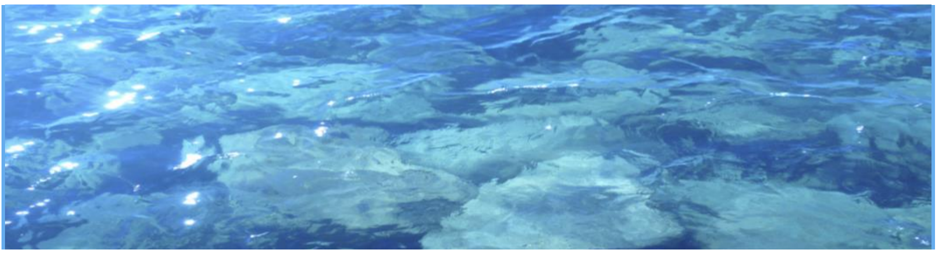
COWES HARBOUR COMMISSIONERS

Sediment Flux Measurement in the Medina Estuary Monitoring Results 2018

Report AmbCHC05

April 2019



ambios environmental consultants ltd

Contents

Executive Summary

Measurements of fine sediment dispersion through and around the Medina estuary have been made since January 2016. This report covers the third year of monitoring, 1st January- 31st December 2018. The monitoring is being undertaken to facilitate a more sustainable approach to the management of dredging in the estuary, including the real-time monitoring of the suspended sediment regime during any trials of new dredge methods.

The flux-measuring methodology combines water flow measurements from a hydrodynamic model of the estuary and field observations of total suspended solids made at four sites within the estuary. The main objectives are to determine the temporal patterns of fine sediment accumulation and erosion within the estuary (subdivided into seven polygons) and to add precision to annual (bathymetric) measurement of spatial patterns of accumulation and erosion (multibeam surveys). Serious maintenance problems with the turbidity measuring systems during 2018 resulted in poor data collection and in consequence it has not been possible to attempt the aspects of the flux measurement programme based on turbidity data. A complete revamp of the turbidity data gathering system in late 2018 should ensure that this problem does not occur again.

The monitoring continues to confirm the conclusions drawn from initial studies undertaken in 2016. These indicated that the principle source of mud to the estuary is from winter erosion of the seabed and coast of the wider Wight region, providing a clay-rich material from the Oligocene strata that outcrop in that area. Significant inter-annual variability in this input can be expected and 2018 was probably a near typical year, based on storm wave records. Continuing slight local erosion of the bed within the estuary (south and east of the new breakwater) provides a secondary input of mud (identifiable from its high silt/low clay content). This erosion is thought to have been exacerbated by the emplacement of the new breakwater, and rates of change have been steadily decreasing since 2016. Tidal flow, principally over spring tides, is the main agent of fine sediment redistribution within the estuary generally and is most active during and in the months immediately following the influx of mud from offshore (during the latter part of the year in 2018). Storms (wind and wave action) play a lesser role, with effects most seen in the vicinity of the harbour entrance.

Results from the outer harbour (between the new breakwater and the chain ferry) indicate that some 6,300 dry tonnes of sediment accumulated in the area over the year 2018. Results from the upper estuary (above the chain ferry narrows) indicate accretion of ~1,400 dry tonnes of mud in that zone, the net change for the estuary as a whole being a gain of some 7,700 dry tonnes of fine sediment. Historically the estuary is known to naturally import mud each year, hence requiring dredging (of the order of 10,000 dry tons per year, averaged over many years). 2016 and 2017 both saw a much decreased input (net loss in 2016), although accretion still occurred in the known long-term sink zones for mud. In 2018 there was a much more normal level of mud import, with all the marinas of the estuary seeing significant levels of mud accumulation.

The nearshore zone in the approaches to the Medina estuary continues to see adjustments in sand-bed levels most likely related to the new breakwater emplacement, but the rates of change are generally slowing towards a new equilibrium.

Recommendations related to improvement the monitoring system/methodology to allow continued accurate monitoring to proceed were implemented during the closing months of the year.

Sediment Flux Measurement in the Medina Estuary Monitoring Results 2018

1. Introduction

The monitoring of fine sediment flux through the Medina Estuary was initiated by Cowes Harbour Commissioners (CHC) in January 2016. This work is a new and experimental approach to monitoring of sedimentation, which is being undertaken with the aim of enhancing the ability for dredging requirements within the estuary to be managed on a more sustainable basis. The results of the first year of sediment flux monitoring was published in August 2017[1]. The monitoring design was based upon previous surveys [2] [3] undertaken in the lower Medina estuary to provide a detailed conceptual appreciation (model) of the local processes of sediment transport. These reports should be consulted for a full background to the monitoring programme.

Two complementary approaches to quantifying fine sediment movement are used. The first is annual bathymetric change, with surveys conducted in December of each year. The second involves bringing together near-continuous monitoring data of water turbidity at four key sites in the lower estuary with modelled water-volume exchanges [4] through selected estuary cross-sections, to give a time-series of sediment exchanges between seven polygonal zones that represent the estuary. Comparing and merging the two sets of results is believed to provide the best method of quantifying sediment flux into, out of and through the Medina estuary.

This report covers the third year of sediment flux monitoring, from 1st January to 31st December 2018. Methods used are near-identical to those used in 2016-17. During 2017 shortcomings in the practicality of collecting near continuous turbidity data became evident, limiting the accuracy of the analyses that could be undertaken. These problems were exacerbated significantly during 2018, to the point where data poor data continuity has prohibited a full analysis of sediment flux based on turbidity monitoring for this year.

This report describes the methodology adopted, the constraints imposed by data loss inaccuracies, and provides the observed sediment flux patterns and tonnages. It also covers the steps taken to improve the turbidity data collection efficiency in the future.

2. Methods

2.1 Approach

Four sources of information have been relied upon in measuring the flux of fine sediment through and around the Medina Estuary.

1. A mathematical model [2] of tidally-driven water flow in the Medina Estuary. This predicts volumes of water flowing through a series of key estuary cross sections (Figure 1), determined at 30-minute intervals over a full spring-neap cycle.

---

[1] Ambios 2017. Sediment Flux Measurements in the Medina Estuary. Monitoring Results 2016. Report AMBCHC03a. August 2017

[2] Ambios 2016. Sedimentary Processes in the Medina Estuary May 2016 Report AmbCHC02

[3] Ambios 2017. Sediment Management in the Medina Estuary: Monitoring Results 2016. Report AmbCHC03. March 2017

[4] Data derived from a rerun of the ABPmer model of water circulation in the Medina Estuary. ABPmer, 2015b. Cowes Local Model Calibration, ABPmer Report No R.2517

2. Water level (tidal stage) data from a single site in outer harbour, determined at 15-minute intervals. These data are recorded by the Environment Agency and accessed via a web-based download system.
3. Water turbidity data at four sites within the lower Medina Estuary (Figure 1) determined at five-minute intervals. These optical measures are calibrated to gravimetric (mg l^{-1}) total suspended solids (TSS) values. The sensors are serviced by CHC staff on a fortnightly basis, when data are (retrospectively) downloaded and archived.
4. Bed level data (bathymetry) measured using a precision multibeam system once per year (in December). Continuity of methodology is critical to enable accurate comparison of inter-annual data, and to date all surveys have been undertaken by Shoreline Surveys Ltd.

Each of the dynamic variables (1-3 above) is related to tidal hour (measured from low water, addressing variability within the semi-diurnal tidal cycle) and to the range of each individual tidal cycle (high water level minus low water level) addressing variability within the fortnightly spring-neap cycle and seasonal variability in the latter.

