Characterisation of water levels on the lower Afon Dysynni

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1. Overview

A field survey was undertaken by Bangor University to deploy two pressure sensors on the lower Dysynni river and Broadwater, mid-Wales, UK. The aim was to characterise the water level patterns at the two mooring locations over a period of several months, to establish whether water levels at these locations were influenced by tidal processes with specific reference to the Normal Tidal Limit.

The Normal Tidal Limit (NTL) has been defined by Ordnance Survey as "*The highest point in tidal rivers to which mean tides (in Scotland, mean spring tides) flow at high water where there is no other feature present*". This definition is slightly ambiguous since it is not clear whether this limit includes the region influenced by the 'backwater effect' of freshwater building up in the lower river during high tide and potentially influencing the river level. It is not clear whether the upstream limit of tidal "flow" also refers to the limit to oscillations in tidal elevation since the limit of tidal flow and tidal elevation change are not necessarily in the same location. Further, it is unclear how tidal movements are assessed independently of atmospheric sea-level fluctuations, such as storm surge set-up, wave-tide interactions, coastal wind effects and influences of freshwater, since astronomical tides and atmospheric sea-levels are inherently linked, and normal and extremes of these characteristics are continuously changing with consequences on thresholds such as "mean tides". Further ambiguities arise from other (contradictory) definitions of NTL that have been presented on the UK Government website and related documents (e.g. https://www.gov.uk/guidance/marine-licensing-definitions). However, in this study we have assumed the Ordnance Survey definition of NTL as quoted above.

2. Methods

Two RBRsolo3 pressure sensors were deployed by Bangor University at the locations depicted in Figure 1: Mooring-1 was on Rhydygarnedd Farm's Broadwater marsh (258599.8 East, 302732.5 North, referenced to OSGB36) and Mooring-2 was opposite Rhydygarnedd Farm in the lower Dysynni river (259010.4 East, 302533.4 North). Both moorings were deployed on 2021-01-12 09:00:00 and retrieved on 2021-05-20 08:35:44 and successfully recorded water pressure every second for the duration of this period. DGPS loggers (Leica System 1200) were also placed at each mooring to record the height reference level of each pressure logger.

In addition to the pressure sensor recordings, Dysynni river discharge and sea-level data were downloaded. River data was measured by a river gauge at Pont-Y-Garth (Station ID: 64002). Data covers Jan-May 2021 in 15-minute intervals and was provided by Natural Resources Wales (NRW). Sea-levels were measured at Barmouth tide gauge. Data covers Jan-May 2021 in in 15-minute intervals and was provided by the British Oceanographic Data Centre (BODC). All the above data is plotted in Figures 2-4.

In our results section, we have plotted time series of each data set. We have established from the pressure sensor data and sea-level data when the fluctuations in heights of each data set are in-phase, taking note of the high water level relative to mean high water (MHW), since this is assumed a key threshold from the Ordnance Survey NTL definition.

