

# **Plymouth Deep (PL035) Dredge Disposal Monitoring**

May – June 2017

Report



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**Prepared by:** Tim Smyth

**PML Applications Ltd  
Prospect Place  
West Hoe  
Plymouth  
Devon  
PL1 3DH  
UK**

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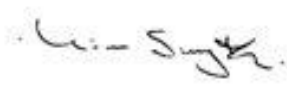


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<b>Project Coordinator:</b>	Dr. Tim Smyth
<b>E-Mail:</b>	<a href="mailto:tjasm@pml.ac.uk">tjasm@pml.ac.uk</a>
<b>Telephone:</b>	+44 (0)1752 633412
<b>Fax:</b>	+44(0)1752 633101
<b>WWW:</b>	<a href="http://www.pml.ac.uk">www.pml.ac.uk</a> & <a href="http://www.pml-applications.co.uk">www.pml-applications.co.uk</a>
<b>LinkedIn PML Applications:</b>	<a href="http://linkd.in/1LZzywt">http://linkd.in/1LZzywt</a>

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	<b>Name and Address</b>	<b>Signature</b>
<b>Author</b>	Dr Tim Smyth PML Applications Limited Prospect Place West Hoe Plymouth UK	
<b>Reviewed By</b>	Costanza Zanghi PML Applications Limited Prospect Place West Hoe Plymouth UK	
<b>Approved By</b>	Tim Fileman PML Applications Limited Prospect Place West Hoe Plymouth UK	

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## I Introduction

Following the licensing of the Plymouth Deep dredge disposal site PL035 by the Marine Management Organisation (MMO) in early 2017, the first disposal campaign was carried out by the dredging vessel *Shoalway* over a thirteen-day period between 22 May and 02 June 2017. During that time, 31 individual disposal events occurred with a total amount of 56.7 kt being removed from the Tamar Estuary and deposited at the Plymouth Deep site (MMO pers. comm.).

PML Applications carried out a field campaign to map the extent of the disposal plume on 25 May 2017. In retrospect this was probably too early in the disposal cycle to judge the full extent of the impact of dredge disposal around the PL035 site, and in particular within the environs of the Natural Environmental Research Council funded Western Channel Observatory (WCO). Due to mechanical problems with the *Shoalway*, only 10.3 kt had been disposed of up to that date. However, the continuous monitoring at a fixed point station (L4: 50 15'N, 4 13'W) by an autonomous data buoy and satellite remote sensing data provided by the NERC Earth Observation Data Acquisition and Analysis Service (NEODAAS) at PML ensured that at least surface observations were available before, during and after the disposal period.

The field campaign on the *RV Plymouth Quest* allowed multiple profiles (8) to be taken in the PL035 area of temperature, salinity, turbidity (Nephelometric Turbidity Units - NTU), transmission (%) and Photosynthetically Available Radiation (PAR), with discrete samples being taken of Suspended Particulate Matter (mg/L). The *RV Plymouth Quest* is equipped with an underway monitoring system, which samples every minute for surface meteorology and in-water (depth 4 m) temperature, salinity, turbidity, transmission, oxygen and chlorophyll fluorescence. The discrete samples allowed the turbidity sensor on the profiler, autonomous L4 buoy and the *RV Quest* underway system to be field transfer calibrated from units of NTU to mg/L.

At the end of the field campaign, the *RV Plymouth Quest* was positioned in order to take water column measurements immediately after a disposal event by the *Shoalway*. This, qualitatively at least, allowed observations to be made of the immediate impact of a single disposal event in contrast to the integrated impact over time and space observed by the L4 buoy and satellite remote sensing.

## 2 Methods

### 2.1 L4 autonomous buoy

The Plymouth Marine Laboratory has operated an autonomous scientific buoy (Smyth *et al.*, 2010) at the historic time-series site of L4 (50° 15'N, 4° 13'W) since 2009. L4 forms part of the wider NERC National Capability funded Western Channel Observatory ([www.westernchannelobservatory.org.uk](http://www.westernchannelobservatory.org.uk)) which has been the subject of intense scientific investigation for over a century (Harris, 2010, Smyth *et al.*, 2015, Southward *et al.*, 2005). For a full description of the buoy and its technical specifications see Smyth *et al.* (2010).

The in-water measurements are made hourly at a depth of 1.5 m within a “moon-pool” which is essentially a metal tube which protrudes beneath the buoy float into the water. A Wetlabs Water Quality Meter (WQM), housed within the moon-pool, simultaneously takes measurements of temperature, salinity, chlorophyll fluorescence, oxygen and turbidity. These measurements, together with surface meteorology are recorded hourly by a Satlantic StorX data logger in 2 – 3 minute bursts. The data are reported in a reduced volume form back to shore (burst average, hourly) every three hours. These are defined as the preliminary near-real time data.

After each season in the field, the entire record is downloaded from the StorX to allow quality control and error characterisation, enabling correction or data reduction for effects such as bio-fouling. In this report, data between 2009 and 2016 should be described as having a level of quality control; data from 2017, although of high quality will not have full error statistics associated with it. The L4 buoy was deployed for the 2017 season on 16 March and was fully operational over the period of the dredge disposal campaign (22 May – 02 June).

