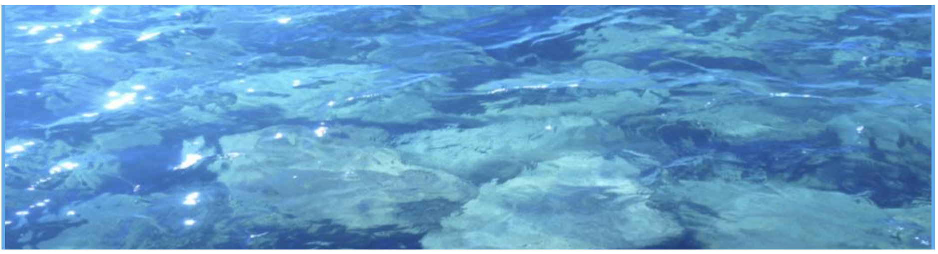
COWES HARBOUR COMMISSIONERS

Sediment Flux Measurement in the Medina Estuary
Monitoring Results 2017

Report AmbCHC04

DRAFT

June 2018



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Executive Summary

Measurements of fine sediment dispersion through and around the Medina estuary have been made since January 2016. This report covers the second year of monitoring, January-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). Due to a variety of maintenance problems with the turbidity measuring systems during 2017 the objectives could not be fully met.

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 Wight region, providing a clay-rich material from the Oligocene strata that outcrop widely in that area. Significant inter-annual variability in this input can be expected and the winters of 2016 and 2017 probably provided only a modest influx, based on storm wave records. 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 the erosion rate is still significant in 2017 but is less than that seen in 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 winter influx of mud from offshore. Storms (wind and wave action) play a lesser role, with effects most seen in the vicinity of the eastern harbour entrance (Shrape Flats).

Results from the outer harbour (between the new breakwater and the chain ferry) indicate that some 850 dry tonnes of sediment were lost from the area over the year 2017. Results from the upper estuary (above the chain ferry narrows) indicate accretion of ~2,400 dry tonnes of mud in that zone, the net change for the estuary as a whole being a gain of some 1,500 dry tonnes of fine sediment.

Historically the estuary is known to naturally import mud each year, hence requiring dredging (~10,000 dry tons per year). 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. The decreased level of mud import is explainable both by a low level of winter regional suspended sediment source input, and increased erosion from the estuary floor in the vicinity of the new breakwater.

Across the eastern outer approaches to the estuary (shore-slopes east of the Shrape breakwater) sand accumulation has increased since the emplacement of the new breakwater. This effect, most likely caused by the predicted modification of tidal flow in this area, does not seem to be impacting on adjacent zones inside the estuary.

Various recommendations are made to improve the monitoring system/methodology to allow continued accurate monitoring to proceed.

Sediment Flux Measurement in the Medina Estuary Monitoring Results 2017

1. Introduction

The monitoring of fine sediment flux through the Medina Estuary was initiated 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 full details of the monitoring programme.

This report covers the second year of sediment flux monitoring, from January to December (inclusive) 2017. Methods used are near-identical to those used in 2016. 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 exchanged 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 describes the methodology adopted, the constraints imposed by data loss and modelling inaccuracies, and provides the observed sediment flux patterns and tonnages.

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.
2. Water level (tidal stage) data from a single site in outer harbour, determined at 15-minute intervals.
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.

[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

4. Bed level data (bathymetry) measured using a precision multibeam system once per year (in December).

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.

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 ~$800m^3s^{-1}$.

Some minor changes in the analytical method have been trialled, and these are highlighted in following sections.

The effects of dredging at several sites in the estuary during mid-late February 2017 have been fully taken into account within the various analyses undertake.