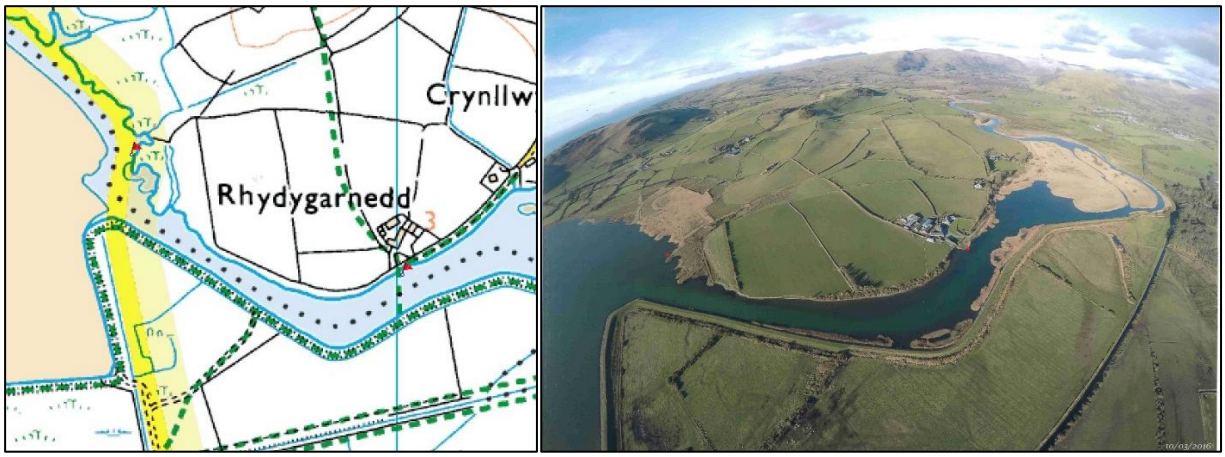

Figure 1: Ordnance Survey map (left) and aerial photo (right) showing the lower Dysinni and Broadwater, and locations of the pressure sensor Moorings-1 and -2 (red flags and red dots).

3. Results

3.1. Water levels at Mooring-2 (at Rhydygarnedd Farm)

Water levels at Mooring-2 fluctuated at a tidal frequency during spring tides, of the order 10 cm, but did not fluctuate during mean or neap tides. This is shown in Figure 2, denoted by the periods within the nine yellow boxes in the bottom panel. These periods each lasted approximately one week and coincided with spring tides. Importantly, for every time that the Mooring-2 water level fluctuated at a tidal frequency, the high water level (measured at Barmouth and assumed similar for the tidal entrance to the Dysynni) was greater than mean high water (MHW). This means that mean tides (or lower) did not influence the water level at Mooring-2.

Although our data shows that water levels fluctuated at a tidal frequency during spring tides, the behaviour of the change in elevation was markedly non-tidal. This is shown in Figure 3, which is a zoomed-in section of the data shown in Figure 2, during the spring tides of 25 April – 04 May 2021. Notably, the gradient of the rise and fall of the water elevations does not match that of the tidal elevations. This suggests either non-linear modification of the tidal signal due to interactions with the riverbed, or the backwater effect, whereby freshwater builds-up upstream of the tidal influence and then flushes out as the tide recedes – or a combination of these processes. Since the gradient of the water level rise was more gradual than that of the flooding tide, we have assumed at least some backwater effect, since non-linear tidal modifications due to shallow water tidal progression steepens the gradient of the rising tide (rather than flattens as seen here).

Interestingly, the period in late January 2021 was very wet with high river discharge – peaking at 97 m^3/s, which is well in excess of the 90^{th} percentile flow. During this period, the water level at Mooring-2 was not visibly influenced by fluctuations at a tidal frequency. The latter period (February to May 2021) was particularly dry with long periods without rain and mainly very low river flows. Hence, the water level fluctuations at a tidal frequency during this period can be considered maximal, especially since several high tides were some of the largest of the year and in excess of MHWS (e.g. during late May 2021). This survey period therefore covers a large range of river discharge conditions.

3.2. Water levels at Mooring-1 (at Rhydygarnedd Farm's Broadwater marsh)

Water levels at Mooring-1 on Rhydygarnedd Farm's Broadwater marsh are compared with those of Mooring-2, in Figure 4. There are two striking features of this data. Firstly, the water levels are similar between the two data sets. Secondly, the data implies strongly that the Broadwater does not drain on a tidal frequency – it remains full of water throughout the year. There are higher frequency fluctuations within the Bradwater data set, presumably caused by surface wind effects, or potentially other processes such as seiche waves, or fluctuations generated by uncertainties in the measurements.