### 2.2 RV Plymouth Quest field campaign: 25 May 2017

A field campaign of a series of transects through the disposal site and extending out to the west was carried out on 25 May 2017 on the *RV Plymouth Quest*. A decision was made to sample out to the west as this was the likely direction of travel of any surface plume associated with the disposal given the tidal residual (westwards) and the wind direction (easterly) that day (and preceding period).

We started by taking a CTD profile at station L4 and then cutting diagonally across the disposal site box (Figure 1), with the underway system recording data every 1 minute along track, to a point about 5 NM west of the box. We then proceeded due south for around 3 NM before heading back to the disposal site box. Whilst in the box we carried out a decreasingly small survey area to get the optimal coverage. Once the survey was over we started to go back to Plymouth, but as we were passing Rame Head sighted the *Shoalway* on route to the disposal site. This gave us an opportunity to sample within the water column disturbed by a newly released dredge waste volume. In total 8 CTD profiles were performed with position information given in Table 1.

### 2.3 In situ Suspended Particulate Matter (SPM) Measurements

Discrete samples for SPM were taken in order to calibrate the turbidity sensors used in the field campaign, by gravimetric analysis. Discrete depth shipboard samples were taken from a CTD rosette into 10L carbuoys. These were transported back to the laboratory and known volumes of water were filtered through ashed (450°C in a muffle furnace overnight), pre-weighed 47 mm GF/F filters in triplicate. Post-filtration, the GF/F filters were rinsed with Milli-Q to remove residual salt. They were then dried at 80°C in a drying oven overnight and stored in a dessicator prior to re-weighing.

This method of calibration is most appropriate for the turbidity sensor mounted on the CTD rosette sampler. This is because a direct comparison with multiple fixed points is made possible, reported by the sensor in either NTU or Volts, shown in Table 2 as columns 6 and 7 respectively. Not enough range in turbidity was encountered on the surface sensors (*RV Plymouth Quest* underway and L4 buoy) to enable a meaningful regression to be carried out. Therefore a transfer calibration was carried out by using the regression of NTU (column 6) against mean SPM (mg/L). This assumes that the retrieval of NTU is accurate by the buoy / underway system. The relationship between NTU and SPM was found to be:  $SPM = 1.2942NTU$  with an  $R^2$  of 0.955 (N=10). A non-linear relationship was found when the SPM sample of 60.9 mg/L was included. However, this point was considered to be an outlier and therefore removed from the analysis.

### 2.4 Satellite Earth Observation

Near-real time data (<12 hr) support was provided by the PML based NERC Earth Observation Data Acquisition and Analysis Service (NEODAAS) on a daily basis between 20 May and 20 June 2017. The main satellite sensors utilised were the NASA MODIS Aqua and NOAA Suomi VIIRS sensors, as well as the newly launched Sentinel 2a MSI and Sentinel 3 (OLCI) sensors. MODIS Aqua and VIIRS are mapped at spatial resolution of 1.1 km; OLCI has a resolution of 300 m and Sentinel 2a 10-60 m (in the RGB bands). MODIS Aqua and Suomi VIIRS data were processed using an automated version of the SeaDAS V7.3.2 software and the ESA Sentinel data were processed using the SNAP toolbox.

During the dumping campaign there were daily overpasses available from MODIS, VIIRS and OLCI. Sentinel 2a has a longer repeat cycle so only 3 passes were available. The data were atmospherically corrected and processed to create GIS layers of water leaving reflectance at a wavelength between 550 – 560 nm. This wavelength was selected as it generally gives a good indication of suspended particulates within the water. Throughout the period preceding, during and after the campaign there was a large amount of cloud in the area. However, there were excellent clear overpasses on the day of the field campaign (25 May 2017).



## 3 Results

### 3.1 Survey - 25 May 2017

Figure 2 shows the *RV Plymouth Quest* underway system parameters of turbidity, transmission (determined by beam attenuation) and chlorophyll. The turbidity results show some spatial variability on the transect from Plymouth towards L4. This is likely to be a combination of increased turbidity due to a phytoplankton bloom (associated detrital material) and possible influence due to the River Tamar. Westwards from L4 and indeed for the rest of the survey, the value of the turbidity remained below 1 NTU (approximately 1.2 mg/L) and for the eastward transect the values were between 0.3 – 0.4 NTU (0.4 – 0.6 mg/L). The transmission was consistently >90% and approached 95% for some sections.

Figure 3 shows a composite, as a function of time, of the CTD profiles taken during the survey. The temperature and salinity plots show that the region sampled is strongly heterogeneous because of the proximity of the coast. All the stations exhibited a thermocline, although this varied in depth between 5 and 20 m depending on location. The depth of the chlorophyll maximum also varied between 20 and 10 m, this largely being driven by hydrodynamics and light availability. Station 3 (shallow CTD at 09:44 GMT), shows some influence of a surface sediment filament, a residual of previous dredging disposal with surface turbidity being > 2NTU (~2.5 mg/L). Station 8 (13:32 GMT) clearly shows the separation of the surface and deep sediment deposition from the freshly disposed material. In situ values of SPM were ~60 mg/L. A layer beneath 40 m and extending to the seafloor showed <5% transmission and turbidity > 5 NTU. Above 40 m the transmission was ~90% apart from a thin ~1 – 2 m layer at the surface where the transmission dropped below 70%.