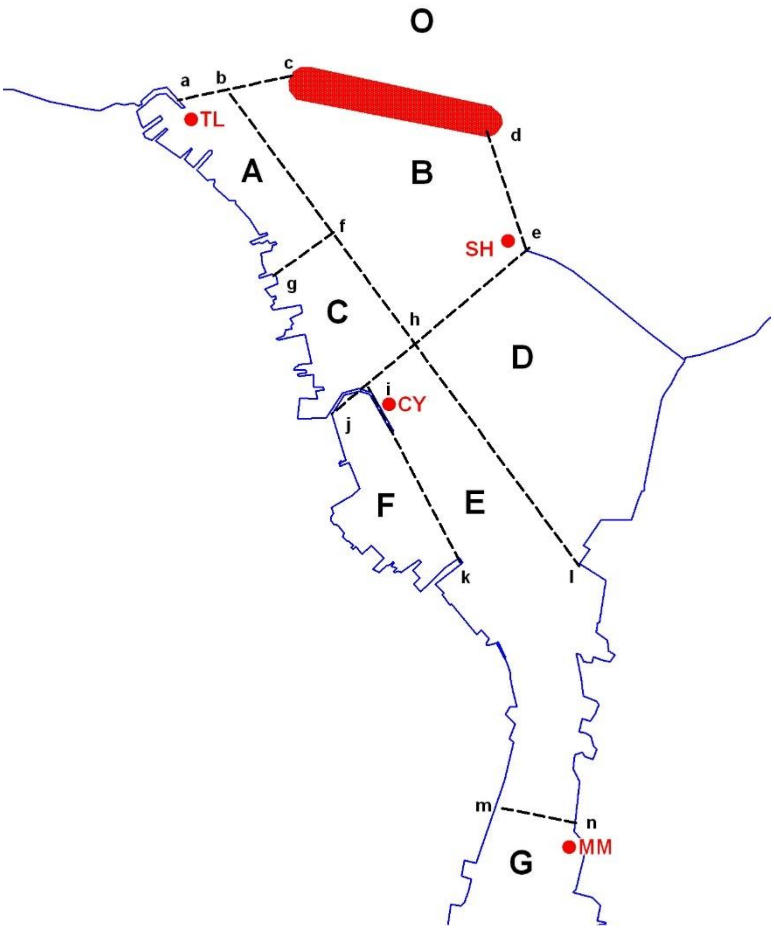


Figure 1. The lower Medina Estuary showing turbidity measuring sites (red dots), key area polygons (labelled A-G) and cross-sections (ab, bc etc) through which water flow was predicted from the ABPmer model.

Two basic assumptions have been made in relation to the dynamic variables, based upon recent field observations. The first is that there is no significant vertical stratification in the estuary water column, and the second is that river inflow and wind/wave effects play a subsidiary role to tidal effects in driving the WATER circulation. With river flow for example, it is known that maximum inflow, occurring for only short periods, is about $10m^3 s^{-1}$, and mean gauged river flow is of the order of 0.5 m^3s^{-1}. These are very small values compared to the average discharge[5] value of water through the harbour entrance of ~800m^3s^{-1}.

No dredging was undertaken at any site in the Medina Estuary during 2018.

2.2 Modelled Water Flow

The ABP model runs a full spring-neap cycle simulating the two-dimensional water flow in the Medina estuary based on the period 13-29th December 2014 (full spring-neap cycle). The data from this model had been calibrated to recent velocity observations.

Six polygons were specified for the outer harbour (A-F, Figure 1) based on the known general pattern of water circulation the area. In addition the offshore zone (Area O) and the complete estuary above the chain ferry narrows (polygon G) were defined. Creation of these regions defined twelve cross-sections of the estuary (ab, bc, bf, fg etc Figure 1). The model then predicted flow through each of these sections for 30-minute periods through each of the tidal cycles in the 16-day interval. Discharges were identified as positive (flowing to the east or south) or negative (flowing to west or north). The data from each profile were then sorted by tide hour and neap-rising-springs and springs-falling-neap categories, and for each half hour interval and category a 4th order polynomial curve was fitted between tide range (x) and discharge through section (y).

During December 2018 a programme of current meter measurements was initiated, recording flow just above the bed over 14 day periods at a variety of sites. These observations will continue through 2019. The objective of the observations is to a) cross check the accuracy of the ABP model predictions and b) identify any changes in flow patterns resulting from the spring 2019 dredging of the new eastern approach channel.

2.3 Total Suspended Solids (TSS) Data

2.3.1 Data loss

Through the year about 55% of the potential number of turbidity readings were lost for a variety of reasons (Table 1). These included:

- Power failure. Three of the sensors have small 12v batteries charged by a mains supply, giving 1-2 days of power in the event of a mains cut. Unfortunately at all three of these sites, for various reasons, the mains power was cut. As the control of the mains power was in some instances outside CHC's control, sometimes the cuts lasted for many weeks, and often the failures were recurrent.
- Sensor malfunction and upgrade. Memory failure and wiper failure required two sensors to be sent away for several months for servicing. No replacement sensor was available to replace these units. Upgrading of the sensors (see below) also meant that no data were collected during November and December 2018.
- Staff shortages. These dictated that on several occasions servicing took place a week or more after the required date. Data were lost (the loggers being full).
- Weed/biota contamination of the optical windows. The Medina estuary has proven very productive in biofouling terms particularly through the late spring and summer. Some periods one-week service intervals should have been instigated. Staff shortages did not allow this to happen.

This acute shortage of data made impossible to 'infill' missing data, as can be attempted for short gaps when three of the sensors are working. 2018 was therefore a very bad year for turbidity data

[5] Taken from the ABP model of a spring-neap cycle, with absolute values averaged.

collection, and that has made accurate sediment flux modelling impossible. The seriousness of the problem has prompted CHC to address the situation however, and from 1st January 2019 the following changes will have been implemented.

1. All loggers are internet connected, downloading data (visible in the CHC office) at 15 minute intervals. In this way power supply, sensor failure or fouling problems can be quickly spotted and dealt with.
2. All sensors are now fitted with easy-clean, replaceable weed guards and copper sheathing. The latter inhibits the growth/infestation by biofouling organisms around the optical sensor head/wiper area.
3. A portable replacement turbidity sensor is always on standby to cover temporary downtime of any sensor.
4. CHC staff recognise the importance of rapid response to problems.

	Loss due to power failure, sensor repair and staff shortages	Loss due to biofouling	Total loss
SHRAPE	50%	12%	62%
TRINITY LANDING	40%	10%	50%
COWES YACHT HAVEN	29%	4%	33%
MMC DIVERS	64%	11%	75%

Table 1. Turbidity data loss, by site and cause, during 2018. Expressed as % of total possible readings to be taken at each site.

2.3.2 Data Processing

A system of Excel workbooks is used containing all the (5 minute) TSS observations from the four sites over the one-year period, together with the tide hour and tidal range data derived from the simultaneously recorded water levels. These data were then grouped into 15-minute values, representing the average and minimum of the three grouped values. The grouped data was then loaded into a standardised Excel workbook, together with the control data (servicing history, local wind and wave data, dredging records). The data were compared with storm and dredging timetables, and clearly spurious average values were either deleted or replaced by the minimum value, if the latter was more realistic. This process is designed to remove the effects of biofouling, in particular the temporary effect of weed strands in the water, a problem at certain times of the year in the Medina estuary, often difficult to clearly identify.

General statistics describing the suspended sediment regime in 2018 in the Medina estuary were calculated, as previously, but no analysis of sediment flux was attempted. As the data describe less than 50% of the observations possible, caution should be exercised in relying on the data statistics.

2.4 Bed Level Changes

The results of the bathymetric surveys conducted in December 2015, 2016, 2017 and 2018 have been compared. The volume of sediment that had eroded or accreted on the Medina bed between each of the surveys was determined by comparing the data-averaged values on a 1m^2 grid from surveys, using GIS analysis. The total area of the outer harbour surveyed (below the chain ferry, inside the breakwater) is ~395,000m^2, and above the chain ferry ~481,000m^2, the total being

876,000m^2. The overall precision of multibeam surveys is about ±5cm. A one-centimetre slice of the surveyed area contains 8,760m^3 of mud, or about 7,880t of (dry) sediment at a typical bed density. Estimation of total volume changes on the estuary bed over one year are therefore imprecise unless some form of calibration can be applied to finely tune the data.