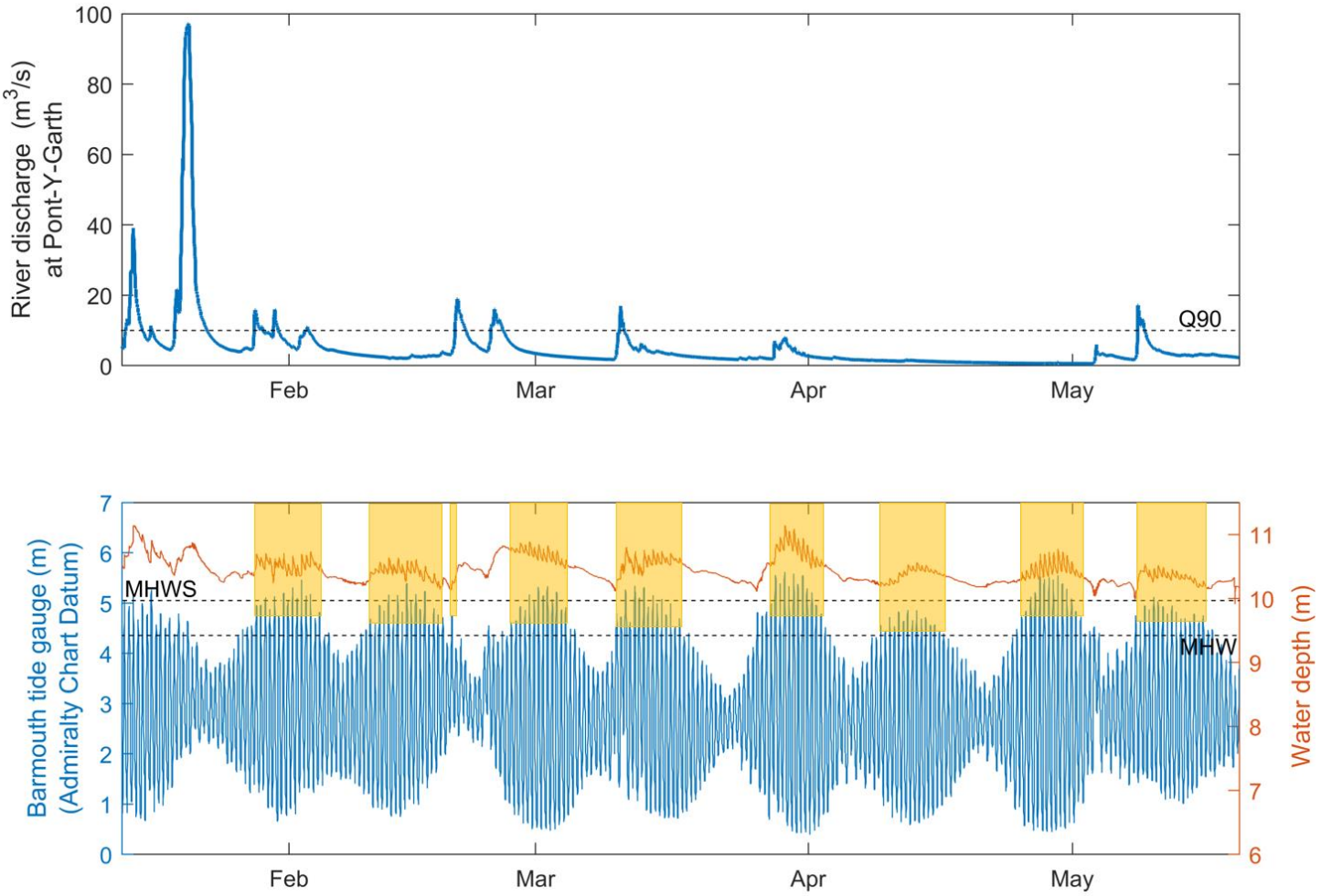

Figure 2: Top panel: *River discharge (blue curve, in m^3/s), measured at Pont-Y-Garth (Station ID: 64002). Data covers Jan-May 2021 in 15-minute intervals and was provided by Natural Resources Wales (NRW). The black dashed line represents the 90^{th} percentile discharge during the period 1966-2001.* ***Bottom panel:*** *Water depths (orange curve, in m), measured at Mooring-2 (opposite Rhydygarnedd Farm, see Fig. 1). Data covers Jan-May 2021 in 1-second intervals and was measured by Bangor University. Sea levels (blue curve, in m relative to Chart Datum), measured at Barmouth tide gauge. Data covers Jan-May 2021 in in 15-minute intervals and was provided by the British Oceanographic Data Centre (BODC). The upper dashed line represents mean high water springs (MHWS) and the lower dashed line represents mean high water (MHW). The widths of the nine yellow shaded boxes covers each time period where the water depths at Mooring-2 were influenced by high tide, and the lower level of each yellow box denotes the minimum high hide level during that period (for example, the first yellow box shows that water depths at Mooring-2 were influenced by the tide from 28 January to 4 February and the minimum high tide level during this period was 4.7 m, which is 0.35 m above MHW).*

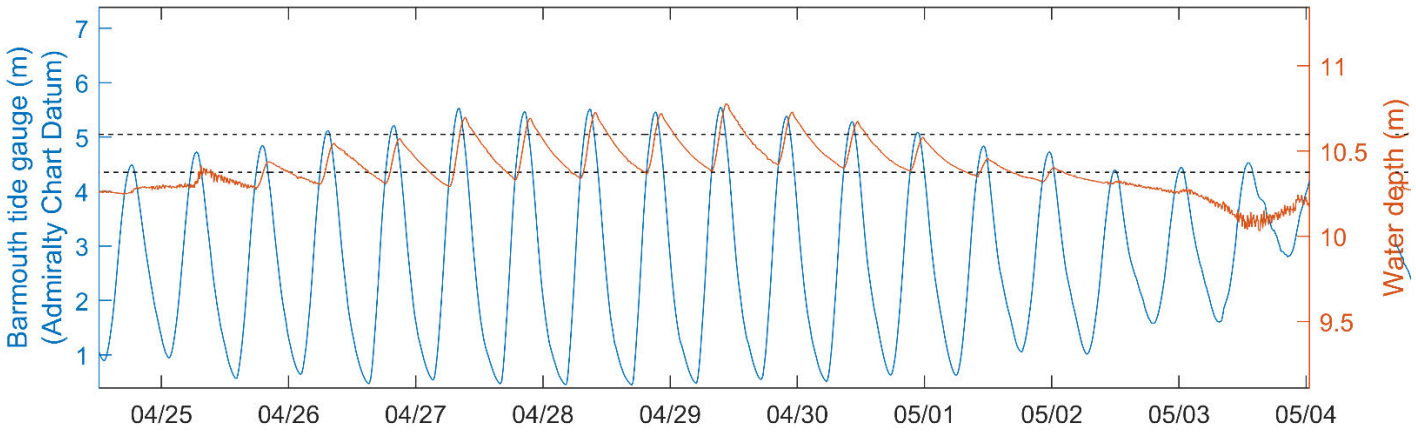

Figure 3: *Zoomed-in period (25 April – 04 May 2021), showing Water depths (orange curve, in m), measured at Mooring-2 (opposite Rhydygarnedd Farm, see Fig. 1) and sea levels (blue curve, in m relative to Chart Datum), measured at Barmouth tide gauge. The upper dashed line represents mean high water springs (MHWS) and the lower dashed line represents mean high water (MHW).*