### 3.2 Station L4: Autonomous Buoy

Figure 4 shows the hourly observations of turbidity (transfer calibrated in mg/L) and salinity (PSU) autonomously made by the buoy permanently moored at station L4 (50° 15'N, 4° 13'W) between 16 March and 21 June 2017. The period of dredge waste disposal is highlighted by the coloured rectangle. It can clearly be seen that during the disposal campaign that the turbidity levels immediately responded, increasing from values < 0.5 mg/L to a maximum of ~5 mg/L during the maximum disposal activity level (30 May – 01 June: 4 – 6 visits per day). There is some tidal modulation of the peak values (~ 1 mg/L) as the resultant sediment plume, with differing concentrations of suspended particulates, would have been advected around L4. At the cessation of the campaign the turbidity levels quickly dropped back to ~1 mg/L.

However, from 5 June the turbidity levels started to increase again, reaching a peak of 4 mg/L on 14 June. This almost immediately dropped back to 2 mg/L on 15 June. This feature is possibly caused by two effects: (1) the minimum neap tides occurred on 4 June and the maximum spring tide on 10 June, this would have the effect of resuspending dredged material into the water column and advecting it towards L4; (2) there was a period of intense rainfall between 2 – 6 June with rainfall totalling 23.8 mm being recorded at Penlee Point Atmospheric Observatory, situated on the mouth of Plymouth Sound. The intense rainfall event would have increased the river flow and associated fresh water inputs in the environs around L4; this is shown as a rapid drop in the surface salinity in Figure 4 on the period around 10 June from 35.2 to 34.8 PSU which corresponds to the peak in turbidity. There is

likely to be a subtle interplay here between the tidal modulation and the river outflow. A similar effect (although outside the period of the dredge disposal) can be seen at the end of March / early April. A period of rainfall between 28 to 31 March (18.9 mm) also resulted in a corresponding increase in the turbidity at L4, this time driven by purely fluvial processes.

One factor that cannot be completely ruled out in the dredge disposal and mid-June turbidity feature is biofouling of the turbidity sensor. There could be a gradual increase in the baseline value over the period since 15 May: but overall this should not detract substantially in this instance from the increase in turbidity observed during the dredge disposal campaign. The drop in the turbidity from 1.6 to 0.5 mg/L on 20 June was caused by cleaning of the sensor for biofouling. There was only a thin film across the optics of the sensor (J. Fishwick *pers. comm.*). When to apply this offset to the sensor is difficult to judge and there are no standard protocols to our knowledge to account for the highly non-linear nature of biofouling effects on optical sensors in the field. It is unlikely to have been accruing linearly since the launch of the buoy in March. Our best estimate is that the increase in the background offset was likely to have occurred during the period of dredge disposal.

When set within the context of the time-series of automated turbidity measurements at L4, it can clearly be seen in Figure 5 that the dredge disposal event in May / June 2017 was significant in magnitude in comparison with the naturally occurring signal caused by fluvial inputs from the River Tamar increasing the sediment loading. It is not however outside the observational envelope of previously observed events.

### 3.3 Satellite Earth Observation

Figure 6 shows the water leaving reflectance at 560 nm for the Sentinel 2a MSI sensor (11:21GMT 25 May 2017). It clearly shows a patch of higher reflectance material to the west of the disposal box approaching  $\rho_{wn}=0.015$  (non-dimensional) which is approximately 1km x 1km in spatial extent. Unfortunately, the detailed survey of the region around the disposal box narrowly missed this feature as the processing time for the image was too long to have this information to hand and therefore to direct the vessel to sample in this specific location. This feature, clearly visible in the 10 m resolution data, is also apparent in the 300m Sentinel 3 (OLCI) imagery (not shown), although less distinct because of the coarser resolution of the data.

Earlier data from Sentinel 2a obtained during March 2017, did not show such a feature in the data, which rules out that this is a stationary natural feature within the region.

### 3.4 Qualitative Observations

During the survey there were opportunities to qualitatively observe the behaviour of the suspended particulate matter plume in the field.

On the first leg of the survey, patches of previously disposed material were observed (Figure 7). They were highly patchy and filamentous in nature and an attempt was made to sample within one with the CTD (station 2).

At the end of the survey observations were made of a disposal event by the *Shoalway*. Observations using the *RV Plymouth Quest's* echo sounder were made possible by this and are shown in Figure 8. It clearly showed a rapid separation of material between dredged matter descending rapidly to the seafloor (below 25 m) and a lower concentration of diffuse material remaining at the surface (above 15 m). This was also shown in the CTD profile undertaken at that time (Figure 3, Table 1). The surface material was rapidly strained and started to form filamentous structures, driven by the fresh easterly winds and tide. Indeed it was challenging to obtain surface samples of the newly disposed material such that the surface parts of the CTD station 8 are slightly offset in position (~100 m or so) from where the lower water column observations were made.