QC Procedure #1: Slipway sites

Slipway	Mean level mODN		(+0.04m)	(+0.06m)	(-0.01m)
Site	1992	2015	2016C	2017C	2018
1	-0.44	-1.93	-2.07	-1.96	-1.85
2	-1.14	-2.35	-2.30	-2.33	-2.12
3	0.43	-1.58	-1.63	-1.66	-1.59
4	0.14	-2.18	-2.25	-2.27	-2.15
5	-1.52	-1.93	-2.01	-1.98	-1.93
6	-1.28	-1.49	-1.56	-1.48	-1.49
7	-1.86	-1.67	-1.58	-1.58	-1.58
8	-1.08	-1.14	-1.06	-1.04	-1.06
9	-2.41	-0.68	-0.43	-0.61	-0.65
10	-2.37	-1.11	-1.06	-0.96	-0.92
11	-2.21	-2.20	-2.01	-1.97	-1.95
12	-0.10	-0.83	-0.82	-0.9	-0.93

	Differences (on corrected levels)			
	2015-1992	2016-2015	2017-2015	2018-2015
	-1.49	-0.14	-0.03	-0.08
	-1.21	0.05	0.02	-0.23
	-2.01	-0.05	-0.08	0.01
	-2.32	-0.07	-0.09	-0.03
	-0.41	-0.08	-0.05	0.00
	-0.21	-0.07	0.01	0.00
	0.19	0.09	0.09	-0.09
	-0.06	0.08	0.10	-0.08
	1.73	0.25	0.07	-0.03
	1.26	0.05	0.15	-0.19
	0.01	0.19	0.23	-0.25
	-0.73	0.01	-0.07	0.10
Mean	**-0.44**	**0.03**	**0.03**	**-0.07**
SD	**1.16**	**0.12**	**0.10**	**0.10**
Range	**2.49**	**0.40**	**0.19**	**0.28**

Slipway sites are shown in the figure (numbers are on land with lines connecting to location)

QC Procedure #2: Full Chain Ferry polygon

	Polygon statistics metres		
	Mean	Max	Min
1992	-4.39	-1.57	-5.66
2015	-4.61	-1.82	-6.07
2016C	-4.62	-1.79	-6.09
2017C	-4.65	-1.75	-6.13
2018	-4.64	-1.79	-6.1
2015-1992	-0.21	-0.25	-0.42
2016C-2015	-0.01	0.04	-0.02
2017C-2015	-0.04	0.07	-0.06
2018-2015	-0.03	0.03	-0.03

QC Procedure #3: Thalweg Chain Ferry polygon

	Polygon statistics metres		
	Mean	Max	Min
1992	-5.35	-4.01	-5.66
2015	-5.5	-4.73	-6.07
2016C	-5.52	-4.76	-6.1
2017C	-5.54	-4.76	-6.13
2018	-5.53	-4.69	-6.1
2015-1992	-0.15	-0.72	-0.41
2016C-2015	-0.02	-0.03	-0.03
2017C-2015	-0.04	-0.03	-0.06
2018-2015	-0.03	0.04	-0.03

Table 2. Bathymetry Quality Control data.

As an initial step in this calibration process, a quality control procedure is followed. This involves comparing the bed levels recorded at expected stable areas of the estuary bed. Two types zones have been identified:

- Intertidal slipway sites (hard areas, not overgrown by weed). Twelve sites have been identified (Table 2, Procedure #1) and point readings taken from each.
- On the basis of the argument that the hard, scoured seabed area in the vicinity of the chain ferry narrows is likely to be the most stable area of seabed in the estuary, two polygons have been identified and all readings within each polygon analysed (to give mean, maximum and minimum levels). The smaller of the two polygons is enclosed within the larger and encompasses just the deepest part of the channel at the narrows (Table 2 Procedures ~2 & 3).

The 2015 multibeam survey bed levels have been taken as the baseline.

The quality control procedure (Table 2) suggested that all bathymetric levels recorded during the 2018 survey should have -0.01m added to them to be consistent with the 2015 baseline levels. This compares with the +0.04m correction applied to the 2016 dataset, and the +0.06cm added to the 2017 dataset. The bed volume change from December 2017 to December 2018 has been calculated for 49 sub-polygons covering the detailed morphology of the estuary bed, as originally designated in the 2016 report. Maps and tables of these data are presented in the results section.

2.5 Reconciling Flux and Bathymetric Data

The Flux and Bathymetry methods of looking at how mud circulates in the Medina estuary have their individual strengths and weaknesses.

- Bathymetry data show clearly WHERE sediment is accumulating but cannot say when (beyond the annual period) and lacks fine precision in determining absolute volumes
- Flux data show WHEN sediment is accumulating but not where in detail (beyond between the polygons used)
- Importantly, for the outer harbour area (where both methods have 100% coverage), the comparison of results from the two methods provides a check potential and also the possibility of calibration to enable an optimum quantitative estimate of total sediment budget.

On this basis, it is sensible to compare [6] the flux and bathymetry data and potentially:

1) fine-tune the bathymetric data sediment volume changes for the whole outer harbour to the absolute value determined from the flux data and

2) calibrate the cumulative flux data by individual polygon to the annual sediment erosion/deposition volumes derived from whole-harbour-calibrated bathymetric data.

This analysis was successfully undertaken for the 2016 data, and partially for the 2017 data. Due to the poor turbidity data collection seen in 2018 the reconciliation process has not been undertaken for this year.

3. Results

3.1 The 2018 Turbidity Regime.

3.1.1 Annual Variability

The fortnightly[7] mean values and standard deviations of Total Suspended Solids (TSS) data collected from all sites are shown in Figure 2. Three data groups are plotted:

- All data (but cleaned of spurious readings)
- 'No Storm' data, which is the All Data dataset with all complete data-days (midnight to midnight) that contain a storm event[8] deleted. Thus the variation in TSS seen in this data set should be caused only by season variation in regional TSS condition, regular tidal variability and shipping effects.
- 'Just storm data', from storm event days only.

[6] Note an allowance has to be made between to total area of the flux polygons (Figure 1) and the total bathymetric surveyed area, which is significantly smaller.

[7] Data averaged over a spring neap cycle (lowest neap to lowest neap) in 2017 and 2018. In 2016 a monthly average had been used, giving less sensitive results.

[8] Storm Events have been previously defined (ref. 3): Days containing wind gust speeds>30km/hr from the north (180°) sector, wind gust speeds >50km/hr from the south (180°) sector, more than 10mm local rainfall or Solent Approach wave condition >1.5m Hs and 10s period.

These data are plotted as 'all sites averaged' and also for individual sites. Inspection of the data (Figure 2) allows the following observations to be made:

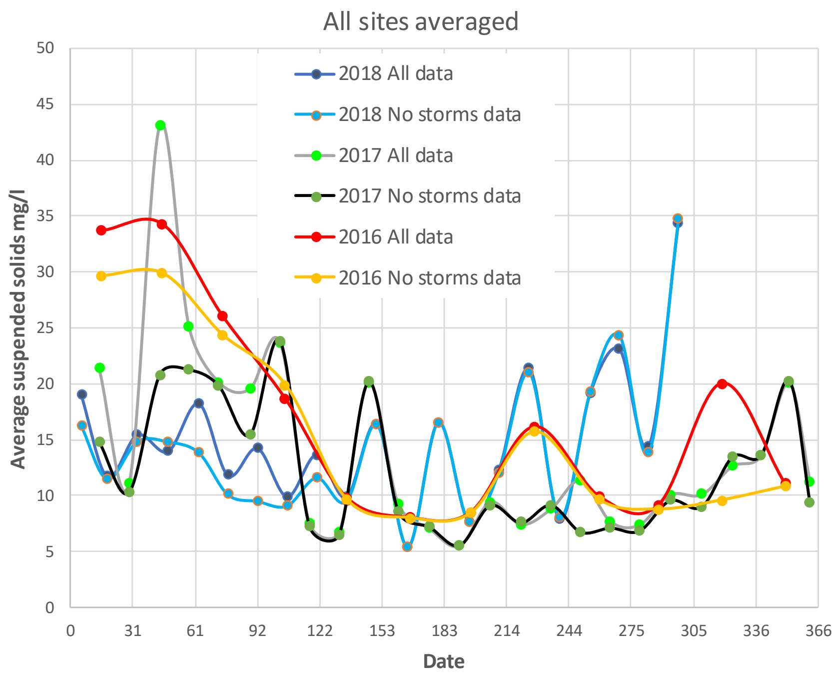
a) The seasonal pattern of variation in the ~14 day average values was less marked in 2018 than in the previous two years. The January-April TSS values varied between 8-20 mg l-1, lower than in previous years, whereas the summer/early autumn period saw variation from 5-25 mgl-1, rising higher than in previous years. In September and October the expected seasonal rise in average values was seen, ranging between 15 and 35 mg l-1 No data were available for November-December 2018.
b) There was a very regular cyclic pattern during 2018 in the average TSS values between successive spring-neap tidal cycle periods. This was seen but in a much less marked fashion in 2017. The pattern was not visible in 2016 due to the different method of data analysis initially adopted [7]. This pattern reflects the much increased ability of high spring tides to rework fine sediment than the (slower velocity) low neap tides. This distinction is clearly brought out in Figure 4 where the 14-day averages are calculated and separated on the basis of the range (spring or neap) of each tide.
c) There was only a modest difference between the storm/no storm averages in January, February and March 2018, and hardly any difference at all through the period April-September, local storm events apparently playing a small role in creating turbidity. In late October high storm averages were evident.
d) The standard deviations of all data increased through the summer/autumn period, as was seen in previous years. This lack of association of short-term data variability with the 'stormiest' periods of the year suggests that the instability seen in the data may reflect 'boating activity', frequent stirring up bottom sediments, or simply a spurious biofouling effect, notably the breakdown and release of the extensive brown seaweed deposits that annually build in the East Shrape coastline through the summer/autumn period.
e) Storm-induced increases in TSS were most evident at the Trinity Landing site.

