

Measurements of near-bed current, suspended sediment concentration and waves at the Milford Haven Maerl bed

Report No: 962

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Crynodeb gweithredol

Algâu coch cwrelaidd sy'n tyfu'n araf yw maerl. Mae'r unig wely maerl y gwyddom amdano yng Nghymru yn Aberdaugleddau, o fewn ACA Morol Sir Benfro. Comisiynodd Cyfoeth Naturiol Cymru waith i gasglu data cerrynt a chymylogrwydd yn union uwchben y gwely ar y safle er mwyn helpu i ddeall cyflwr y gwely maerl. Gall newidiadau i amodau hydrodynamig a chael eu mygu gan waddodion mân, effeithio'n negyddol ar welyau maerl.

Rhwng 04/12/2025 a 14/01/2026, mesurwyd ceryntau gan ddefnyddio Mesurydd Cyflymder Doppler Acwstig (ADV) ar ffrâm, wedi'i leoli ochr yn ochr â dau synhwyrdd 'backscatter' optegol (OBS) i fesur crynodiadau gwaddodion crog (SSCs). Yn ogystal, bu synhwyrdd gwasgedd yn mesur dyfnder y dŵr ac amodau'r tonnau. Yn ystod y cyfnod pan oedd yr offer yn cael ei ddefnyddio, cafwyd tywydd ansefydlog ar gyfer rhan gyntaf mis Rhagfyr, a oedd yn cynnwys gwyntoedd cryfion a glaw o'r de-orllewin. Achosodd yr amodau hyn gynnydd lleol mewn uchder tonnau arwyddocaol yn ogystal â lefelau dŵr uwch mewn afonydd (gan arwain at lwythi gwaddodion afonol uwch) sy'n bwydo i mewn i Aberdaugleddau. Roedd diwedd mis Rhagfyr yn dawelach gyda gwyntoedd ysgafn gogledd-ddwyreiniol ac ychydig iawn o law. Cafwyd mwy o law a gwynt eto ym mis Ionawr.

Roedd cyflymderau'r ceryntau yn union uwchben y gwely yn dangos signalau llanwol lled-ddyddiol a lleuadol misol. Roedd llifoedd llorweddol o hyd at 0.3 m/s yn bresennol yn ystod y gorllanw mwyaf. Mewnllif y llanw, yn hytrach na'r trai, oedd yn dominyddu, gyda lefelau brig uwch ar y llanw sy'n dod i mewn. Dengys amodau hydrodynamig cyhoeddedig ar gyfer gwelyau maerl hysbys y DU ystod eang o geryntau (0.5 i 1.5 m/s), tra gall safleoedd yn Ffrainc fod mor araf â 0.02 m/s. Felly, mae'r data hydrodynamig o Aberdaugleddau yn cyd-fynd ag arsylwadau eraill o lif ceryntau mewn cynefinoedd gwelyau maerl.

Roedd amrywioldeb cyfyngedig SSC y samplau a gasglwyd i'w graddnodi, yn atal graddnodi OBS; mae hyn yn cyfyngu ar y casgliadau meintiol y gellir eu tynnu o'r data OBS. Canfuwyd bod gwerthoedd OBS cynyddol, a ddefnyddiwyd fel procsi ar gyfer SSC, yn cyfateb i'r tonnau uwch ar ddechrau mis Rhagfyr. Mae'r SSCs uwch hefyd yn cyd-fynd â chynnydd mewn llif afonydd. Er bod rhywfaint o arwydd o fodiwleiddio cymylogrwydd yn gysylltiedig â'r signal misol lleuadol, roedd signalau eraill (tonnau, mewnbwn afonol) i'w gweld yn dominyddu. Roedd signal llanwol lled-ddyddiol yn amlwg yn y data OBS: dangosai'r signal lled-ddyddiol lefelau brig mewn cymylogrwydd ar y llanw sy'n mynd allan, yn union cyn y llanw isel.

Mae lefelau brig lled-ddyddiol yng nghyflymder y cerrynt a chymylogrwydd wedi'u camosod, sy'n awgrymu nad yw cymylogrwydd fel arfer yn cael ei achosi wrth i waddodion lleol gael eu symud eto yn y safle lle mae'r gwaith mesur yn digwydd. Mae ystyried diriant croesrym cyfunol tonnau-cerrynt y gwely a gwerth critigol diriant croesrym y gwely ar gyfer y gwaddodion lleol yn cadarnhau hyn: dim ond pan geir gorllanw a thonnau mawr yr eir heibio'r gwerth critigol ar gyfer symudiad gwaddodion. Mae'n bwysig cydnabod bod y canlyniad hwn yn dangos na fyddai unrhyw waddodion lleol a fyddai'n setlo ar y maerl yn cael eu symud eto'n gyflym ac felly gallai fygu'r maerl.

Mae'n ymddangos bod y data yn dangos bod cymylogrwydd yn cael ei lorfudo dros y gwely maerl o ran uchaf yr afon, fodd bynnag, ni ellir pennu ffynhonnell y cymylogrwydd o'r mesuriadau hyn. Dylai gwaith a wneir yn y dyfodol bennu paramedrau natur gwaddodion crog yn yr aber yn well a fyddai'n caniatáu gwell dealltwriaeth o ffynhonnell y gwaddodion a'r tebygolrwydd y byddant yn setlo ar y gwely maerl..

Executive summary

Maerl is a slow growing coralline red algae, the only known maerl bed in Wales is at Milford Haven, within the Pembrokeshire Marine SAC. Natural Resources Wales commissioned collection of near-bed current and turbidity data at the site to help understand maerl bed condition. Changes to hydrodynamic conditions and smothering with finer sediments can negatively affect maerl beds.

Between 04/12/2025 and 14/01/2026, currents were measured using a frame-mounted Acoustic Doppler Velocimeter (ADV), co-located with two optical backscatter sensors (OBS) to measure suspended sediment concentrations (SSCs). Additionally, a pressure sensor measured water depth and wave conditions. The deployment period was characterised by unsettled weather for the first part of December which included strong south westerly winds and rain. These conditions caused both localised increases in significant wave height and higher river water levels (leading to higher fluvial sediment loads) that feed into Milford Haven. The end of December was calmer with light north-east winds and little rainfall. Further rain and wind occurred in January.

Near-bed current velocities showed both semi-diurnal and spring-neap tidal signals. Horizontal flows of up to 0.3 m/s were present under the largest spring tides. Currents were flood dominant, with larger peaks on the incoming tide. Published hydrodynamic conditions for known UK maerl beds indicate a wide range of currents (0.5 to 1.5 m/s), while French sites can be as slow as 0.02 m/s. Therefore, the hydrodynamic data from Milford Haven aligns with other observations of current flows at maerl bed habitats.

Limited variability in SSC of samples collected for calibration, prevented OBS calibration; this restricts the quantitative conclusions that can be drawn from the OBS data. Increased OBS values, used as a proxy for SSC, were found to match to the larger waves at the start of December. The higher SSCs also align with increased river flows. While there was some indication of spring-neap modulation of turbidity, other signals (waves, fluvial input) seemed to dominate. A semidiurnal tidal signal was evident in the OBS data: the semi-diurnal signal showed peaks in turbidity on the outgoing tide, just before low tide.

Semi-diurnal peaks in current speed and turbidity are out of phase, suggesting turbidity is not normally due to local re-suspension at the measurement location. Consideration of the combined wave-current bed shear stress and the critical value of bed shear stress for the local sediment corroborates this: it is only under spring tides and large waves that the critical value for sediment mobilisation is exceeded. It is important to recognise that this result indicates that any local sediment that was to settle on the maerl would not be quickly re-mobilised and hence might smother the maerl.

The data seems to show that turbidity is being advected over the maerl bed from upstream, however, the source of turbidity cannot be determined from these measurements. Future work should better parameterise the nature of suspended sediment in the estuary which would allow for understanding of sediment source and the likelihood of settlement on the maerl bed.

Introduction

Maerl is a purple-pink slow-growing (~1mm per year) corraline red algae, which grows as unattached nodules on the sea floor (Figure 2); they form complex underwater structures which contributes to the high biodiversity of maerl beds. Maerl is not a single species, but a collective term for several species; the primary scientific names for the species that make up maerl beds in Britain are *Phymatolithon calcareum*, *Lithothamnion corallioides*, and *Lithothamnion glaciale*.

The only known maerl bed in Wales is in Milford Haven (Figure 1), which is within the Pembrokeshire Marine SAC. The Milford haven bed is primarily composed of *Lithothamnion corallioides* although some *Phymatolithon calcareum* has also been observed; it is known that the Milford Haven maerl bed is genetically distinct and highly diverse compared to other UK populations and therefore loss would mean loss of irreplaceable genetic diversity (Jenkins *et al.* 2025).