## 4 Conclusions

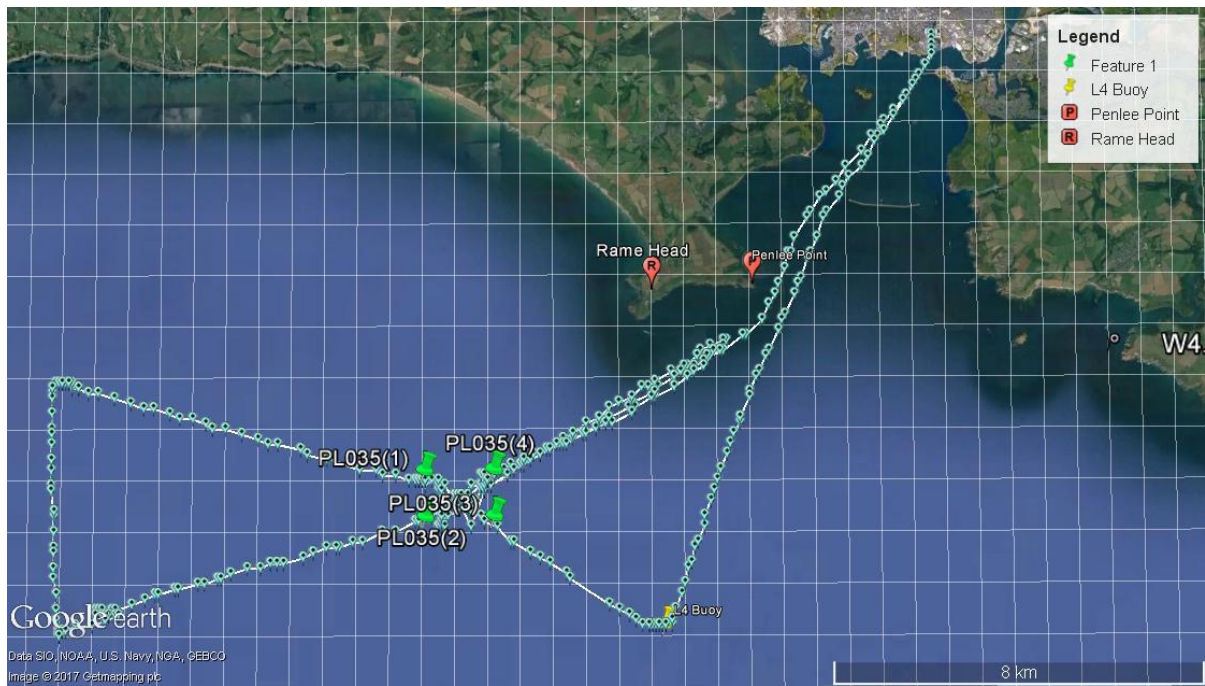
This report shows that the surface expression of the disposal of dredged material within the domain of the WCO can to some extent be monitored by the mooring at station L4. However, a mooring only gives measurements at a fixed point in space, so the spatial extent of the surface plume is not known for this disposal event. Satellite Earth Observation can go some way to solving that problem, and features have been detected in the imagery which are consistent with a disposal plume. The plume was detectable at high (10 m) and medium (300 m) resolution. The weather conditions were not conducive to monitoring the daily progress of the plume in this instance.

The field monitoring on *RV Plymouth Quest* was effective for field calibrating the turbidity sensor on the L4 buoy and also for capturing a dredge disposal event. Future campaigns would be more effective if directed by a combination of mooring and satellite Earth Observation data.