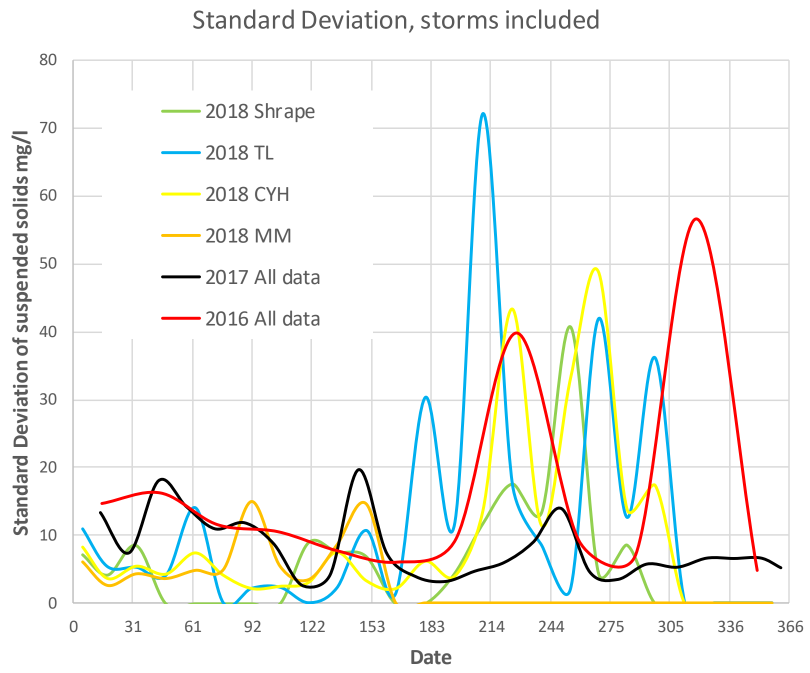
This analysis of the (incomplete) 2018 dataset analysis appears to be consistent with the conclusions reached from the 2016/17 analyses that most of the year local storms have a minor effect on TSS compared with regional/tidal/shipping effects.

3.1.2 Tidal Variability

In order to best-reveal tidal effects within the turbidity regime, only the No Storm data set has been examined. Figure 3 shows the individual fifteen-minute TSS data averaged by tidal hour and grouped by tidal range, for each site. Figure 4 shows separated spring and neap values (above and below 2.5m range), averaged over fortnightly spring/neap cycles, as an annual timeseries. These plots show:

a) The expected condition of highest turbidity under spring conditions and lowest turbidity under neap conditions generally applies.
b) Tidal range has the greatest effect on TSS values at Shrape, followed by CYH then Trinity Landing, with least effect being seen at the MM Divers site.
c) The spring-neap plot lines tend to trend consistently with each other except at the Shrape site which shows a more chaotic situation.
d) TSS values tend to increase during those periods of the tide when the highest water velocities are found (green zones Figure 3). This effect, indicative of local resuspension of bed sediment, is not very marked however, particularly over neap tides.





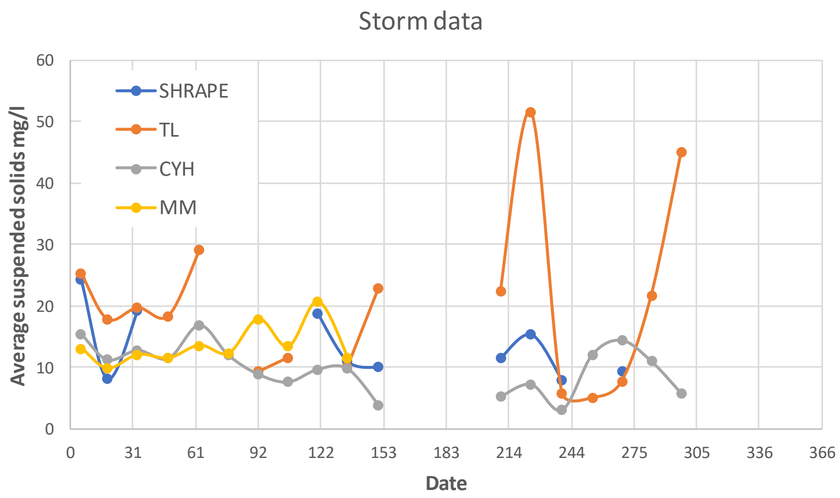
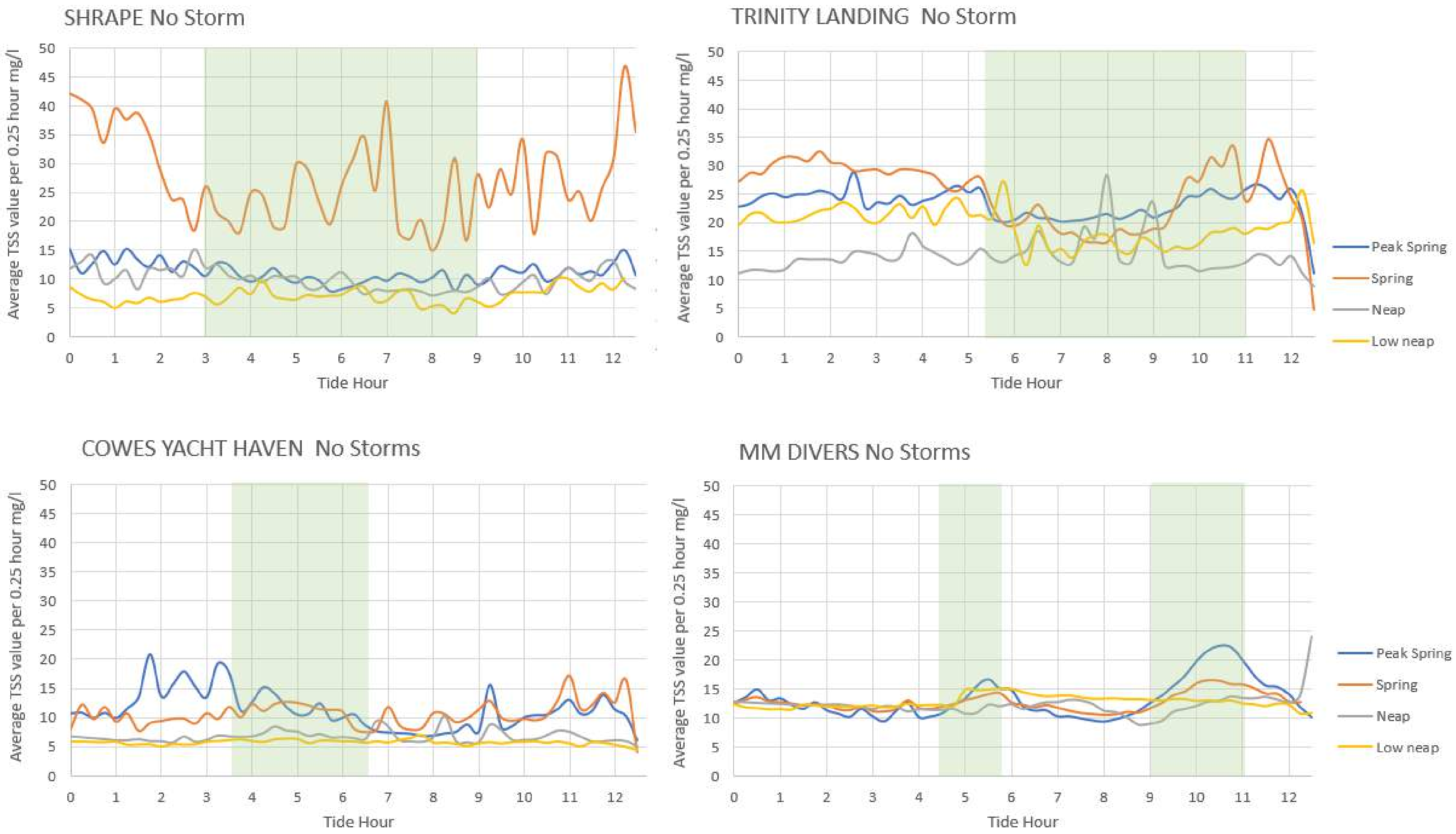


Figure 2. Total Suspended Solids time series, 2016, 2017 & 2018.