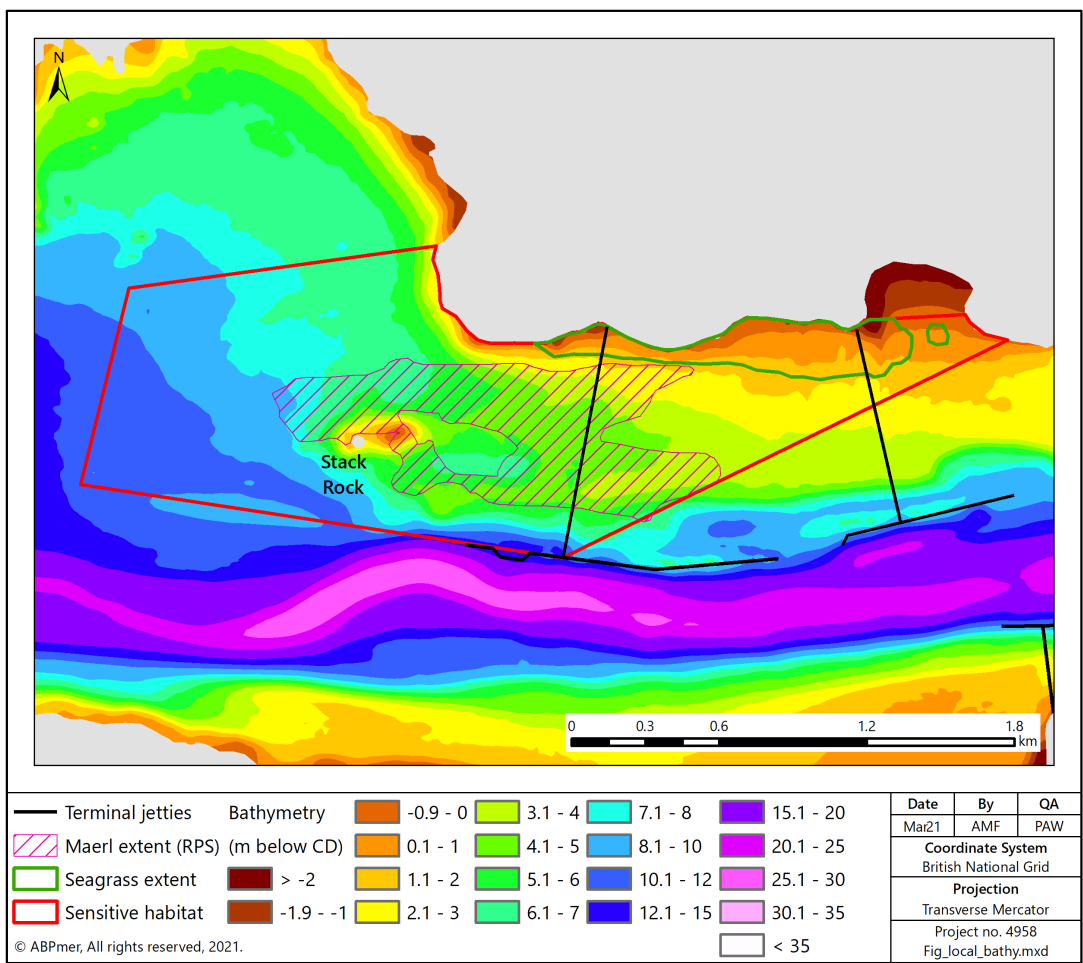


Figure 1. The location of the Maerl bed and bathymetry in Milford Haven, replicated from ABPmer, NRW Evidence Report 551 (unpublished report). Figure provided by NRW.

It is a species of conservation importance (Environment (Wales) Act Section 7 and OSPAR threatened and declining habitats and species). The maerl bed at Milford Haven sits within the Pembrokeshire Marine Special Area of Conservation (SAC) and is a part of two designated features of the site: 'large shallow inlets and bays' and 'estuaries' (Jackson-Bué *et al.*, 2025). Maerl is also a Section 7 habitat and *L. corallinoides* and *P. calcareum* are Section 7 species (Environment (Wales) Act, 2016).

The Marine Biological Association (MarLIN; marlin.ac.uk) has undertaken a review of maerl beds in the UK that provides a synopsis of the habitats and the sensitivity characteristics of the species. In general, the review highlights the importance of suitable flow conditions to ensure neither sediments are removed (too strong flows) nor siltation occur (too low flows). The review highlights the wide range of current flows present at different maerl beds e.g. In Brittany, France, maerl beds are found where the mean current velocity ranges from 0.02 to 0.73 m/s, with a maximum velocity reaching 1.71 m/s (Dutertre *et al.*, 2015; Melbourne *et al.*, 2018), while Connor *et al.*, 2004 records UK maerl beds at sites with between moderately strong (0.5 to 1.5 m/s) to very weak tidal streams. The report summarises the 'high' sensitivity of maerl habitats to changes in current flows giving them 'low' resilience to potential changes in hydrodynamic forcing (Perry *et al.*, 2017)

One of the primary risks to maerl is smothering by sediment, particularly fine sediment (Wilson *et al.*, 2004). Smothering can: block light, reducing the photosynthesis capacity of maerl; block the natural spaces between maerl nodules causing localised oxygen depletion and hydrogen sulphide production which is lethal to the maerl forming algae ([Maerl beds - MarLIN - The Marine Life Information Network](#)). Likelihood of smothering depends on the presence of suspended sediment in the water column and time periods of likely deposition and re-suspension. Therefore, understanding hydrodynamics and the turbidity regime is vital for conservation of maerl beds.

The Milford Haven maerl bed (Figure 2) has experienced a major decline in ecological condition since 2005, with evidence indicating a 71% reduction in live maerl cover and abundance (Mercer *et al.*, *in press*), accompanied by significant declines in associated biodiversity between 2005 and 2010, although some recovery in biodiversity was observed in 2016 (Bunker and Ratcliffe, *in press*). This evidence was submitted for the Fourth UK Article 17 Habitats Directive reporting cycle, based on repeat diver and drop-down video surveys undertaken between 2005 and 2017 (JNCC, 2019). While the physical footprint of the maerl gravel bed has remained broadly unchanged, the bed has shifted. In 2005, some areas supported up to 40% live maerl cover; however, by 2023, the maximum live cover recorded was only 10%, indicating substantial habitat degradation.

Milford Haven, Pembrokeshire, is the UK's largest cluster of energy-related businesses, handling approximately 20% of the UK's energy requirements and up to 30% of UK gas demand. The most likely drivers of change in the maerl population are sediment-related pressures, particularly those associated with dredging, construction activities and other sources of fine sediment deposition. Although direct causation has not been conclusively demonstrated, the evidence suggests that pressures associated with increased sedimentation and physical disturbance have contributed to the observed decline.

The period of greatest deterioration coincided with intensive dredging and construction activity within Milford Haven. Major changes in the maerl bed also coincided with when refurbishment works at the South Hook jetty were undertaken (constructed between 2004-2008 and operational since 2009). In 2006, dredging volumes reached their highest level since 1985, with approximately 232,227 m³ dredged, including 106,273 m³ associated with Valero maintenance dredging and 31,888 m³ associated with the South Hook channel capital dredge (MHPA, 2021).

This project aims to improve understanding of the sensitivity of Milford Haven maerl beds to increased sedimentation and to strengthen the evidence base for future vulnerability assessments and conservation management plans. The focus of the work was on data collection, presentation and initial analysis rather than in-depth interpretation



Figure 2. Generally, more live maerl is found on the crests of sand wave bedforms (which appear to be stationary features). Replicated from ABPMer, NRW Evidence Report 551 (unpublished report) provided by NRW.

Method

Natural Resources Wales (NRW) contracted CMAR to undertake data collection and initial analysis of hydrodynamic conditions around a chosen maerl bed in Milford Haven, Wales.

The agreed data collection included:

- Acoustic Doppler Velocimeter (ADV)
 - Provides near-bed water current speed and direction
- Optical Backscatter Sensor (OBS)
 - Provides an indication of suspended sediment within the water column
- Pressure Transducer (PT)

- Provides a record of the tidal stage and wave conditions during the deployment
- Water sample collection at site
 - Provides a calibration measure against the OBS dataset for the suspended sediments recorded.

The project required the ADV to be fixed to a bedframe (Figure 3) which was deployed at an agreed site. Alongside the ADV, two OBS sensors were installed on the same bedframe and separated vertically off the bed. To calibrate the OBS dataset water samples were collected during deployment and recovery using a subsurface sampler (Niskin bottle; Figure 4).



Figure 3. Instrument frame used to support the ADV and OBS sensors on the seabed. A surface marker buoy was attached to the frame for recovery and instrument visibility.



Figure 4. Niskin bottle used to collect sub-surface water samples from the area of the OBS sensors.

The instrument frame was deployed using a dedicated vessel specially equipped to deploy and recover scientific equipment:

- Vessel Operator: **Haven Marine Surveying**
(<http://www.havenmarinesurveying.co.uk/>)
- Vessel: **Sea Leopard** (Figure 5)
- Home Port: **Neyland Marina**

Once the vessel was on site, prior to deployment, an underwater camera was used to inspect the seabed to ensure the proposed location was suitable and would not impact on any live maerl. Recovery of the rig was planned for the 6th of January; however, shipping activity meant the pier was restricted to any vessel movements and recovery was not possible. A second, successful attempt was made on January the 14th providing five weeks of data at the site.



Figure 5. Sea Leopard operated by Willie from Haven Marine Surveying

Instrumentation settings

The ADV was programmed to sample in burst mode, every 30 minutes, collecting 2400 samples per burst at a frequency of 4Hz (10 minutes). The full deployment settings are provided in Appendix A.