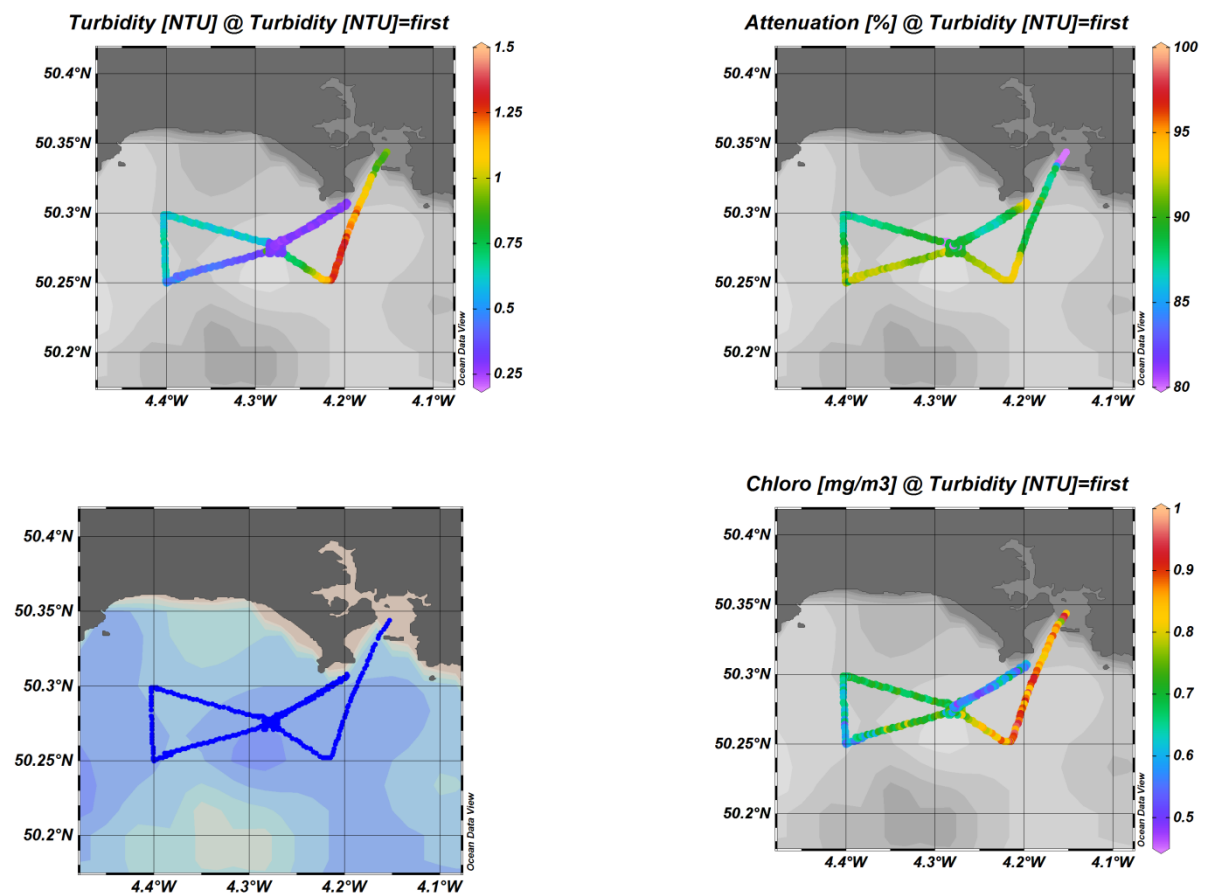
This particular dredge disposal campaign delivered a large amount of suspended particulate matter (4 – 5 mg/L) into the marine environment over a short period of time (~10 days). For this region of the western English Channel these are high loadings of surface sediment (a factor of 10 greater than background), but are within the envelope of extremes which have been observed since 2009 which was the start of the automated monitoring of the area by the L4 autonomous buoy. Non-dredge disposal events are caused by increased fluvial inputs from the River Tamar. The secondary peak (maximum on 14 June) observed after the disposal campaign is likely to have been exacerbated by such an event.

Qualitative observations showed that most of the material drops immediately to the sea floor. It is therefore likely that the dominant environmental impacts will be in the benthos. It is also likely that the ambient hydrodynamics, driven by meteorological and physical factors (density structure, tides), are likely to change the behaviour of the surface bloom. Therefore the impacts of a disposal campaign carried out in autumn / winter are likely to differ substantially from one in spring / summer.

