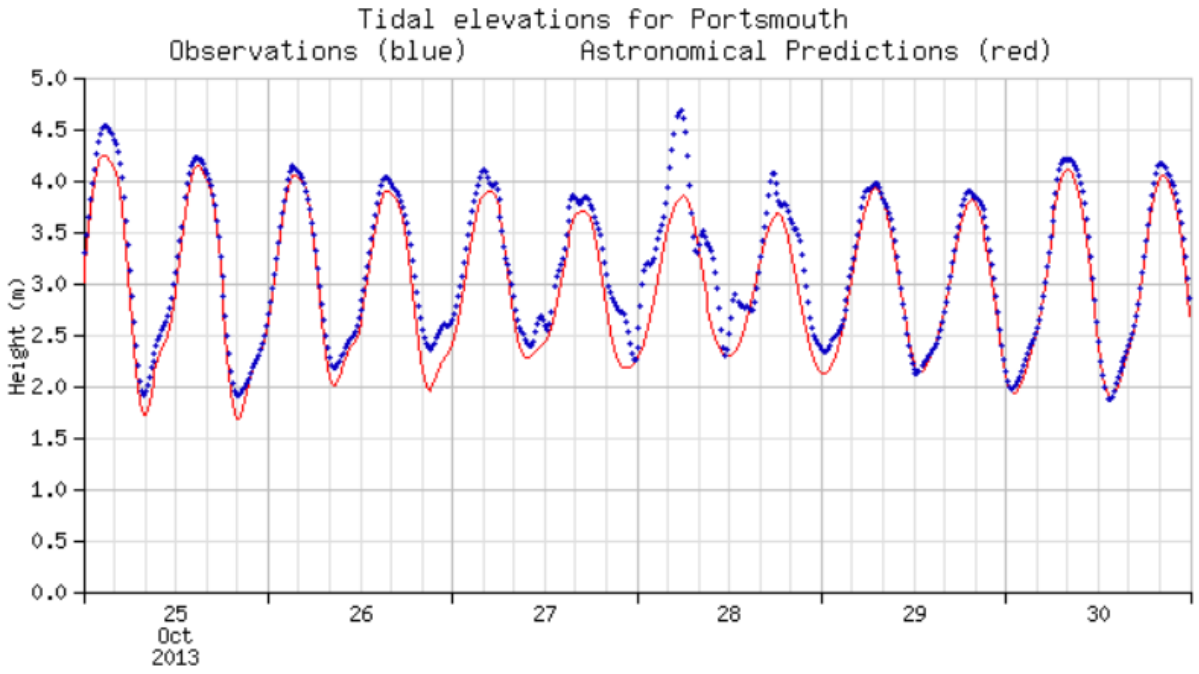

Figure 4. Tidal elevation record for Portsmouth from 25th October to 30th October 2013[2].

Visual examination of the tidal elevation records for both Weymouth and Portsmouth appear to show a higher frequency signal with a period of about 4 hours (the seiche) riding on top of

the slow build up and decline of a surge which lasts just over 2 days. A more sophisticated analysis of these records may be carried out by scientists at the University of Southampton.

Conclusions

1. In the report "Adapting to Coastal Flooding in the Yarmouth Area in the 21st Century" published in 2010, for want of further information and in order not to "cry wolf", it was assumed that the maximum storm surge that Yarmouth would experience in the 21st century would be 1.1m – the height of that experienced on 10th March 2008. This figure was then used to predict, taking into account sea level rise, the maximum sea level heights that Yarmouth could expect in 2050 and 2100. It is now clear, only 6 years after the March 2008 surge, that this figure should be revised upwards to 1.4m. This may still be a conservative assumption, but it remains important to use a figure which is firmly tied to the data. Hence the predictions for maximum sea level height in Yarmouth above Chart Datum in the 2010 report can be revised as follows:

Year	Highest Astronomical Tide	Maximum Storm Surge	Sea Level Rise	Maximum Sea Level Height
2050	3.1m	1.4m	0.3m	4.8m
2100	3.1m	1.4m	0.9m	5.4m

Table 3. Revised prediction of maximum sea level height above Chart Datum at high water for a high Spring Tide.

Year	Height of High Tide	Maximum Storm Surge	Sea Level Rise	Maximum Sea Level Height
2050	2.6m	1.4m	0.3m	4.3m
2100	2.6m	1.4m	0.9m	4.9m

Table 4. Revised prediction of maximum sea level height above Chart Datum for a typical high water Neap Tide.

2. The frequency of occurrence of storm surges in Yarmouth also needs to be revised. In the 2010 report, it was thought that storm surges comparable to the March 2008 event could be expected to occur roughly every 20 years. Of the six significant storm surges experienced in Yarmouth in the 5 months from October 2013 to February 2014, three can be considered to be comparable to the March 2008 event. However, it

is difficult to predict from this the frequency of occurrence of storm surges in decades to come without understanding more about long term weather trends. All one can say at present is that storm surges are likely to be more frequent in future than hitherto thought, and therefore that the chance of storm surges coinciding with high Spring or Neap Tides, and hence causing flooding, has increased.

3. The heights of storm surges at Yarmouth were consistently greater than those observed for the comparable events at Weymouth and Portsmouth. [It would be interesting to know how the heights of storm surges varied through the Solent, but that is beyond the scope of the report.]

4. Some scientists have claimed that one of the consequences of climate change will be increased storminess. In February 2014, a paper entitled "The Recent Storms and Floods in the UK" was published by the Met Office[5]. The question of whether climate change contributed to the severity of the weather and its impacts is discussed. It recognises that "Although no individual storm can be regarded as exceptional, the clustering and persistence of the storms is highly unusual." However, the paper concludes: "In terms of the storms and floods of winter 2013/2014, it is not possible, yet, to give a definitive answer on whether climate change has been a contributor or not."

References

1. http://www.metoffice.gov.uk/climate/uk/summaries/2014/winter
2. Real-time data from the UK National Tide Gauge Network is available from http://www.ntslf.org/data/uk-network-real-time
3. Personal communications: R. J. Nicholls, N. C. Wells, M. P.Wadey (University of Southampton)
4. Wells, N.C., Baldwin, D.J., and Haigh, I., 2005. Seiches induced by storms in the English Channel, *Journal of Atmospheric and Ocean Science*, **10**, 1-4, pp1-14.
5. http://www.metoffice.gov.uk/media/pdf/n/i/Recent_Storms_Briefing_Final_07023.pdf

Tim Francis

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