- Sampling rate 4 Hz
- Burst interval 1800 sec
- Samples per burst 2400

The sensors were mounted in the following configuration:

- ADV head = 35 cm off bed, sample volume is 15.7 cm below the head.
- OBS1 = 20 cm off bed
- OBS2 = 34.5 cm off bed

The ADV provides data in x, y, z format. The ADV head was aligned with the body of the instrument, which contains a compass, to provide an orientation relative to East and North (z is upwards). The unit body 'Heading' was steady throughout the deployment at $\sim 72.4^\circ$. Therefore, the directions of the x, y, current data are:

- X = 72.4° , positive = ENE, negative = WSW
- Y = 342.4° , positive = NNW, negative = SSW
- Z = vertical flows, positive = upwards, negative = downwards

After arrival on site a subsurface camera was used to inspect the proposed deployment site to ensure that the planned deployment location was suitable i.e. no evidence of live maerl beds. Once confirmed the instrument rig was deployed at (Figure 6):

- Grid Reference (6 figure): **SM874050**
- X (Easting) , Y (Northing): **187477 , 205007**
- Latitude , Longitude (decimal): **51.703450 , -5.0771000**
- Latitude , Longitude (degs, mins, secs): **51°42'12"N , 005°04'38"W**

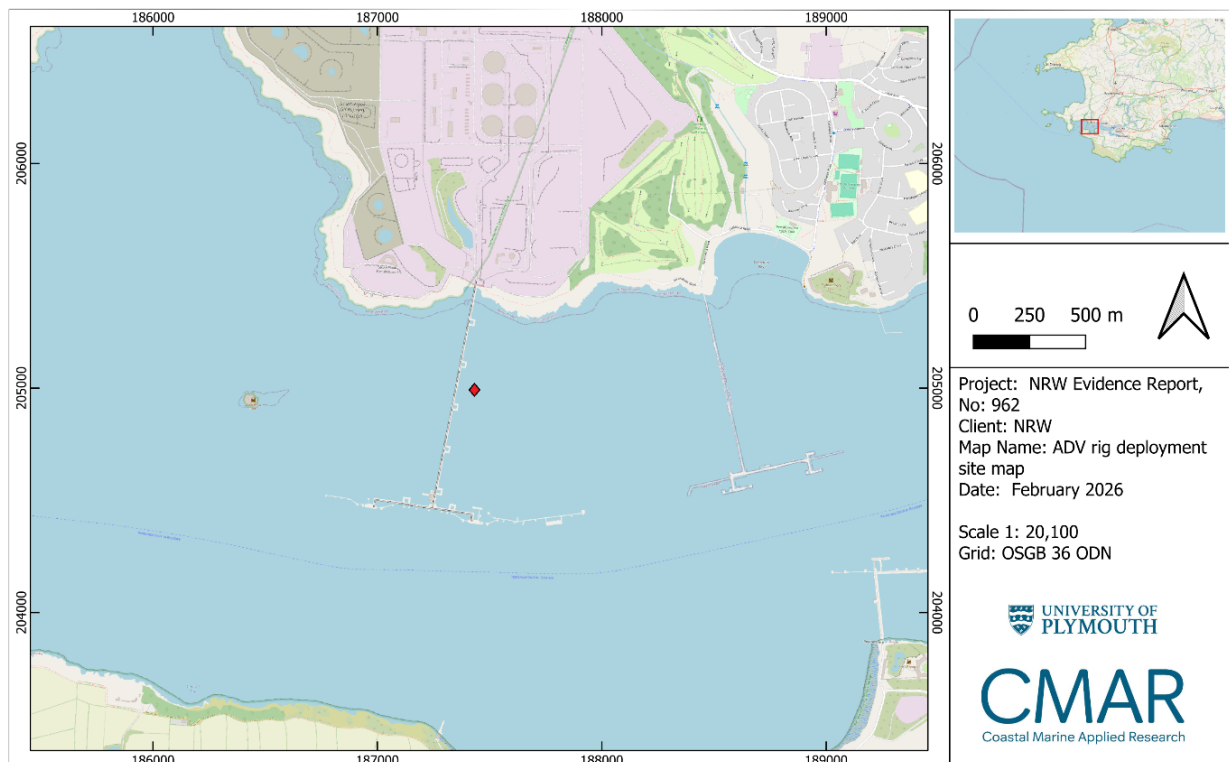


Figure 6. A map of showing the location of the deployment site for the frame (red diamond).

Data processing

Once the instrument rig was recovered all datasets were reviewed before QC was undertaken to remove outliers and unreliable data points.

All data

- Removal of data pre and post deployment
- Removal of outliers
- Removal of data >3 times the standard deviation of each burst

ADV

- Removal of data where the amplitude of the signal is <55
- Removal of data where the correlation of the signal is <70

Pressure

- Correction of the pressure signal using a local atmospheric record to derive water depth. The pressure signal was also corrected for attenuation due to water depth.

For all timeseries data a 'clean' dataset was generated as well as an average value for each ten-minute sample burst to provide easier comparison of the parameters.

To provide analysis of the wave-current interaction and the OBS readings the combined wave-current shear stress was computed for the burst data. This was computed using the Grant-Madsen (GM) model (Grand and Madsen, 1979). The approach computes the shear stress from currents and wave separately before providing a value that represent the combined bottom shear stress. For each data burst the wave height (H_s), period (T) and water depth (h) are combined with near-bed current velocities derived from the ADV. Furthermore, the critical bed shear stress has also been computed using a given mean bed grain size (232 μm) as provided by NRW from the nearest previous sampling location to the frame position. For reference the full equations are provided in Appendix B.

The water samples were processed to provide a measure of the suspended sediment in the water column. A vacuum filtration method was adopted to capture the suspended sediment within the samples. Two samples were collected during the deployment and recovery of the frame. Each sample was filtered through a glass microfibre filter with a pore size of 1.2 μm . The filters were weighed before filtration and once dried to derive the sediment load per sample volume (g/L).

Results

The following results show that tidal currents at the maerl bed are at a moderate level (within the previously described range for maerl beds) and that the site experiences low to moderate waves exposure. Suspended sediment dynamics are primarily externally driven (turbidity advected into the site rather than re-suspended from within it). This is covered in detail below.

The timeseries of water depth, derived from the pressure signal, shows the spring – neap – spring tidal cycle present throughout the deployment period (Figure 7). Water depths at the site ranged from a minimum of 3.5 m to 10.5 m.

Significant wave height at the site (Figure 8), shows an active period for the first eighteen days, with waves up to $H_s = 0.55$ m followed by a period of very calm conditions for approximately fourteen days where wave heights were $H_s < 0.1$ m. The final eight days see conditions become slightly more energetic with $H_s = 0.3$ m (Figure 9).

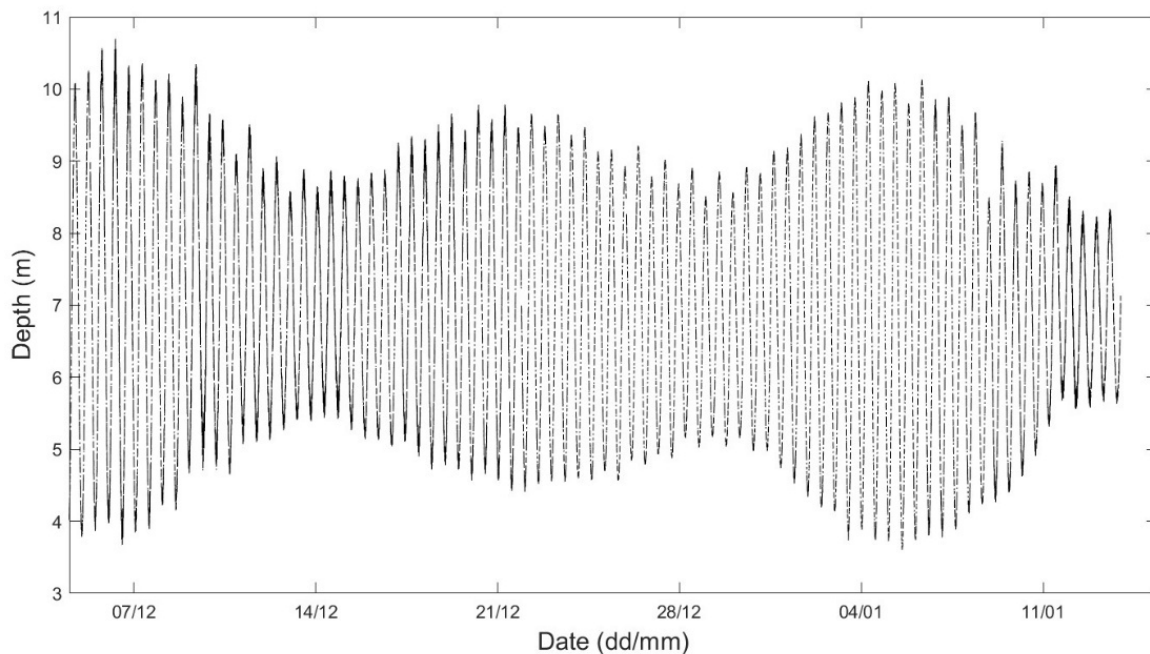


Figure 7. Timeseries plot of water depth (m) during the deployment period. Data points represent mean values of each ten-minute data burst.

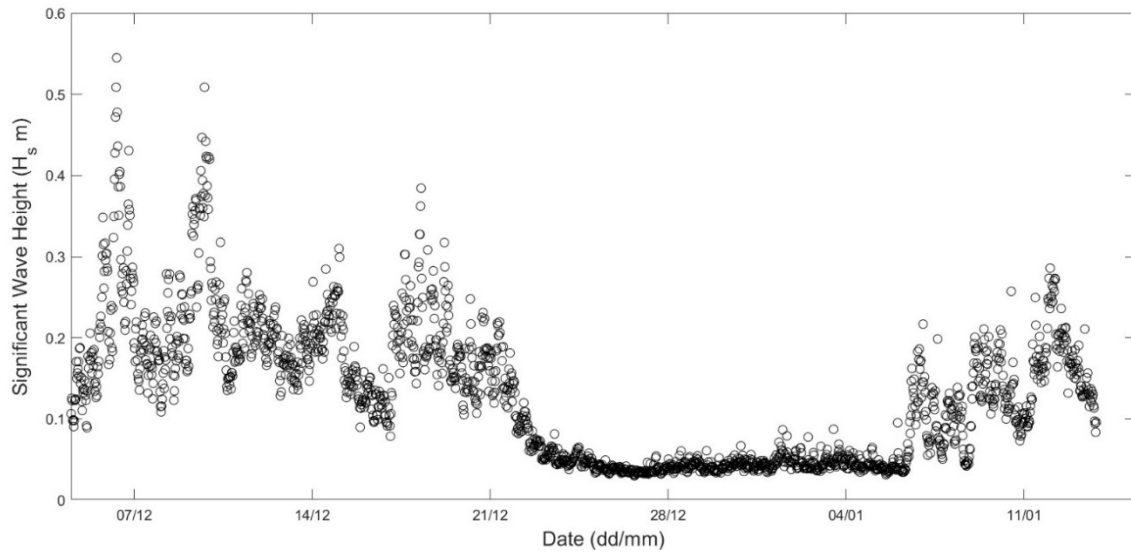


Figure 8. Time series of significant wave height (H_s) for each ten-minute data burst during the deployment period.