Top left – data from all four sites averaged per neap-spring cycle. 2016 - 2018, both 'all data' and 'storms removed'

Top right – Variability (shown by standard deviation) at individual sites. 2016 and 2017

Bottom left. Storm data only from the four sites in 2018.



0

Figure 3. Fifteen-minute data values for each site, averaged by tide hour (after LW) and sorted by tide range (spring-neap). 2018 'No-storm data' only. Green zones indicate periods of strongest tidal currents.

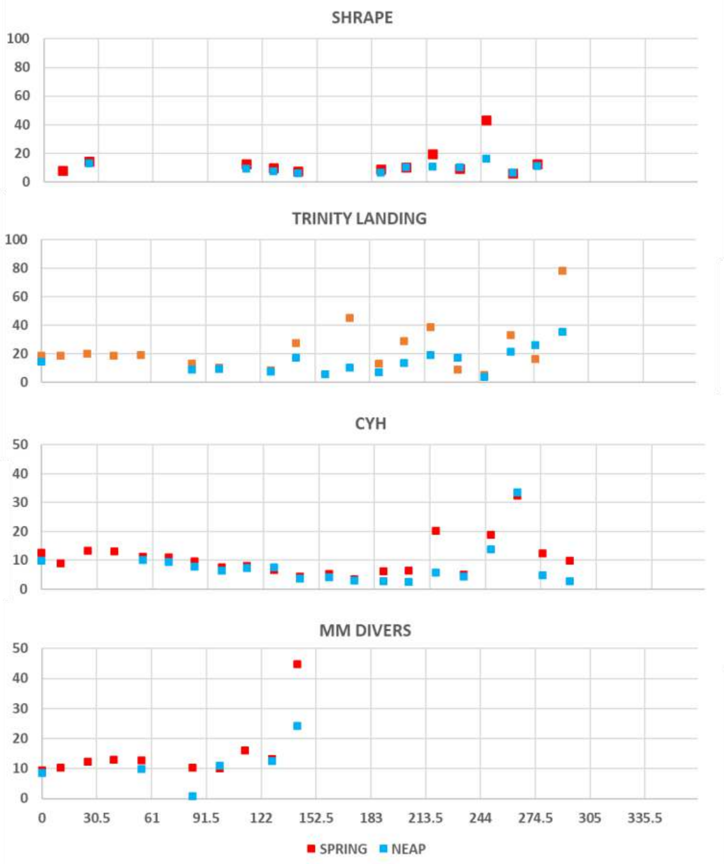


Figure 4. Spring and neap (>2.5m< range) TSS values (no storm) averaged over each spring/ neap cycle.

e) Late ebb elevated TSS concentrations were seen at Shrape, thought to be due to erosion of and runoff from adjacent exposed intertidal mudflats.

This analysis is consistent with the conclusions drawn from the 2016, 2017 data, namely:

- Local tidal scour is not a major source of fine sediment in suspension. Rather, Solent-derived turbidity, created on a regional scale by storminess in the English Channel brings sediment to the Medina estuary during the winter half of the year.
- The local accumulation of this regionally-sourced material can initially provide a readily eroded source of fine sediment that the tidal currents (especially on spring tides) rework to generate the local turbidity regime. In 2018 the regional fine sediment supply was weak through the winter of 2017-2018, and did not begin to feed until the autumn of 2018. As a result of this situation, the first half of the year saw little difference in the spring-neap tide ability to cause turbidity.
- The tendency for a landward gradient in the mean TSS values (highest at Shrape, lowest at CYH-MMC Divers) is consistent with the conclusion that the Solent is the prime source of turbidity.

The characteristics of the turbidity regime in terms of tidal influences, as observed in 2018, support the conclusions reached from analysis of the 2016/17 data [1, 3].

3.1.3 Inter-annual Variability

Significant inter-annual variability in the regional supply of fine sediment to the estuary has previously been identified as an important feature of the TSS regime. It has been speculated that this variability is driven by annual differences in English Channel storm activity, affecting the Wight sea area and generating a region of more turbid water in the English Channel coastal zone as a result of increased erosion of exposed clay strata. This process creates large-area (regional) and prolonged turbidity conditions in contrast to the effects of local-erosion, short-term, storm events. In seeking a control variable which may represent annual variability in the regional storminess of the area, and associated widespread turbidity generation around Wight, records from the Sandown Bay offshore wave recorder were initially relied on (2016). In the autumn of 2017 this instrument began to fail however, and the situation became worse through 2018 with no repair being instigated. The use of this recorder has therefore been abandoned in favour of two other data sources. These are the Milford-on-Sea and Hayling Island offshore wave buoys, representing the western and eastern approaches to the Solent respectively (Channel Coastal Observatory data). A time series of the January-June ('Spring') and July-December ('autumn') recorded storm [8] events at these two sites is plotted in Figure 5.

These time series show that the inter-annual variability in storm intensiveness is marked, varying through the period 2004-2018 between 400 and 1600 events [7] per year. 2017 saw well below the median number of events, 2016 saw above the median number of events and 2018 saw the second highest number of events for the period. In 2016 the 'spring' period saw the most storm events and in 2018 the 'autumn' period was the stormiest. This seasonal feed of suspended sediment to the Medina estuary is seen clearly in the 'All-Sites Averaged' plots of Figure 2 for January-April 2016, and in the September-December period for 2018, although turbidity records are not available for November and December when most effect would be expected.

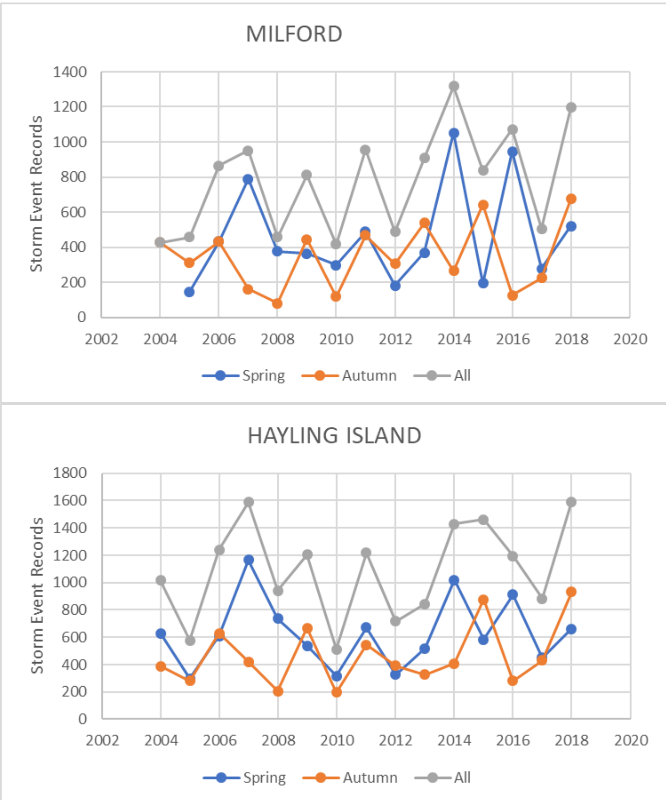


Figure 5. Frequency of occurrence of severe storms, 2003-2017, at the west Solent entrance (Milford-on-Sea) and east Solent entrance (Hayling Island) wave data buoys. Data courtesy of Channel Coastal Observatory.

3.1.3 Storm, shipping and dredging effects.

The combination of the relative infrequency of storm days and large gaps in the turbidity records has made it impractical to analyse in detail these effects from the 2018 dataset. Local storm effects were most obviously seen at Trinity Landing but do not appear to have had a significant impact at the other sites (bottom Figure 2). The peak turbidity seen in August at Trinity Landing (same Figure) may reflect the impact of high yachting activity during that month.

3.2 Bathymetric Change

3.2.1 2018 Quantitative Summary

From comparison of the annual bathymetric surveys (Tables 3 & 4, Figure 6), the estuary as a whole[9] naturally gained approximately 7,700 dry tonnes of mud during 2018, with no dredging occurring. The outer harbour gained ~6320 dry t and the upper estuary (whole area above the chain ferry narrows) gained 1,440 dry t.