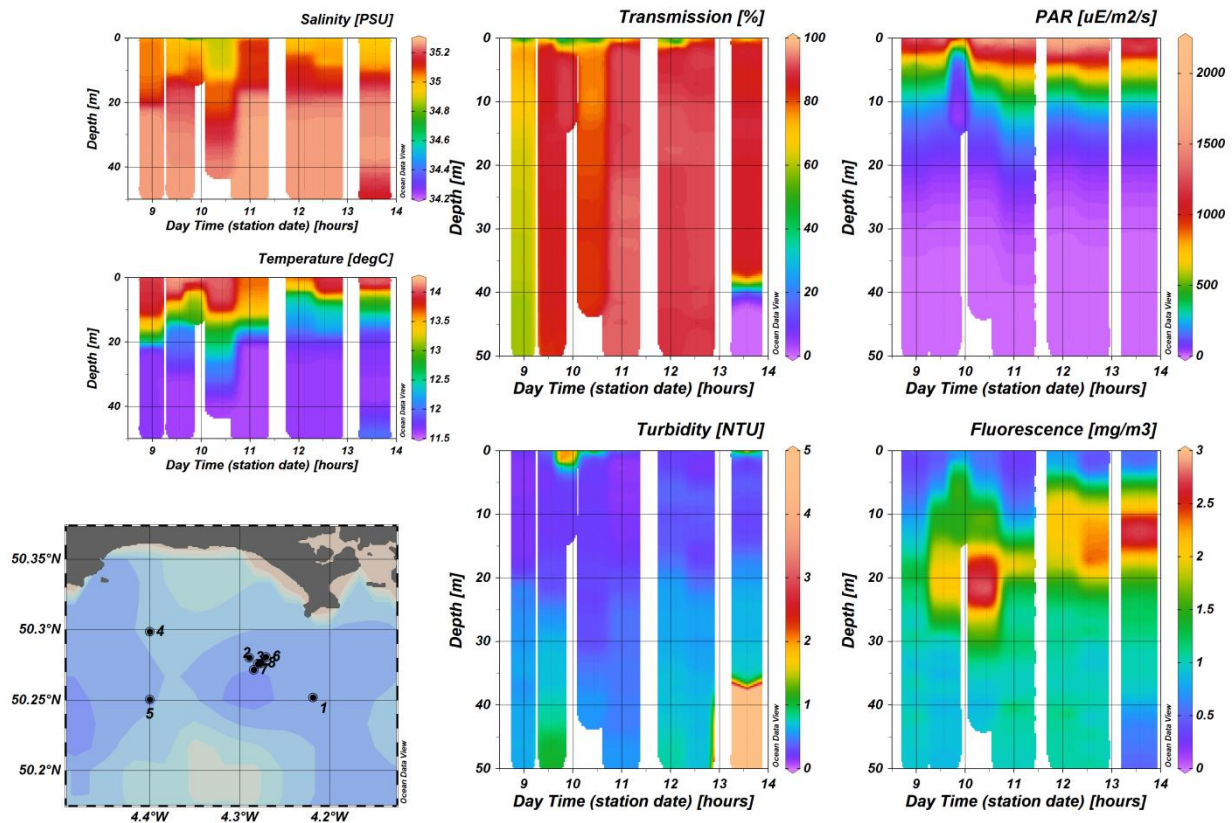
## 5 Figures



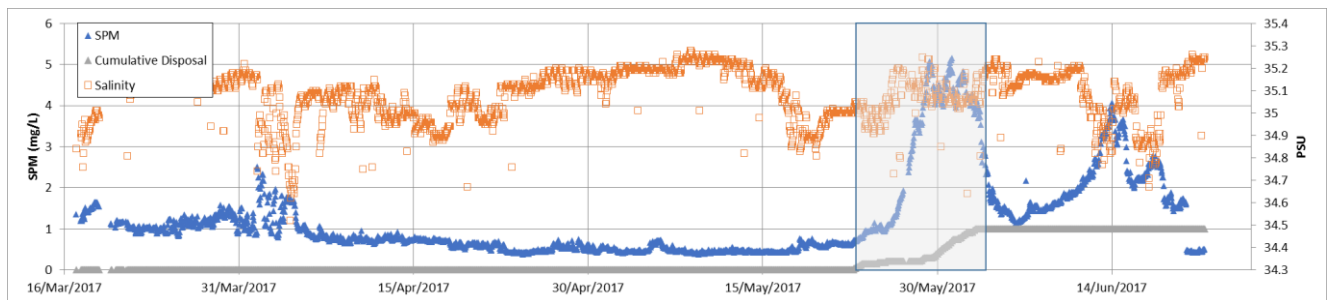
**Figure 1:** RV Plymouth Quest survey track including positions of Rame Head, Penlee Point and L4 buoy. Corners of PL035 disposal site marked in green.



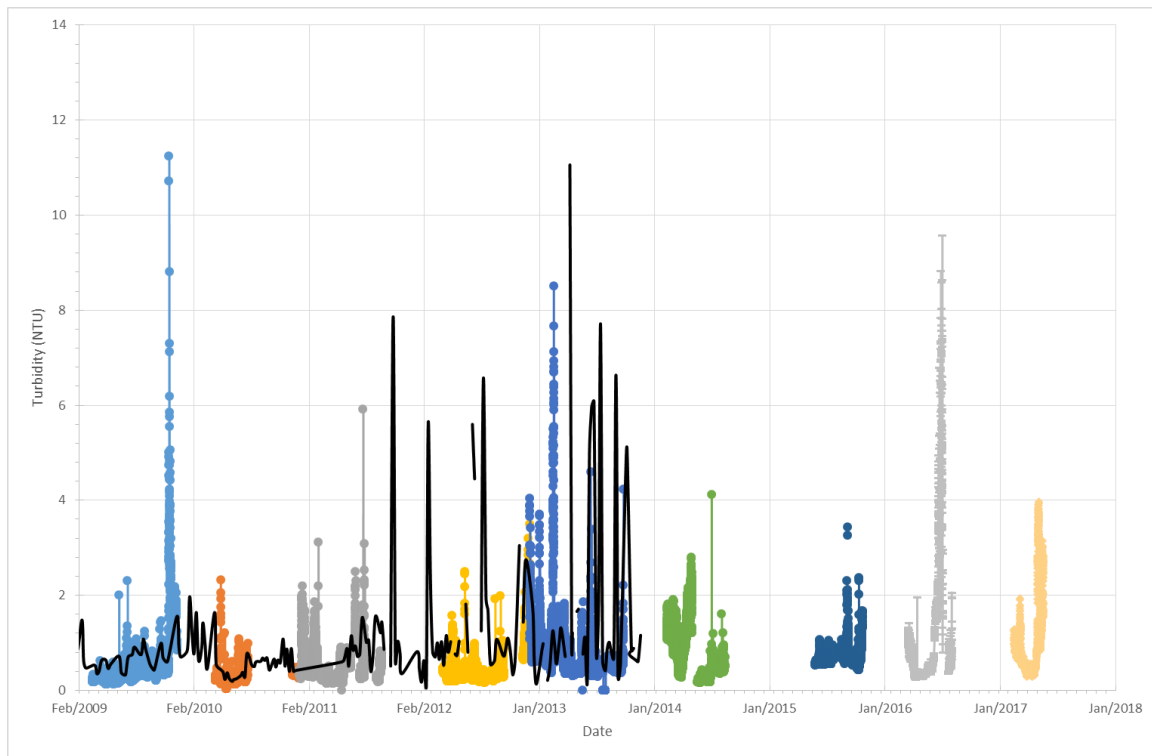
**Figure 2:** RV Plymouth Quest underway system parameters. Clockwise from top-left: Turbidity (NTU), Transmission (%) and chlorophyll ( $\text{mg}/\text{m}^3$ ). Insert map background is bathymetry. (Ocean Data View (ODV V4)).