The ADV captures flow velocity in three dimensions (Figure 9). The horizontal 'x' component (top panel) represents ENE (positive) and WSW (negative) flows with burst average speeds reaching 0.3 m/s. The horizontal 'y' component (middle panel) represents NNW (positive) and SSW (negative) flows which peak at 0.2 m/s. Vertical flows ('z' component, bottom panel) exhibit some weak upward directed flows (positive) which peak at 0.02 m/s at the end of the deployment period. All three current flows exhibit a tidal modulation in the mean flow speed, both semi-diurnal (Figures 9 and 13) and due to the spring-neap cycle, with peak flows closely aligned with the spring phases of the deployment window (Figure 7). Figure 10 illustrates the spring-neap modulation by plotting timeseries of 24 hour smoothed current and 24hr tidal range (difference between high and low water).

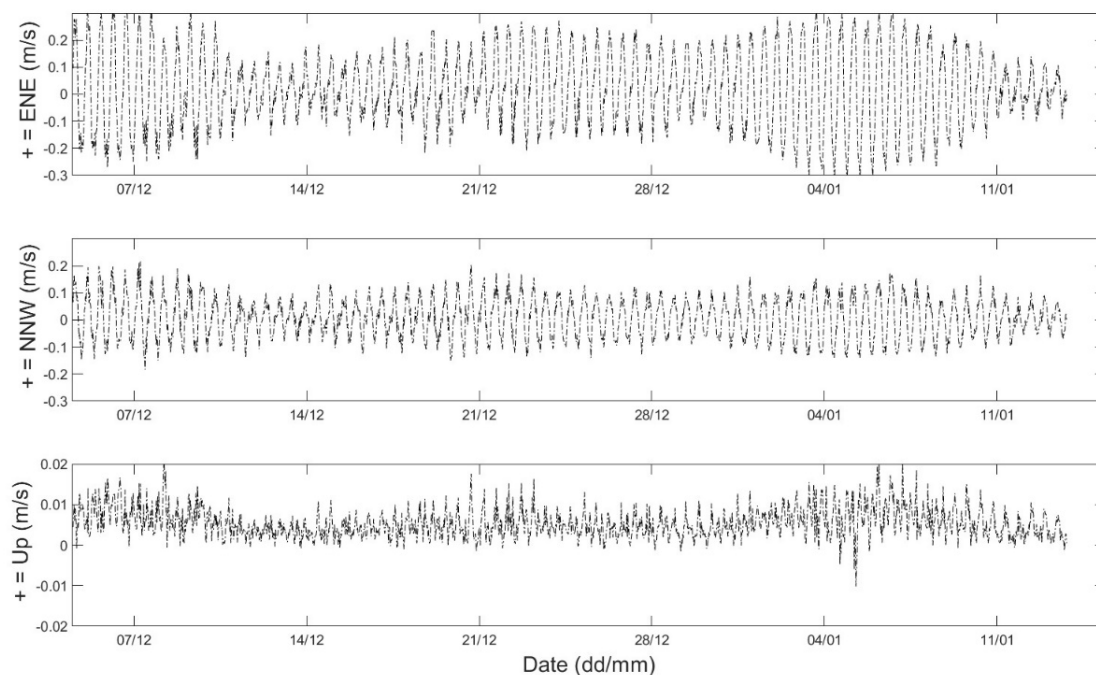


Figure 9. Time series of current velocities (m/s) recorded by the near-bed ADV. The top panel shows horizontal flow speeds for directions moving ENE (positive) or WSW (negative), the middle panel shows flow speeds for directions NNW (positive) and SSE (negative)

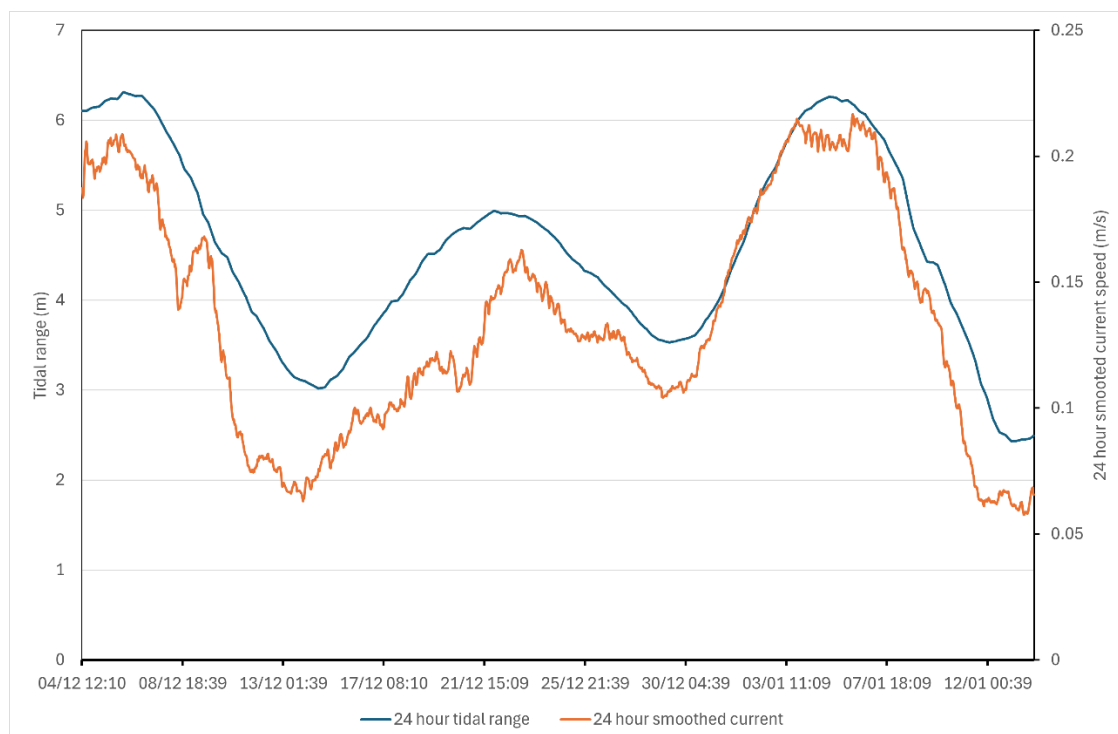


Figure 10. Timeseries of 24 hour smoothed horizontal current (m/s) and 24 hour tidal range (m).

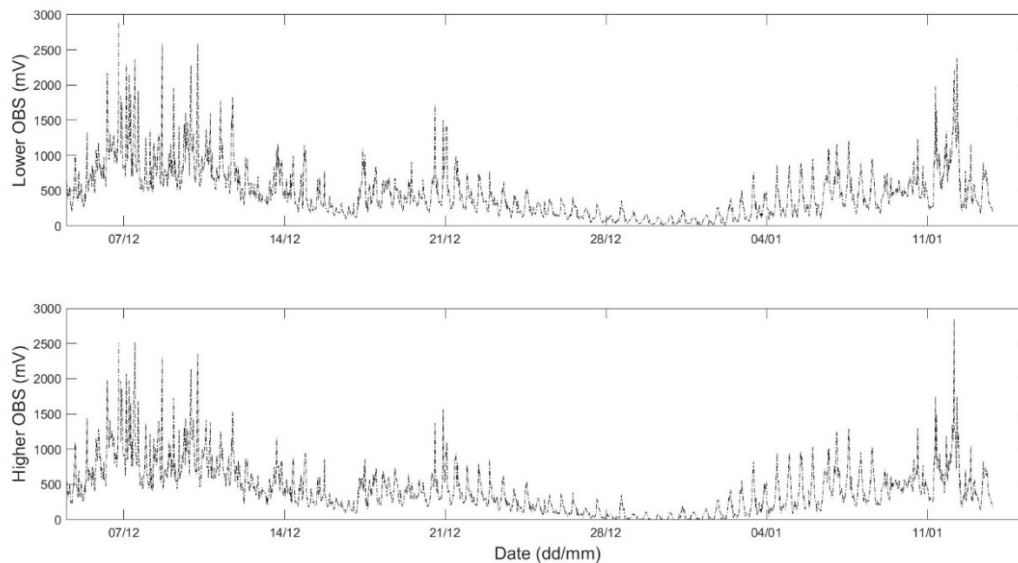


Figure 11. Mean OBS readings (mV) for each data burst during the deployment period. The top panel shows the OBS closer to the bed, the bottom panel is OBS2, further from the bed. The OBS readings can be taken as a proxy for turbidity, while noting that response becomes non-linear for higher mV values.

Suspended sediments present during the deployment can be inferred from the OBS sensors that were co-located with the ADV. Results from the two sensors (vertically separated) provide an overview of the variability in the sediment within the water column. Figure 11 provides a summary of the two datasets for the lower sensor (top panel) and the higher sensor (bottom panel). Both datasets present near identical variability over the five weeks with sustained peaks present between the 7th and 11th of December. A second peak is then evident on the 21st of December before conditions become calmer until the 12th of January when a third peak is evident (Figure 11).