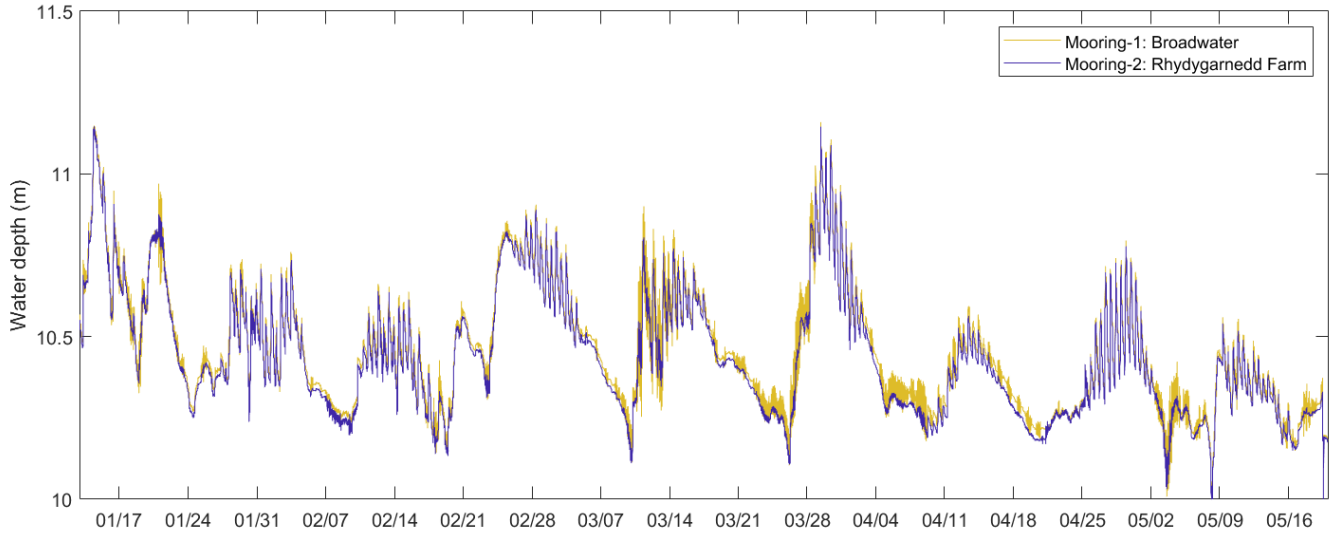

Figure 4: *Water depths (in m), measured at Mooring-1 (Rhydygarnedd Farm's Bradwater marsh, see Fig. 1) and Mooring-2 (opposite Rhydygarnedd Farm, see Fig. 1). Data covers Jan-May 2021 in 1-second intervals and was measured by Bangor University.*

4. Conclusion

Water levels at Mooring-2, opposite Rhydygarnedd Farm, fluctuated at a tidal frequency during spring tides, of the order 10 cm, but did not fluctuate during mean or neap tides. The period of observation covered a full range of river discharge conditions, from one of the largest events on-record (flows peaking at 97 m^3/s), to periods of minimum flows that lasted several weeks. From these results, we can assume that water levels at Mooring-2 are upstream of the position of the normal tidal limit (NTL).

Our assessment is based on the Ordnance Survey definition of NTL (see section 1) with further assumptions that the upstream limit of tidal flow and tidal elevation changes occur at the same location. Our assessment comes with a degree of uncertainty, but is a robust estimate using high-resolution data over several months and given the ambiguities within Ordnance Survey's definition of NTL. Total sea-levels used here (from the Barmouth tide gauge) consist of astronomical tide levels plus atmospheric water levels (which usually increased total sea-level from astronomical levels during this survey). Therefore, our estimate is thought to be conservative given the measured fluctuations at a tidal frequency during spring tides at Mooring-2 may be due instead to the backwater effect rather than "tidal flow" and hence we are confident in our assessment that this is beyond the normal tidal limit. Further clarification on the contribution of the backwater effect at the river-estuary transition zone is required for a more precise assessment of NTL. We also acknowledge that the mean high water level might change in the future due to several factors and this would therefore change the position of NTL.

Finally, we have shown that the waters on Rhydygarnedd Farm's Broadwater marsh, on the eastern shores of the Broadwater of the Dysynni (Mooring-1), behave similarly to the waters at Mooring-2 in the lower river opposite Rhydygarnedd Farm – and that the Broadwater volume predominantly fluctuates in response to river inputs rather than tidal exchange.