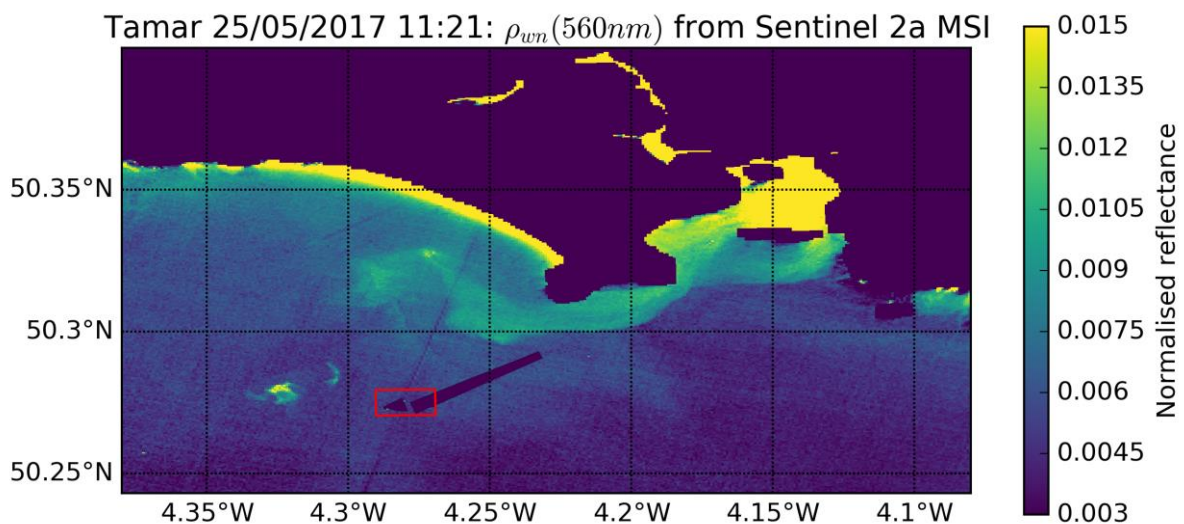
**Figure 3:** CTD profiles taken during the field campaign as a function of time (refer to Table 1 and insert map for station numbers and timings). Large panels clockwise from top-left: Transmission (%), PAR ( $\mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ ), Turbidity (NTU), Chlorophyll fluorescence ( $\text{mg}/\text{m}^3$ ). Small panels: Salinity (PSU) and temperature ( $^{\circ}\text{C}$ ). Insert map background is bathymetry.



**Figure 4:** Time-series of turbidity ( $\text{mg}/\text{L}$ ) and salinity (PSU) observed at the L4 buoy between 16 March and 21 June 2017. Background salinity values are generally around 35.1 for L4. Period of dredge disposal by the Shoalway are shown as the grey rectangle with the peak in SPM being between 4 – 5  $\text{mg}/\text{L}$ ; cumulative fraction of total disposal by the Shoalway is shown as grey triangles (between 0 and 1). Secondary peak likely to be caused by a combination of riverine and dredged material resuspension / advection. Drop from 1.6 to 0.5  $\text{mg}/\text{L}$  on 20 June 2017 due to cleaning of a small amount of bio-fouling.



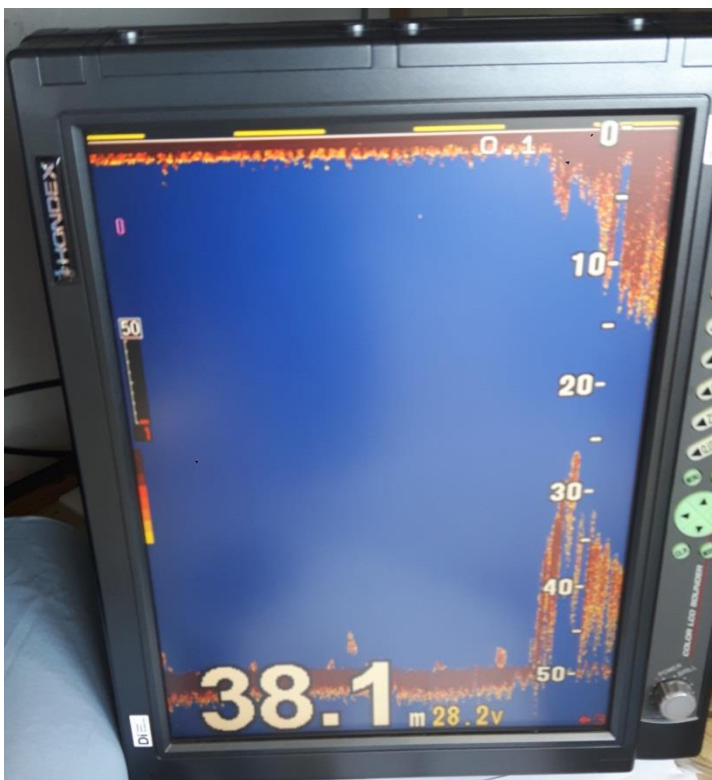
**Figure 5:** Entire time-series of turbidity measured by the L4 buoy between 2009 – 2017. Coloured points are the autonomous (hourly) measurements (units NTU). The solid line represents in situ measurements taken weekly at L4 (units mg/L).