The OBS readings shows some alignment with tidal flows. The second peak on the 21st aligned with the larger tides at this time; however, there is less obvious correlation with the larger tides at the start and end of the deployment (Figure 7). Figure 12 highlights this: while there are some indications of greater OBS values at spring tide periods, other signals are overlain on this and are more prominent.

Figure 13 provides a close up of the time series for both absolute horizontal current (upper two panels) and OBS trace (bottom two panels), with water level also displayed. Two periods are shown, one at the start of the experiment under spring tide conditions with large waves and high river flow conditions (left hand panels) and one period from 28th December during neap tides with low waves and low river flow conditions. For both the spring and neap cases, peaks in horizontal flow are greater on the flood tide. For the OBS traces, peaks in the trace are on the outgoing tide as the tide approaches low tide. A similar pattern is evident in the spring tide traces, though it is less clear due to additional peaks (presumably related to wave action or fluvial sources). The OBS traces have significantly higher values for the spring tide case, however as noted above it is not clear that this increase is only related to the spring tides or a combination of tidal and other forcing (Figure 13). A longer term record would better capture the importance of the spring-neap cycle.

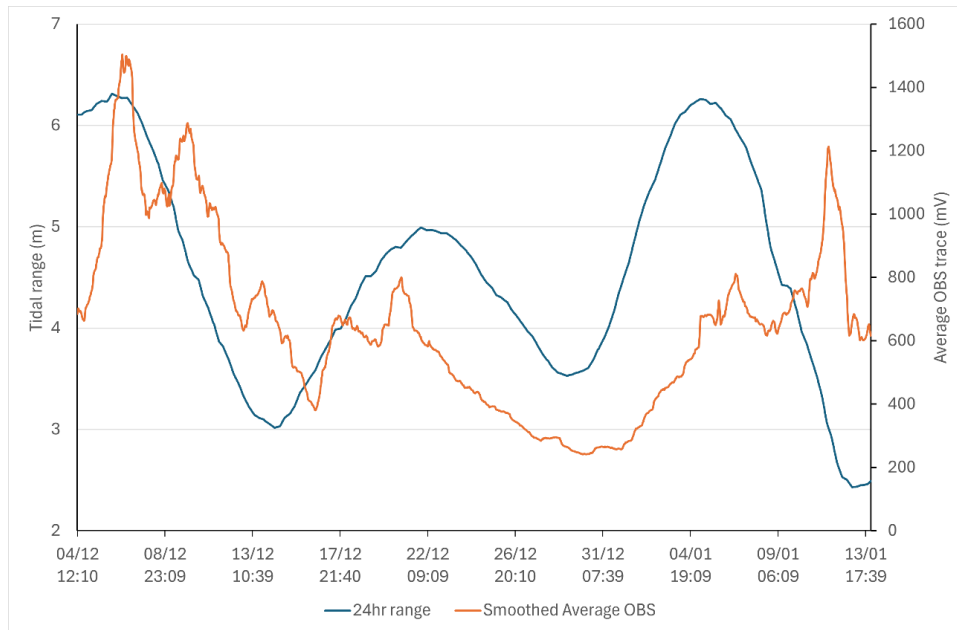


Figure 12. Timeseries of 24 hour tidal range (m) and 24 hour smoothed OBS readings (mV). The OBS readings can be taken as a proxy for turbidity, while noting that response becomes non-linear for higher turbidity.

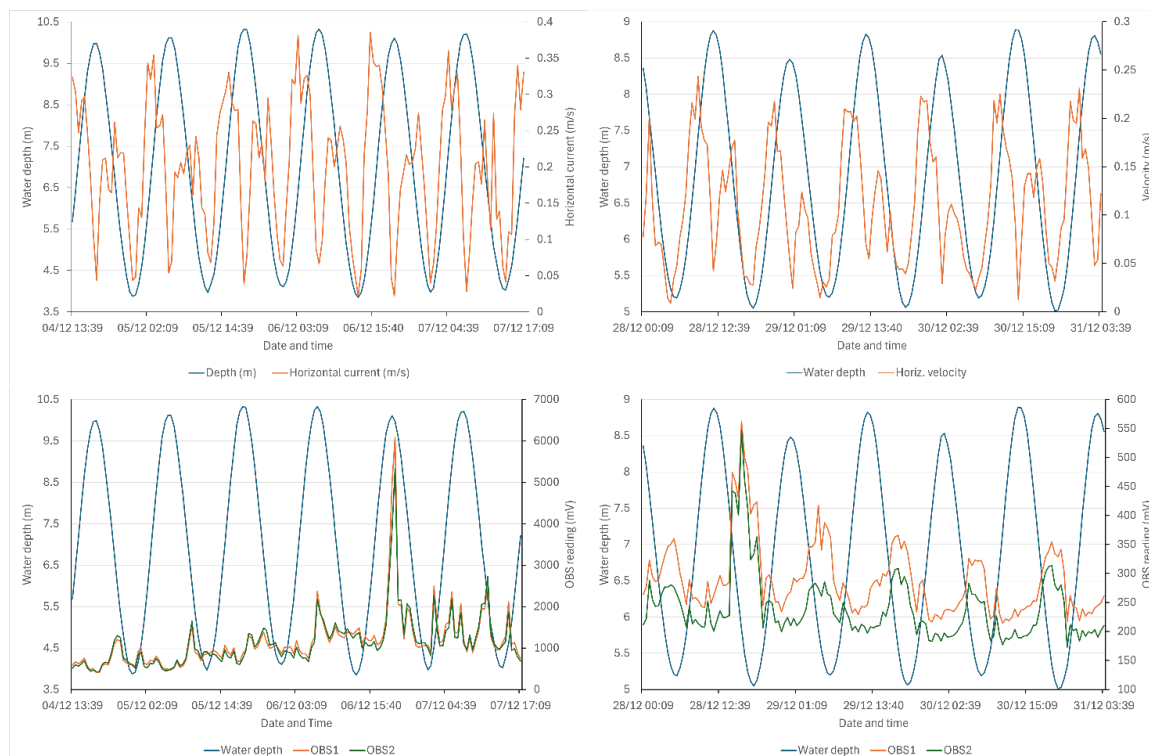


Figure 13. Close-ups of the timeseries for spring tide currents (top left), neap tide currents (top right), spring tide OBS (bottom left) and neap tide OBS (bottom right). The OBS readings can be taken as a proxy for turbidity, while noting that response becomes non-linear for higher turbidity.

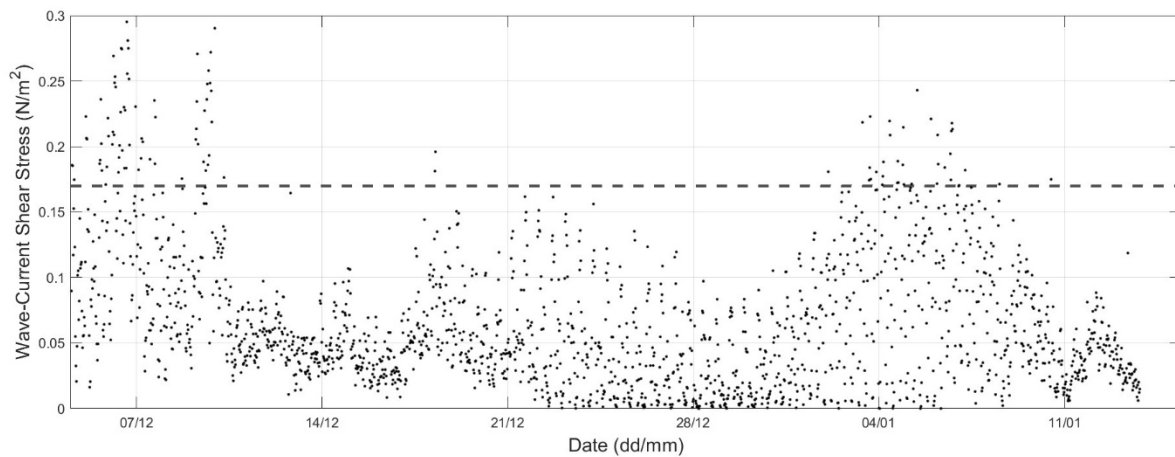


Figure 14. A timeseries of burst values for the combined wave-current bed shear stress. The horizontal dashed line shows the critical shear-stress value (0.17 N/m^2)

A closer relationship can be observed when considering the combined wave-current conditions during the deployment (Figure 14 and Figure 15). The relationship between wave-current shear stress (Figure 14) and suspended sediments, as represented by the lower OBS, is explored in Figure 15, below. While there is noise in the relationship, increased OBS readings are associated with more energetic conditions at the site, as we may likely expect. To aid in the interpretation the critical shear-stress has been added to Figure 14 and Figure 15 (Appendix B).