This amount of accumulation is around the norm for the modern estuary. Since 1992 (Table 3) the whole estuary has naturally imported of the order of 10,000 dry tonnes of mud each year (counteracted by dredging). A mud loss situation was found in 2016 (both upper and lower estuary) and in the lower estuary in 2017, these atypical results possibly reflecting the short-term effect of the new breakwater (2016-17) and a low level of regional mud feed to the estuary in 2017.

ZONE	Poly	92-15	2016	2017	2018
		dry t	*dry t*	*dry t*	*dry t*
Approaches	**O**	-1,600	5,590	3,854	5,883
Outer harbour	**A**	-1,300	-1,300	-369	701
	B	-500	-2,370	-1,690	658
	C	-650	-860	108	693
	D	700	1,190	-130	230
	E	7,005	-3,200	-6	1,314
	F	1,785	1,600	1,232	2,720
	Tot	7,040	-4,940	-855	6,316
Upper Estuary	**G**	4,604	-180	2,409	1,444

Table 3. Historical summary of erosion and accumulation in the Medina Estuary, 1992-2018. Dredge quantities are allowed for, including capital dredge campaigns '92-'15. See Figure 1 for polygon locations. Data derived from Table 4 using measured[2] sediment dry density values appropriate to the bed type.

Despite the shortcomings of the 2018 turbidity data collection programme it is possible to conclude that the Medina estuary as a whole saw a near-normal level of fine sediment influx during the year, consistent with a higher than average level of regional sediment supply as indicated by English Channel wave recorders (Section 3.1.3).

[9] Excluding the harbour approaches, seawards of the breakwater. A further ~5,880t of sand accumulated in this zone through 2018.

3.2.2 Local Spatial Variability

The bathymetry-change data for the year show very clearly where erosion and deposition are occurring. This can be seen in tabular form in Table 4, where individual small zones [10] (of similar history of bed change [1, 3]) are identified. For each zone the bed level changes 1992-2015 (reduced to an annual mean) and the 2015-16, 2016-17 and 2017-18 changes are listed. The 2018 data are plotted in the three charts of Figure 6.

The key 2018 accumulation areas (>0.05m deposit, ordered by bed level change) are:

- Cowes Yacht Haven south (13.2) 0.21m 2820m^3
- Cowes Yacht Haven north (13.1) 0.15m 1300m^3
- Shepard's Wharf (5.1) 0.14m 1130m^3
- Corinthian YC (13.3) 0.09m 410m^3
- West margin off Shrape Flats (9.2) 0.07m 1260m^3
- Shrape Breakwater zone (12) 0.07m 840m^3
- West Cowes Shore (14.3, 8.2, 8.3) ~0.05m ~1000m^3
- Trinity Landing (14.2) 0.05m 640m^3
- Embayment off Maritime Museum (10.2) 0.05m 170m^3

Sites showing about 0.04m of accretion were the coast slope north of the breakwater (17.1), the fairway off Shephard's Wharf (5.2), East Cowes Marina (30.3) and Medina Wharf (30.4). In most instances, except where dredging had taken place in 2017, the accretionary trends identified above were present in the 2017 data analysis.

Erosion was most seen at the Red Jet turning site (-0.02m, polygon 8.4) and across the Inner Shrape Flats (-0.03m, polygon 11). All other eroding sites have level changes less than 0.02m. Slight erosion continues in polygons 19 a & b, south and east of the new breakwater, but more slowly than in 2017, suggesting that change brought about in this area by the breakwater emplacement is tailing off. Adjacent zones 18 a & b, eroding in 2017, are now showing slight accretion.

The most notable changes compared to the 2017 rates of bed level change are as follows (dredge sites excluded):

a) Coast slope north of bkwtr (17.1). Accreting, then stable 2017, now accreting x 46 fold
b) Solent Shore: West of Entrance (21.2). Eroding, stable 2017, now accreting x 36 fold
c) Inner Shrape Flats (11). Was stable now eroding x 13 fold
d) Embayment off Maritime Museum (10.2). Was eroding now accreting x 6 fold
e) *North of Chain Ferry, west bank (2a). Was eroding now accreting x 5 fold*

Increased sand deposition along the coast in areas a), & b) in the above list may be the result of changed wave patterns and/or increased current velocity in this zone, a response to the new breakwater emplacement. Change in current strength was predicted by the ABP model [2] and may be increasing sand mobility into the zone. Similarly, the new erosion across the Inner Shrape Flats (c) may be related to changed wave conditions in the outer harbour relating to the new breakwater. The accretion seen at d) & e) immediately north of the Chain Ferry could be related to the changed pattern of operation of the new larger ferry introduced in 2017, although this link may be tenuous.

[10] Note these zones and the flux polygons are not exactly contiguous, explaining some level of discrepancy between values derived from each approach.