**Figure 6:** Sentinel 2a imagery obtained during the field campaign (11:21 GMT on 25 May 2017) showing surface reflectance (dimensionless). Position of the PL035 licensed disposal box is shown in red, with the region in black masked out due to artefact caused by aircraft contrail. Regions of high reflectance are apparent within the Tamar Estuary, Whitsands Bay and around Rame Head. Feature to the west of the disposal box is likely caused by dredge disposed material.



**Figure 7:** Photograph taken from the *RV Plymouth Quest* showing the patchy nature of the newly disposed material at the surface.



**Figure 8:** *RV Plymouth Quest* echo sounder image taken during disposal event. High reflectance shown in red is indicative of surface and lower water column sediment separation.



## 6 Tables

CTD #	Date (dd/mm/yyyy) Time (hh:mm)	Latitude (°N)	Longitude (°W)
1	25/05/2017 08:54	50.25208°N	4.21688°W
2	05/05/2017 09:27	50.27558°N	4.27708°W
3	25/05/2017 09:44	50.28022°N	4.28984°W
4	25/05/2017 10:22	50.29872°N	4.39792°W
5	25/05/2017 10:55	50.25040°N	4.39998°W
6	25/05/2017 12:03	50.28036°N	4.27026°W
7	25/05/2017 12:28	50.27144°N	4.28404°W
8	25/05/2017 13:32	50.27612°N	4.27510°W

**Table 1:** Sampling positions of the CTD profiles. All times in GMT and mark the beginning of the downcast time.

CTD	Bottle	Carbuoy	Depth (m)	Mean SPM (mg/L)	Obs (NTU)	Obs (V)
1	1	1	40.75	1.7	0.5847	0.0836
1	2	2	1.90	0.6	0.1733	0.0733
3	1,2	3	1.20	4.4	2.1440	0.1226
5	1,2	4	45.80	1.0	0.4747	0.0809
7	1,2	5	35.08	1.9	0.6195	0.0845
8	1,2	6	47.76	18.6	104.4308	2.6798
8	3,4	7	41.20	60.9	61.9815	1.6206
8	5	8	38.85	4.6	10.1667	0.3232
8	6	9	2.09	8.4	4.0185	0.1695
8	7,8	10	3.18	12.7	6.3145	0.2278
8	9,10	11	1.68	6.6	4.9579	0.1929

**Table 2:** Details of *in situ* samples taken for SPM on the rosette sampler. Mean SPM is for the triplicates taken, and the Obs V & NTU are (averaged) values retrieved by the Seabird system at the depth the bottles were fired at.

## 7 Appendix: Data listing

### 7.1 Buoy

L4 buoy data 2009-2016\_NQC\_2017.xlsx

### 7.2 CTD

downcast/dl70525\_ctd1.asc  
downcast/dl70525\_ctd1\_ave.asc  
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downcast/dl70525\_ctd2\_ave.asc  
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downcast/dl70525\_ctd3\_ave.asc  
downcast/dl70525\_ctd4.asc  
downcast/dl70525\_ctd4\_ave.asc  
downcast/dl70525\_ctd5.asc  
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downcast/dl70525\_ctd8\_ave.asc  
ODV/MMO\_CTDf\_ODV\_20170525.png  
ODV/MMO\_CTDf\_ODV\_format.txt  
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upcast/ul70525\_ctd2\_ave.asc  
upcast/ul70525\_ctd3.asc  
upcast/ul70525\_ctd3\_ave.asc  
upcast/ul70525\_ctd4.asc  
upcast/ul70525\_ctd4\_ave.asc  
upcast/ul70525\_ctd5.asc  
upcast/ul70525\_ctd5\_ave.asc  
upcast/ul70525\_ctd6.asc  
upcast/ul70525\_ctd6\_ave.asc  
upcast/ul70525\_ctd7.asc  
upcast/ul70525\_ctd7\_ave.asc  
upcast/ul70525\_ctd8.asc  
upcast/ul70525\_ctd8\_ave.asc

### 7.3 EO

msi\_tamar\_20170326T111211.png  
msi\_tamar\_20170525T110514.png  
olci\_tamar\_20170326T102021.png  
olci\_tamar\_20170525T110514.png

### 7.4 SPM cal

SPM\_calibration\_for\_dredge\_disposal\_May2017.xlsx

### 7.5 Underway

20170525\_080704.txt  
ODV/MMO\_udwy\_ODV\_20170525.png  
ODV/MMO\_udwy\_ODV\_format.txt

Registered Office:  
Prospect Place, The Hoe,  
Plymouth, PL1 3DH,  
United Kingdom

T +44 (0)1752 633100  
F +44 (0)1752 269011  
W [www.pml-applications.co.uk](http://www.pml-applications.co.uk)  
E [forinfo@dml.ac.uk](mailto:forinfo@dml.ac.uk)

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