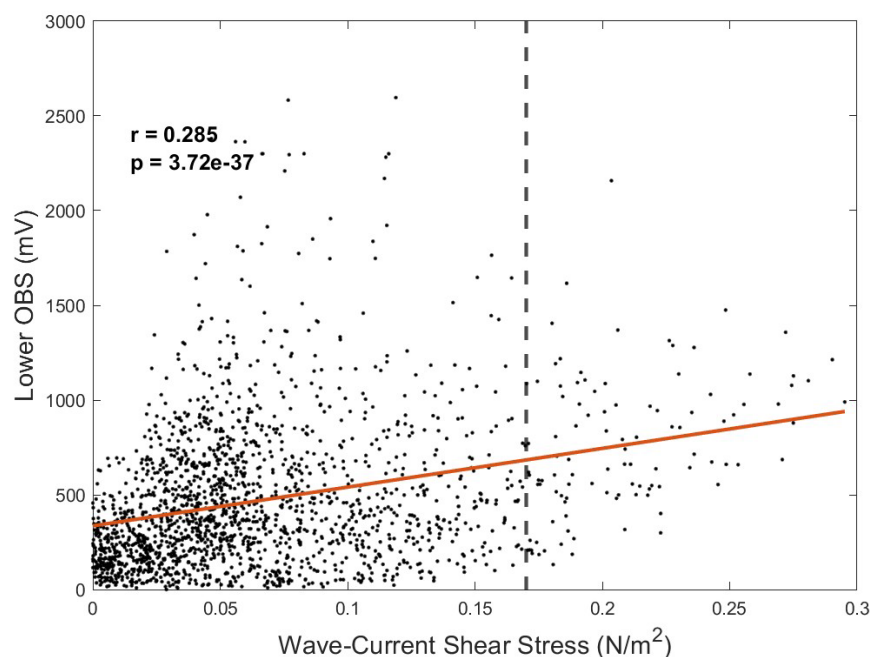


Figure 15. Wave-current shear stress (N/m^2) against the burst mean OBS data (OBS1, mV). The Pearson p and r -value for the data is shown in the plot. The dashed vertical line indicates the critical shear-stress value (0.17 N/m^2).

To further explore the possible relationship between the OBS values and the tidal signal we can perform a cross-correlation of the two datasets (Figure 16). This analysis aims to identify if there is an association between these parameters and if an association exists if there is a time-lag between the two. Figure 16 shows the cross-correlation for the lower (OBS1, top panel) and higher OBS (OBS2, bottom panel). The figures show a very noisy pattern (low correlation) with the highest correlation at or near a lag of 0 s, however the peaks are not that strong. This tells us the signals are not closely correlated and have no consistent time lag.

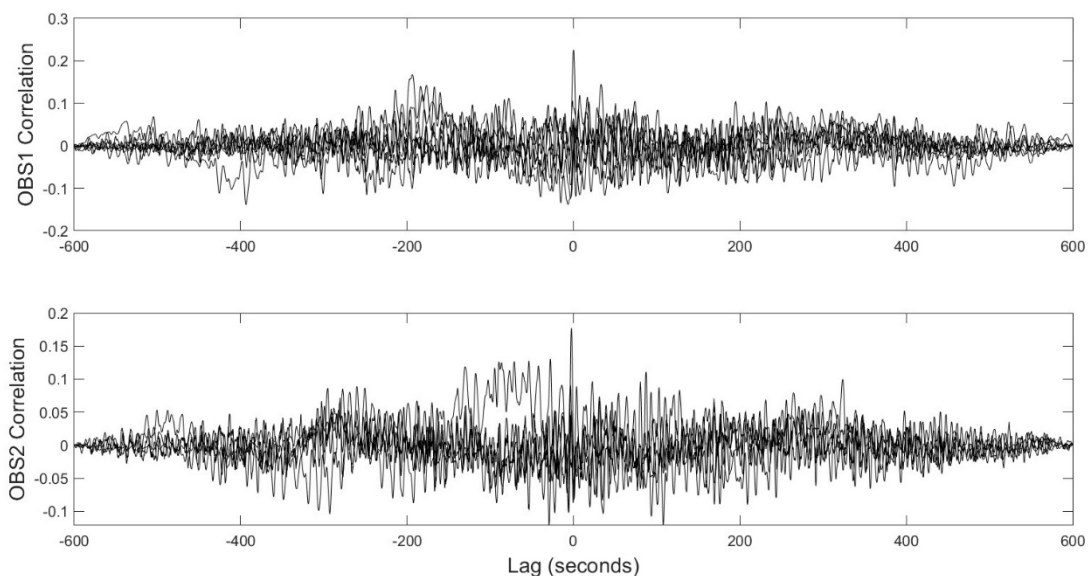


Figure 16. Cross-correlation analysis of **each burst** of the water level signal and the lower OBS (upper panel) and the high OBS (lower panel).

The same cross-correlation analysis can be performed with the horizontal flows and the lower OBS (OBS1, Figure 17) and the higher OBS (OBS2; Figure 18). The plots show the cross-correlation for **each ten-minute data burst** displayed as a timeseries to better display the data. There is a distinct peak at '0' which suggests the two datasets are correlated without a time-lag.

The trend observed between the lower OBS (OBS1) and the combined wave-current shear stress time series presented in Figure 15 is further confirmed through cross correlation of the two time series datasets in Figure 16. This shows a very clear peak at lag = 0 which indicates there is little delay between the increase in OBS readings and the wave-current interaction. Naturally, these are 10-minute time average (burst average) datasets and so the time lag is less reliable, but we can say that the two are responding on broadly the same timescale and reflect mixing of suspended sediments within the water column rather than wave by wave response.

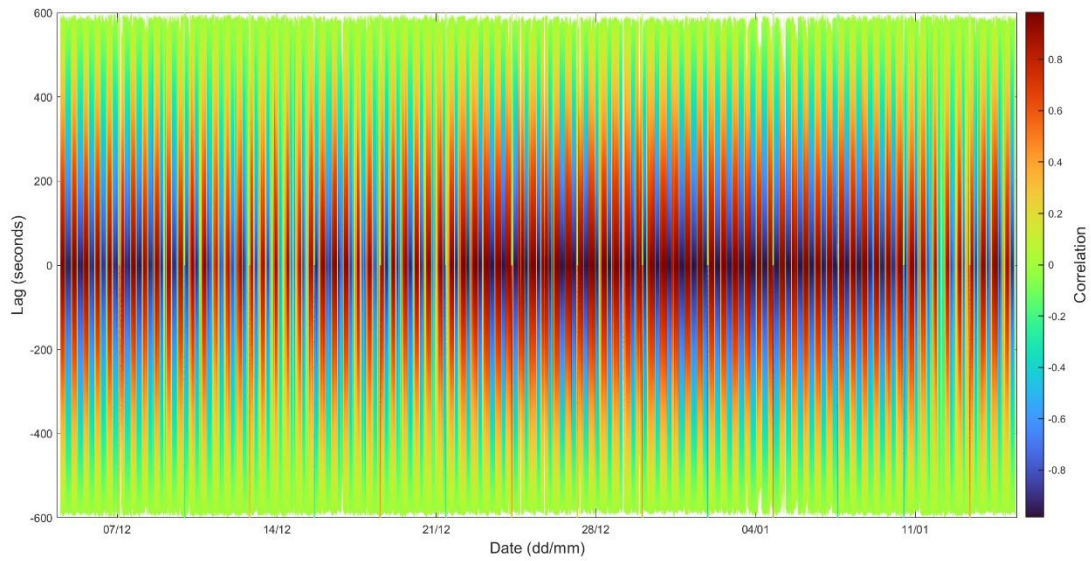


Figure 17. Timeseries plot showing the cross-correlation of **each burst** of the lower OBS (OBS1) with the 'x' component of the flow. The timeseries is on the horizontal axis and the intra-burst lag on the vertical axis, colour indicates correlation.

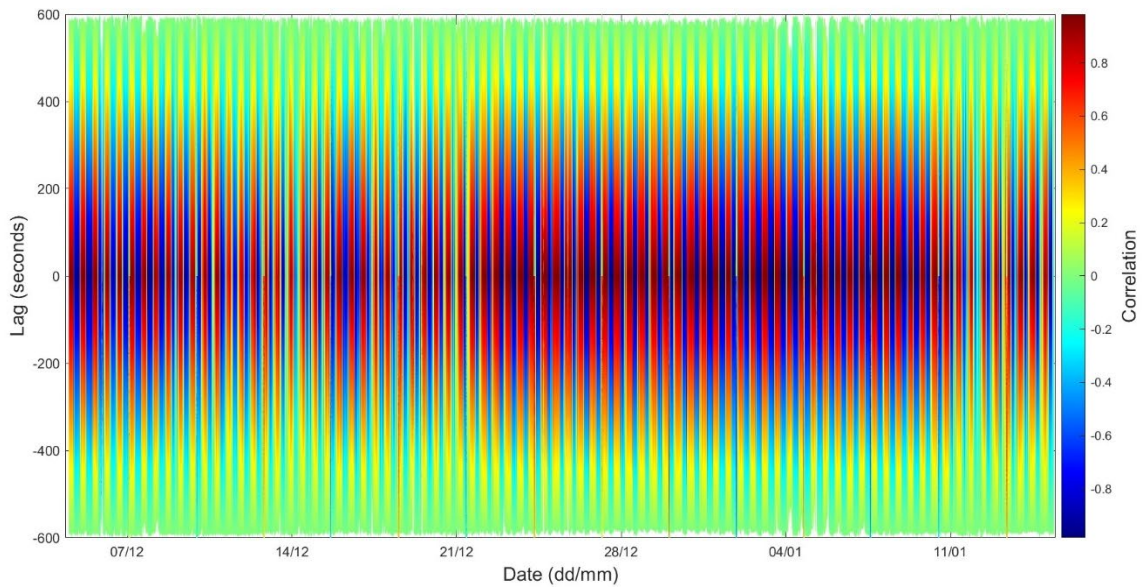


Figure 18. Timeseries plot showing the cross-correlation of **each burst** of the lower OBS (OBS2) with the 'x' component of the flow. The timeseries is on the horizontal axis and the intra-burst lag on the vertical axis, colour indicates correlation.