poly	Site Description	Area m2	1992-15 $m^3 yr^{-1}$	2015-16 m^3	Continuity 92-16 times	Level change 2015-16 cm	Volume by zone m^3	Plus dredge removal m3	2016-17 m^3	Continuity 16-17 times	Level change 2016-17 cm	Volume by zone m^3	Plus dredge removal m3	2017-18 m^3	Continuity 17-18 times	Level change 2017-18 cm	Volume by zone m^3	No dredging 2018
17.1	Coast slope north of breakwater	70,772	729	2,106	2.9	3.0			70	0.0	0.1			3,212	45.9	4.5		
17.3	Coast slope eastern sector	25,891		-41		-0.2			227	-5.5	0.9			772	3.4	3.0		
19b	East Harbour Entrance	40,949	-297	-862	2.9	-2.1			-489	0.6	-1.2			-377	0.8	-0.9		
12	Shrape Breakwater zone	12,492	-945	1,081	-1.1	8.7			-348	-0.3	-2.8			837	-2.4	6.7		**Harbour Approaches**
20.1	Solent shore: West Shrape	59,892	-403	-38	0.1	-0.1			1,463	-38.5	2.4			-1,146	-0.8	-1.9		(outside new breakwater)
20.2	Solent shore: Mid Shrape	83,360		441		0.5			1,451	3.3	1.7			-98	-0.1	-0.1		
20.3	Solent shore: East Shrape	40,663		1,059		2.6		No	103	0.1	0.3		No	180	1.7	0.4		
21.1	Main Fairway entrance	5,032	-106	-15	0.1	-0.3		dredging	-61	4.1	-1.2		dredging	46	-0.8	0.9		
21.2	West of entrance Solent shore	6,910		-146		-2.1	3,585	3,585	-7	0.0	-0.1	2,409	2,409	251	-35.9	3.6	3,677	**OPEN COAST**
14.1	West side of Fairway entrance	18,126	-653	-908	1.4	-5.0		No	-265	0.3	-1.5		2,057	445	-1.7	2.5		
14.2	Trinity Landing & RYS	12,712	-440	-1	0.0	0.0		dredging	-2,225	2225.0	-17.5		m3 dredged	638	-0.3	5.0		
15	West thalweg, inner entrance	7,784	-348	-537	1.5	-6.9	-1,446	-1,446	-206	0.4	-2.6	-2,696	-639	86	-0.4	1.1	1,169	**POLYGON A**
17.2	Eastern fairway sideslope	5,338	-204	-158	0.8	-3.0			-230	1.5	-4.3			-95	0.4	-1.8		
18a	Outer harbour mid-zone	41,299	54	-1,054	-19.5	-2.6			-369	0.4	-0.9			889	-2.4	2.2		
16	East thalweg, inner entrance	7,616	-238	-51	0.2	-0.7		No	-92	1.8	-1.2		No	175	-1.9	2.3		
8.1a	Fairway off West Cowes	20,792	-145	-494	3.4	-2.4		dredging	-499	1.0	-2.4		dredging	366	-0.7	1.8		
19a	East Harbour Entrance	17,611	-1	-874	>100	-5.0	-2,631	-2,631	-688	0.8	-3.9	-1,878	-1,878	-127	0.2	-0.7	1,208	**POLYGON B**
14.3	West Cowes shore private area	8,244	-75	-81	1.1	-1.0			256	-3.2	3.1			531	2.1	6.4		
8.1b	Fairway off West Cowes	14,330	-504	-625	1.2	-4.4			-113	0.2	-0.8			164	-1.5	1.1		
8.2	Shore off Fountain Quay	7,876	-194	-11	0.1	-0.1		No	-465	42.3	-5.9		1,636	439	-0.9	5.6		
8.3	Red Jet inner	2,116	186	51	0.3	2.4		dredging	-854	-16.7	-40.4		m3 dredged	92	-0.1	4.3		
8.4	Red Jet outer	1,920	-76	-275	3.6	-14.3	-941	-941	-437	1.6	-22.8	-1,613	23	-47	0.1	-2.4	1,179	**POLYGON C**
18b	Outer harbour mid-zone	16,709	-147	-492	3.4	-2.9			-174	0.4	-1.0			292	-1.7	1.7		
9.1	Venture Quay and Small Boat Channel	27,461	304	-616	-2.0	-2.2			-548	0.9	-2.0			496	-0.9	1.8		
9.2	West margin off Shrape Flats	17,300	1,050	1,680	1.6	9.7		No	573	0.3	3.3		No	1,262	2.2	7.3		
10.1	Outer Shrape Flats	11,993	71	597	8.4	5.0		dredging	217	0.4	1.8		dredging	-155	-0.7	-1.3		
11	Inner Shrape Flats	34,196	-16	1,361	-87.7	4.0	2,530	2,530	76	0.1	0.2	144	**144**	-956	-12.6	-2.8	939	**POLYGON D**
8.1c	Fairway off West Cowes	35,126	-1,237	-1,977	1.6	-5.6			-1,016	0.5	-2.9			89	-0.1	0.3		
5.1	Shepard's Wharf	8,228	-590	892	-1.5	10.8			-4,291	-4.8	-52.2			1,129	-0.3	13.7		
5.2	Fairway off Shepard's Wharf	4,358	16	-30	-1.9	-0.7			-1,999	66.6	-45.9			166	-0.1	3.8		**Outer Harbour**
5.3	Fairway south of Shepard's Wharf	8,068	15	-325	-21.1	-4.0			-361	1.1	-4.5			190	-0.5	2.4		(inside new breakwater)
6	Fairway off Car Ferry Terminal	11,261	-86	-749	8.7	-6.7			-228	0.3	-2.0			64	-0.3	0.6		
7	Car Ferry Terminal	4,928	-47	-290	6.2	-5.9			-33	0.1	-0.7			-29	0.9	-0.6		
10.2	Embayment off Maritime Museum	2,576	-38	50	-1.3	1.9			-21	-0.4	-0.8			121	-5.8	4.7		
4	Fairway north of Chain Ferry	4,958	-5	-226	41.3	-4.6		No	-58	0.3	-1.2		7,378	129	-2.2	2.6		
2a	North of Chain Ferry west bank	8,430	-90	-253	2.8	-3.0		dredging	-26	0.1	-0.3		m^3 dredged	135	-5.2	1.6		
3a	North of Chain Ferry east bank	9,700	-107	-330	3.1	-3.4	-3,238	-3,238	-171	0.5	-1.8	-8,204	-826	211	-1.2	2.2	2,205	**POLYGON E**
13.1	CYH north	8,204	-90	439		5.4		No	303	0.7	3.7		1,064	1,301	4.3	15.9		
13.2	CYH south	13,764	-165	2,008		14.6		dredging	1,435	0.7	10.4		m3 dredged	2,823	2.0	20.5		
13.3	Corinthian YC	4,320	24	256		5.9	2,703	2,703	-972	-3.8	-22.5	766	**1,830**	409	-0.4	9.5	4,533	**POLYGON F**
1	South of Chain Ferry channel centre	17,639	-31	-601		-3.4			-268	0.4	-1.5			265	-1.0	1.5		
2b	South of Chain Ferry west bank	18,536	174	-224	-1.6	-1.2			-487	2.2	-2.6			615	-1.3	3.3		
3b	South of Chain Ferry east bank	9,874	-1,398	-46	0.6	-0.5			56	-1.2	0.6			107	1.9	1.1		
30.1	West bank south of UKSA	17,408	324	553	2.1	3.2			129	0.2	0.7			320	2.5	1.8		
30.2	Channel off East Cowes Marina Village	61,493	-284	-754	0.2	-1.2			-781	1.0	-1.3			981	-1.3	1.6		**Upper estuary (above chain ferry)**
30.3	East Cowes Marina Village	35,736	-1,398	-14,607	8.5	-40.9			3,654	-0.3	10.2			1,574	0.4	4.4		
30.4	Medina Wharf	10,596	-144	-285	1.3	-2.7		20,500	-264	0.9	-2.5		414	457	-1.7	4.3		
31	Estuary off Kingston Wharf	70,069	-668	-2,364	2.2	-3.4		m^3 dredged	-174	0.1	-0.2		m3 dredged	1,114	-6.4	1.6		
32	Upper estuary to Folly Inn	230,627		-4,460		-1.9	-22,788	-2,288	2,447	-0.5	1.1	4,312	4,726	-2,018	-0.8	-0.9	3,415	**POLYGON G**
	TOTALS	**1,215,341**	**-8,219**	**-22,226**			**-22,226**	**-1,726**	**-6,760**			**-6,760**	**5,789**	**18,325**			**18,325**	

(red=accretion, green=erosion, blue= high difference to previous years)

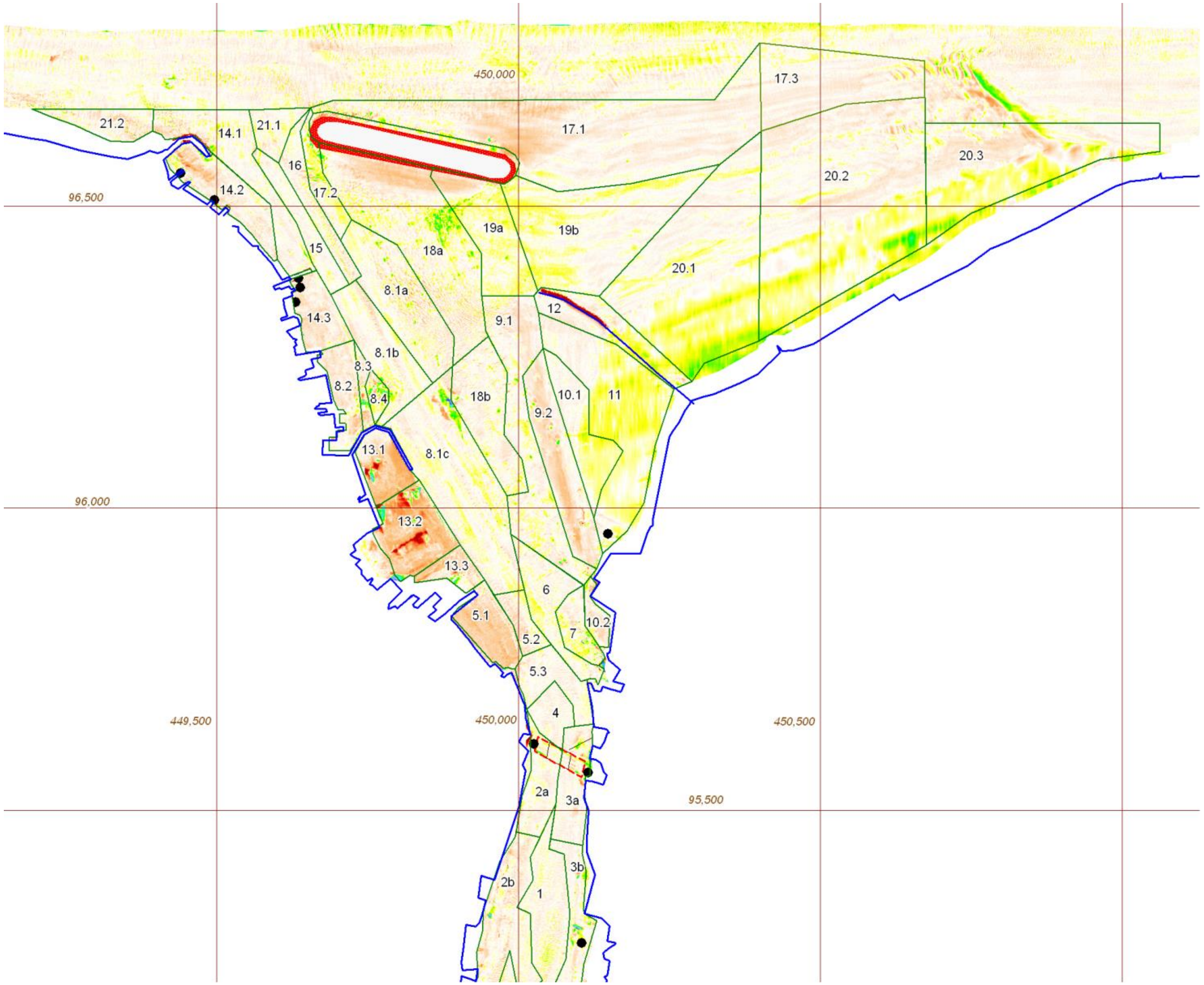


Table 3. (Previous page) Bed level changes between 1992, December 2015, December 2016, December 2017 and December 2018, by estuary zone (see Figure 6 for zone location). Change 2017-2018 is compared to the history of change 2016-2017, change 2015-16 is compared to 1992-2015 annual rate.