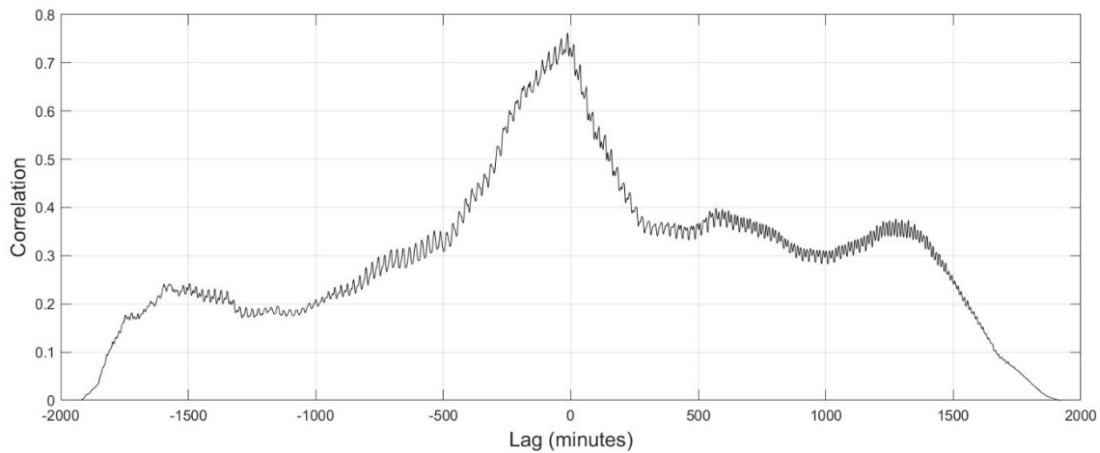


Figure 19. Cross-correlation analysis of the burst average values from the lower OBS (OBS1) and the combined wave-current shear stress.

In-situ water samples were collected at the instrument site, at the time of the deployment and recovery, to provide a measure of the suspended sediments that were present (Table 1). The corresponding OBS readings during the same periods are presented in Table 1. The results of these point measurements suggest suspended sediment loads of 0.0255 and 0.0234 g/L. With only two, very similar, readings it is hard to provide greater quantitative clarity on the range of suspended sediments at the site during the full deployment. The filters used to derive the suspended sediment weights are shown in Figure 20.

Table 1. Suspended sediment sample results from the deployment of the rig (Dep IDs) and the recovery (Rec IDs).

Sample ID	Filter start weight (g)	Filter end weight (g)	Volume (L)	Sample (g/L)
Dep1a	0.1009	0.1209	1.120	0.01786
Dep1b	0.1000	0.1196	0.630	0.03111
Dep2a	0.1001	0.1201	0.840	0.02381
Dep2b	0.1000	0.1205	0.700	0.02929
Rec1a	0.1009	0.1203	0.840	0.02310
Rec1b	0.1009	0.1236	0.840	0.02702
Rec2a	0.1005	0.1172	0.700	0.02386
Rec2b	0.1009	0.1215	1.050	0.01962

Table 2. Mean values of samples (from Table 1) and OBS readings

Collection period	Mean of samples (g/L)	OBS1 (mV)	OBS2 (mV)
Deployment	0.0255	400-600	300-500
Recovery	0.0234	200-300	200-400

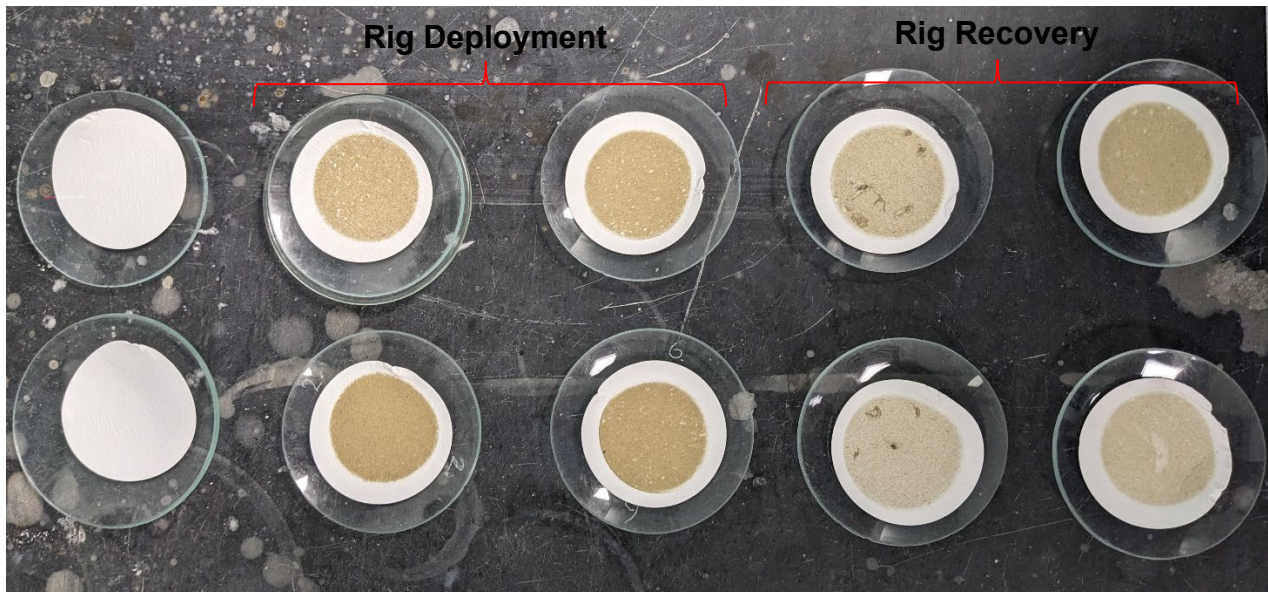


Figure 20. Vacuum filters from the deployment and recovery in-situ water column samples used to derive the suspended sediment weights. The far-left filters are control ones with no sample filtered.

Supplementary data

Without a project-dedicated meteorological station at the site, data from the Pembrey Airport (weatherandclimate.info), located ~50 km away- can be used as representative of the conditions during the deployment period. Figure 21 shows the wind speed, wind direction and rain during December 2025 (2026 data not available at time of writing). The wind speeds align closely with the wave record at the site reflecting the exposure is dominated by short fetch wind driven waves. The direction is particularly apparent with north and eastern winds driving the very calm conditions experienced at the end of December. Rainfall during the deployment period is associated with the south westerly winds during the first part of December (Figure 21).

There are several rivers and streams that flow into the Milford Haven Estuary. The Eastern and Western Cleddaus are the largest two rivers and the only rivers with gauges installed, river level data from these are shown in Figure 22; it is assumed that these river gauges are indicative of wider fluvial inputs into the Haven . In line with the wave and wind data, a similar trend in river level response over the deployment period observed, with higher levels at the start of December before lower river levels from the 21st of December until the 8th of January. Corresponding turbidity data was not available at the time or report writing [Editors note: comparison against turbidity data is made in NRW Evidence Report 1019].

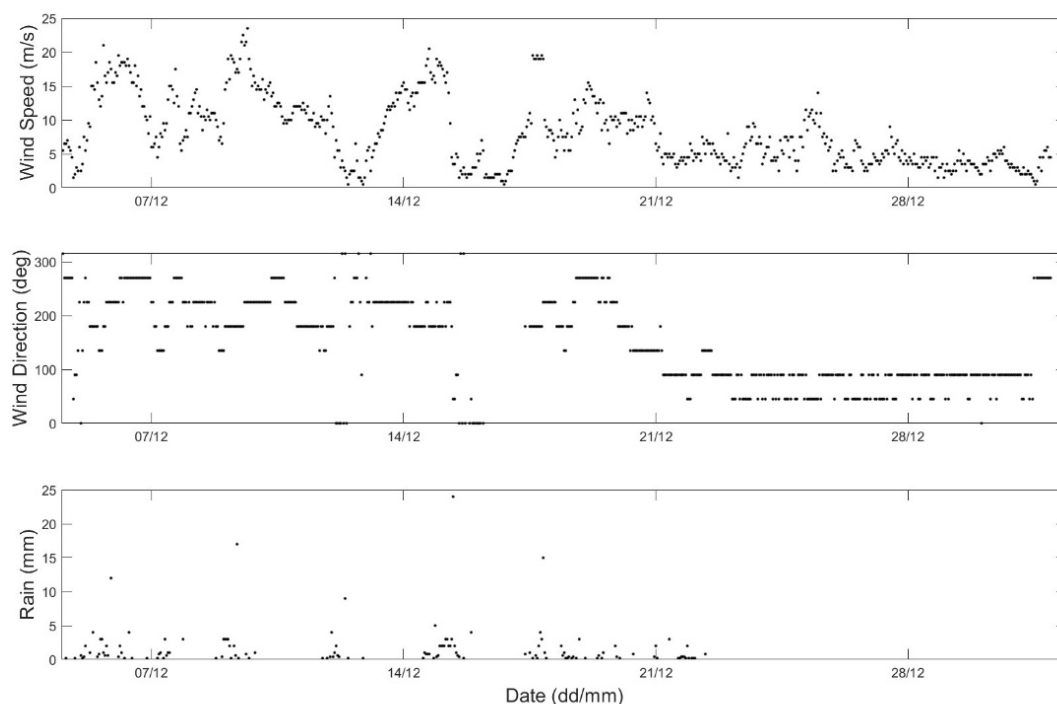


Figure 21. Wind and rain data from Pembrey airport (50 km away) for December 2025 (2026 data not yet available). The top panel shows wind speed (m/s), the middle panel shows wind direction (degrees) and the bottom panel shows the rainfall (mm). Data taken from www.weatherandclimate.info.

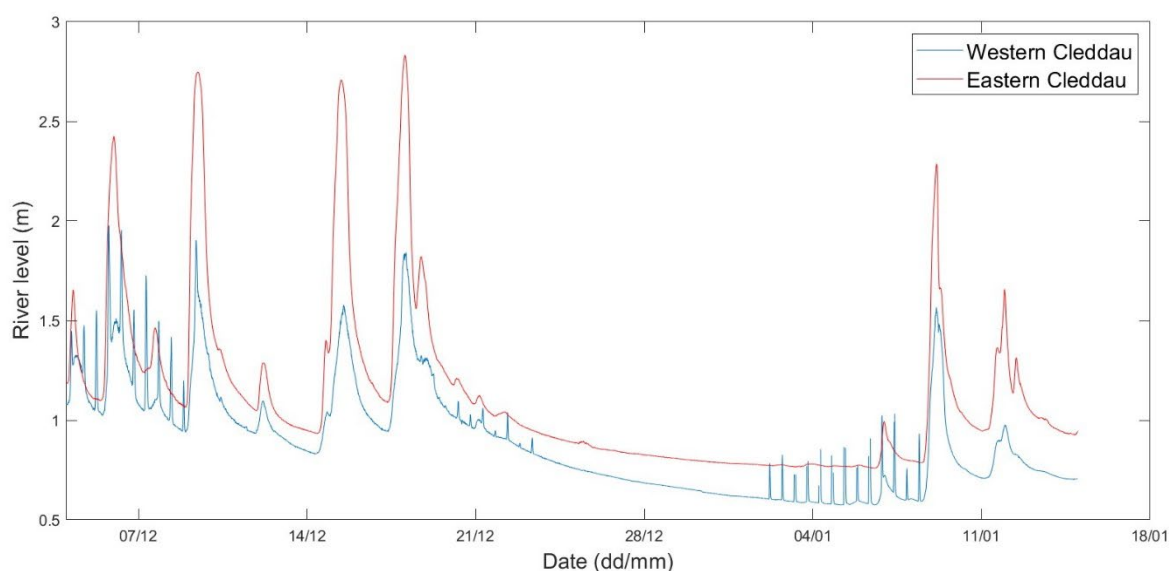


Figure 22. River level data (m) from the Western and Eastern Cleddau, during the deployment period, that feed into Milford Haven. Data courtesy of NRW via <https://rivers-and-seas.naturalresources.wales/>

Discussion and conclusion

This project has successfully recorded near-bed current measurements, optical backscatter traces, water level and wave heights over a spring-spring cycle during December 2025-January 2026 in Milford Haven. The results presented provide a broad range of forcing conditions reflecting energetic and calm periods that were present at the relatively sheltered site. Key results are that hydrodynamics are comparable to other maerl beds in the UK and that turbidity is more likely to be advected into the site rather than local resuspension of sediment within the maerl bed.

Measured wave conditions reflect the relatively sheltered nature of the deployment location which is largely protected from large swells entering the mouth of Milford Haven. Maximum wave heights are between 0.5-0.6m. Fetch limited wind-driven waves are likely to be most dominant at the site.

Near-bed current flows peaked at 0.3 m/s, during spring tides and 0.1 m/s during neap phases. The strongest flows were aligned with the expected tidal flow patterns (east-west), within the harbour, and showed a close relationship with the tidal stages e.g. spring/neap ranges. Peaks in current were at mid-tide on the flood and ebb, typical of the wider region and currents were flood dominant (faster currents on the incoming tide). These flows are within the range of currents noted at other maerl bed locations.

The wave and currents were used to calculate the wave-current bed shear stress, which peaked at almost 0.3 N/m^2 . An existing value for median grain size of $232 \mu\text{m}$ was used to calculate a critical shear stress threshold for erosion of 0.17 N/m^2 . The time series of wave-current near bed shear stress shows that this threshold is rarely exceeded. It is only under spring tides and larger wave conditions that the sediment local to the maerl would be eroded. This is an important result because it suggests that were the maerl to be smothered in the local sediment, it is unlikely that the sediment would be removed again quickly.

Suspended sediment levels can be inferred from the OBS records. Water samples collected from the site, during the deployment and recovery period show $\sim 0.025 \text{ g/L}$ concentration. However, the limited range in samples (both collected during calm periods) did not provide sufficient data to calibrate the OBS data to provide actual turbidity values. Importantly, while the OBS response to increasing turbidity in the water column is linear for lower turbidity levels, it becomes non-linear for higher values.

There was little difference between the two vertically separated sensors which indicates that observations were of suspended sediments in the water column rather than local sediment mobilisation. This is corroborated by peaks in suspended sediment largely occurring on the outgoing tide near to low tide, whereas peak currents are on the incoming tide (if the observations were of mobilisation of sediment from the bed at the sensor location, one would expect peaks in current and OBS data to match). Therefore, the higher levels of turbidity are being transported to the maerl bed from upstream.

The variability in the OBS data shows a positive relationship with wave-current near-bed shear stress calculated from the ADV and PT data ($r = 0.285$) suggesting water column mixing of suspended sediments and not wave by wave suspension present. However, the relationship between the variables is relatively weak although the low p-value indicates it is not a random correlation. It should also be noted that during the data collection period, increased wave heights are co-incident with increased rainfall and fluvial sediment input. The comparison between this dataset and fluvial inputs is covered in a separate evidence report (NRW Evidence Report 1019).

There are some limitations to the work, primarily the short dataset which was due to time and budget constraints of the project. There is obviously a seasonal bias having the deployment in winter, however obtaining winter measurements of hydrodynamics over the maerl bed has previously been suggested as important (NRW Evidence Report 551) and past sonde deployments give a longer term description of turbidity at the site (NRW Evidence Report 1019). The primary limitation is the unsuccessful calibration of the OBSs. Further work over a tidal cycle and variable weather conditions would be required to better characterise the suspended sediments at the deployment site and allow accurate calibration. Alternatively, lab based calibration could be trialled using local seabed sediment, however it should be noted that in estuarine scenarios, bed sediment may have different properties than suspended sediment.

Future work could consider sediment source tracking, better characterisation of suspended sediment and fluvial inputs which would enable understanding of any slack water deposition at the maerl bed.

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Appendices

Appendix A:

Deployment log for the ADV and OBS sensors

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Deployment: NRW

Current time: 04/12/2025 08:32:20

Start at: 04/12/2025 08:35:00

Comment:

NRW DEC25

Sampling rate (Hz):	4
Nominal vel. range (m/s):	4.00
Burst interval (s):	1800
Samples per burst:	2400
Sampling volume (mm):	14.9
Transmit length (mm):	4.0
Measurement load (%):	36
Power level:	LOW+
Output sync:	VECTOR
Start on sync:	DISABLED
Sample on sync:	DISABLED
INS Sensor:	DISABLED
INS Data type:	AHRSC3

Compass upd. rate (s): 1
Coordinate System: XYZ
Speed of sound (m/s) : MEASURED
Salinity (ppt): 0
Analog output: DISABLED
Analog output range: N/A
Analog input 1: FAST
Analog input 2: FAST
Analog input power out: ENABLED
File wrapping: OFF
TellTale: OFF
Acoustic modem: OFF
Serial output: OFF
Baud rate: 9600

Assumed duration (days): 30.0
Battery utilization (%): 29.0
Battery level (V): 13.9
Recorder size (MB): 14796
Recorder free space (MB): 14795.972
Memory required (MB): 104.7
Vertical vel. range (m/s): 1.5
Horizon. vel. range (m/s): 5.2

Instrument ID: VEC18387

Head ID: VCH 6067

Firmware version: 3.46

ProLog ID: 6229

ProLog firmware version: 4.26

SD Card Inserted: YES

SD Card Ready: YES

SD Card Write protected: NO

SD Card Type: SDHC

SD Card Supported: YES

Vector Version 2.00.02

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Appendix B:

Combined wave-current shear stress (GM) calculation form Grant and Madsen (1979).

Inputs

- Wave height (H_s)
 - Wave period (T)
 - Water depth (h)
 - Current speed (U)
 - Current direction (θ_c)
 - Grain size (D_{50}) or roughness (z_0)
 - Fluid density (ρ)
 - Kinematic viscosity (ν)
 - Wave number (k)
 - Bottom orbital velocity (U_w)
 - Friction factors (f_w, C_f)
 - Shear stresses (τ_w, τ_c)
 - Orbital excursion amplitude (A)
- Wave friction factor:

$$f_w = \left[\log \left(\frac{A}{30z_0} \right) \right]^{-2}$$

Wave shear stress:

$$\tau_w = \frac{1}{2} \rho f_w U_w^2$$

Current shear stress:

$$\tau_c = \rho C_f U_c^2$$

GM wave-current shear stress:

$$\tau_{cw} = \tau_c \left[1 + 1.2 \frac{U_w}{U_c} + \left(\frac{U_w}{U_c} \right)^2 \right]^{1/2}$$

Critical Shear Stress (N/m²), Shields equation

Inputs

- critical Shields parameter (θ_c = dimensionless)
- sediment density ($\rho_s \approx 2650$ kg/m³ for quartz)
- fluid density ($\rho \approx 1000$ kg/m³ for water)
- gravitational acceleration ($g = 9.81$ m/s²)
- grain size (in meters) $\rightarrow 232 \mu\text{m}$

$$\tau_c = \theta_c (\rho_s - \rho) g d$$

Data Archive Appendix

Data outputs associated with this project are archived in “[https://cyfoethnaturiolcymru.sharepoint.com/teams/evidence/Marine-Evidence/mcps/Evidence - External Research/CMAR MH measurements contract](https://cyfoethnaturiolcymru.sharepoint.com/teams/evidence/Marine-Evidence/mcps/Evidence%20-%20External%20Research/CMAR%20MH%20measurements%20contract)” on server-based storage at Natural Resources Wales.

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