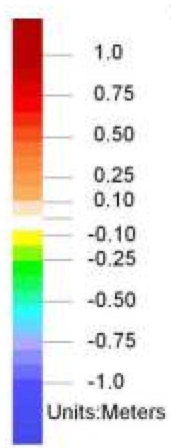
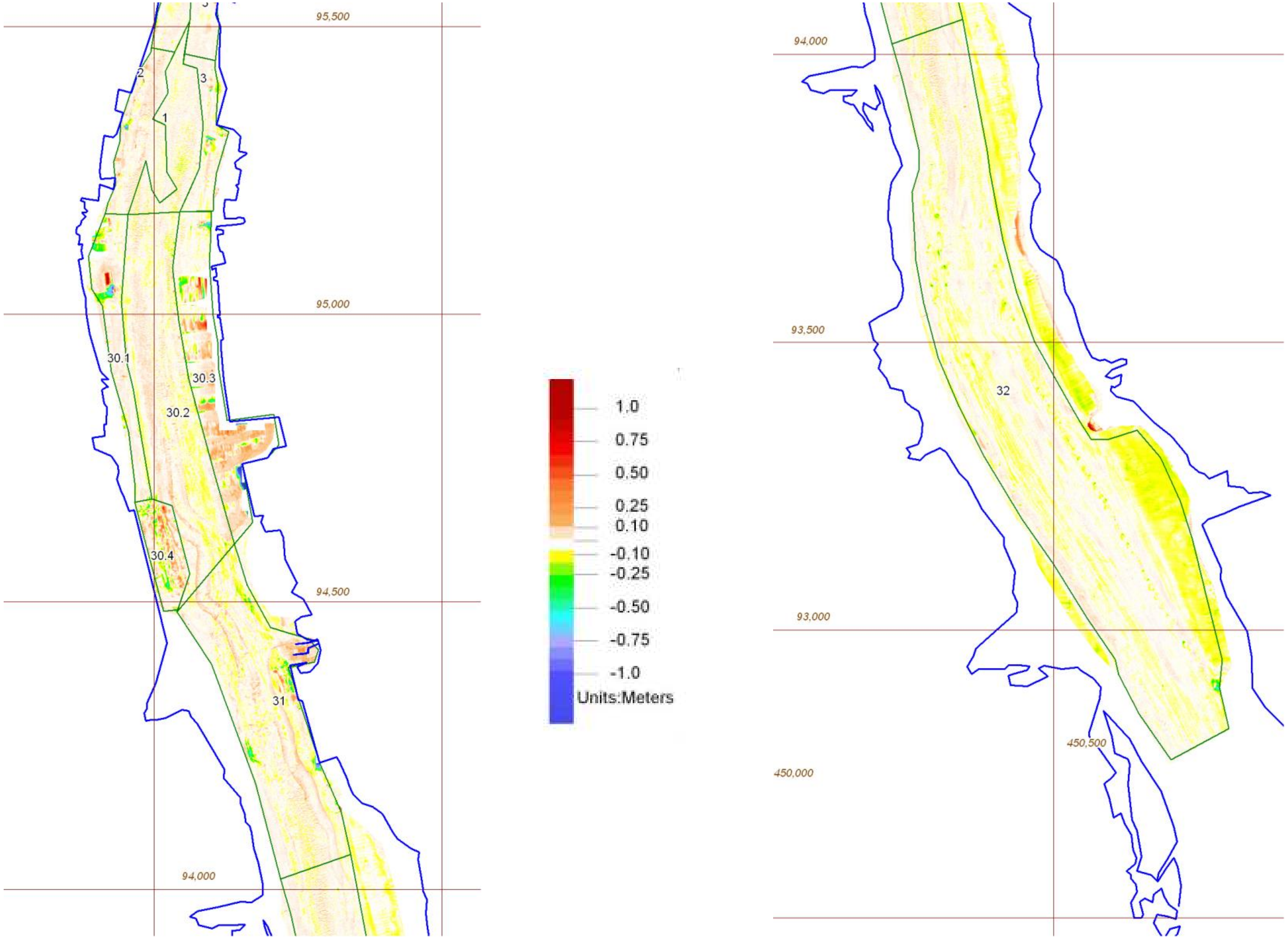


Figure 6. Chart showing change in bed levels from December 2017 to December 2018 (left and continues overleaf).


95,500
95,000
94,500
94,000
1
2
3
30.1
30.2
30.3
30.4
31
1.0
0.75
0.50
0.25
0.10
-0.10
-0.25
-0.50
-0.75
-1.0
Units:Meters
94,000
93,500
93,000
32
450,000
450,500

4. Conclusions and Recommendations

Although there were problems with the turbidity measuring aspects of the 2018 Medina estuary sediment monitoring programme, relating to various practical aspects of the data collection systems, an analysis of the year's results has been successfully completed, although all objectives could not be met.

The data collected are all consistent with the model of processes of sediment circulation identified in the 2015/2016 surveys and from the initial years of monitoring. The annual pattern of turbidity values is dominated by the seasonal (autumn/winter/spring) influx of fine sediment generated by storm-wave-driven erosion of clay sediment along the English Channel coasts from Poole to Selsey. This Channel storminess was lower than average during the autumn of 2017 and the spring of 2018, and consequently the normal pattern of higher spring turbidity averages, seen in previous years, was absent in 2018. However strong storms during the autumn of 2018 created a large influx of fine sediment, contributing to a normal level of mud being imported into the estuary by the close of 2018.

Local tidal reworking occurs at times of peak velocities within each semi-diurnal cycle and is most evident in the months following the input of fine sediment from offshore (in 2018, the latter part of the year), and essentially only over spring tides. Local erosion of mud from the seabed (probably under combined winter wave and tidal action) is still occurring, although slowed, in the zone south and east of the new breakwater (polygon B), indicating a tailing off in the impact of the new structure.

During 2018 the estuary accumulated some 7,700 dry tonnes of mud (Table 3), with some 6,300t being deposited the lower estuary (north of the chain ferry narrows) and 1,400t accumulating upstream of the Chain Ferry narrows. The latter figure has to be treated with some caution however, as the bathymetry monitoring only extends as far south as Folly Point, and there was no reconciliation with TSS flux tonnages this year. Dredging records indicate that the 'status quo' has been historically maintained in the Medina Estuary with an averaged removal of about 10,000 dry tonnes of mud each year. 2018 was therefore a near-normal year, compared with 2016 and 2016 which saw less import of mud (Table 3).

The accumulation seen in various localities will have been partly fed from erosion zones within in the estuary, with the (large) surplus coming in from offshore and from (low) river input. As has always occurred, the main zones for mud accumulation in 2018 were the marinas, with Cowes Yacht Haven seeing the largest accumulation. Polygon D (Shrape Flats inside the breakwater, sub-polygons 9.2, 10.1 and 11), normally a site of significant mud accretion, is currently showing near-stability (slight erosion in 2017 and slight accretion in 2018). This situation appears to reflect a balance between erosion over the shallow inner Shrape Flat zone and significant accretion along its deeper western margin.

The modest increase in sand accretion seen across the eastern approaches to the harbour (sub polygons 20.1 & 20.2) in 2016-2017 appear to have stabilised, with slight erosion replacing deposition in 2018. This is a zone of sand transport, and the ABP modelling foresaw increased tidal flow through this shallow, partly intertidal zone as a result of the breakwater emplacement. The cessation of the pattern of accretion since the breakwater emplacement is reassuring. North of the new breakwater (17.1) and particularly associated with the NE corner of the structure there is widespread slight shallowing. This is probably related both to changed tidal current patterns and the reworking of surplus gravel material left in this (littoral) location on completion of the works.

Recommendations made to CHC during 2017 to improve the efficacy of this project have been acted upon. Turbidity sensor mountings were improved, and internet-connected loggers installed in December 2018. A programme of current metering, to check the ABP model output, is to be carried out during 2019.