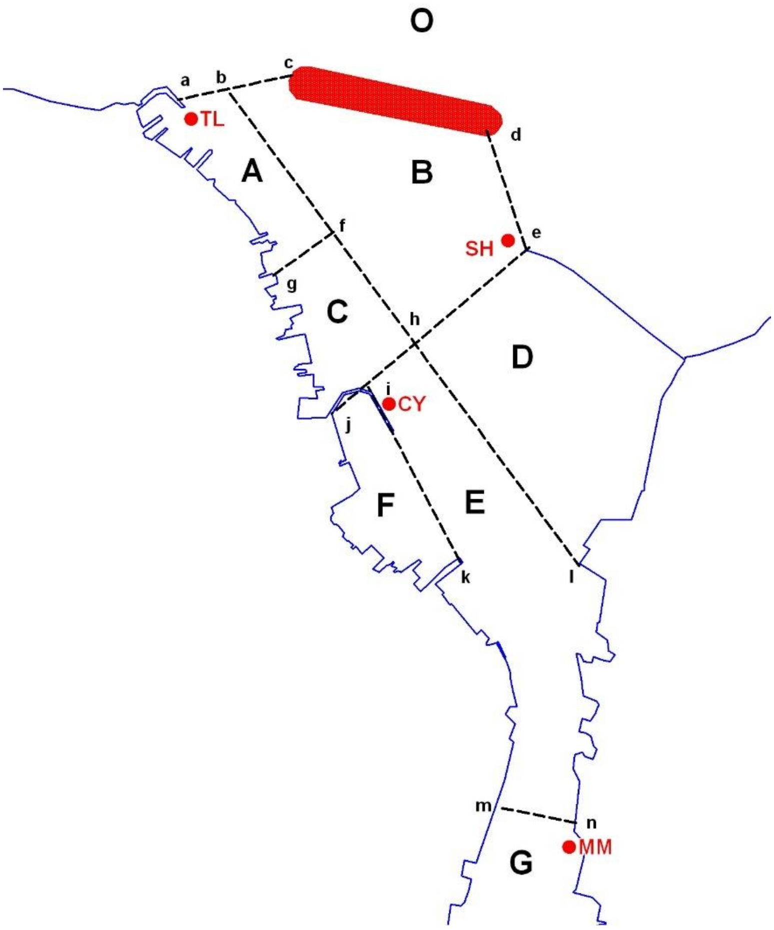

Figure 1. The lower Medina Estuary showing turbidity measuring sites (red dots), key area polygons (labelled A-G) and cross-sections (ab, bc etc) through which water flow was predicted from the ABPmer model.

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

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).

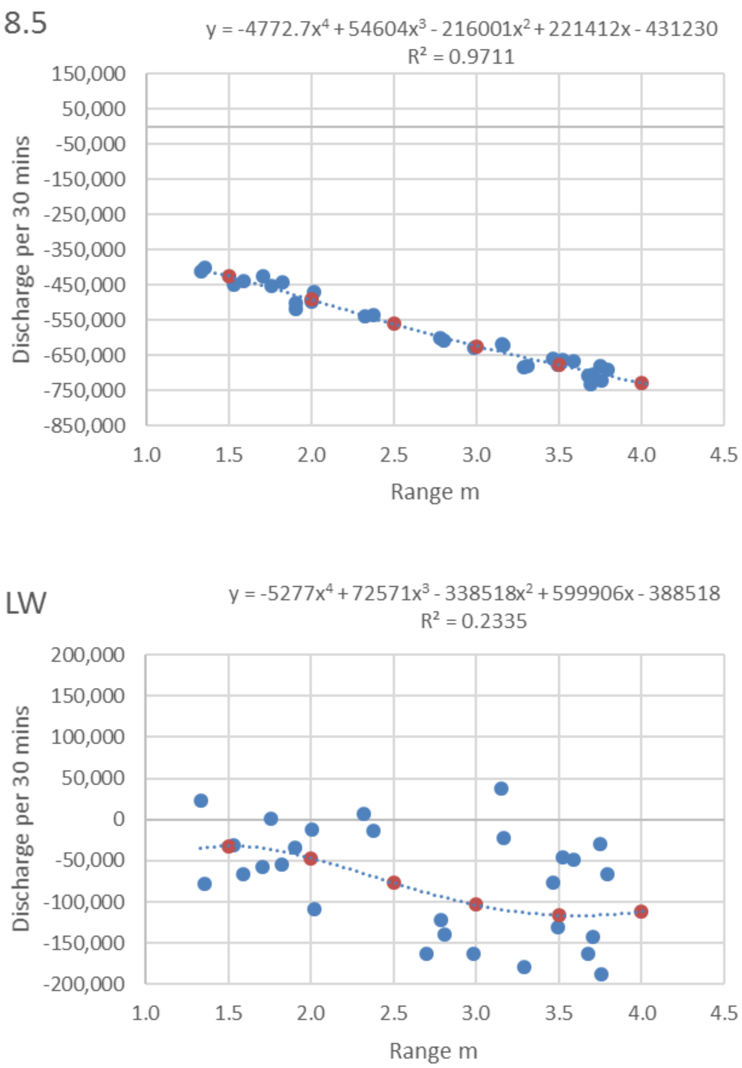

Figure 2. Examples of fitted polynomial curves for individual cross-sections, relating discharge to tidal range (shown for low water LW and 8.5 hours after LW).

Examples of a good fit (R^2>0.9) and worse fit (R^2<0.3) equation are shown in Figure 2. Worst fit simulation tended to occur around the low water period, with slowest flows, therefore poor correlations having minimal impact on precision. An Excel look-up table was created for each profile for the coefficients of the polynomial equation, so that given the range of the tide (subdivided by rising or falling spring-neap limb) and the time after LW, the half-hour discharge through the section could be readily determined.

Minor inaccuracies in these regression procedures and also in the model source data meant that a cumulative error could build in each monthly time series of water volume exchanges, producing a (clearly impossible) situation of constantly rising or falling mean water levels. Several methods for removing this error have been trialled, including fitting linear and polynomial regression lines to the cumulative volume change plots and removing long term trends (monthly linear regression lines were used for correcting the 2016 data). The most consistent method, now relied upon, has been to derive the mean cumulative volume change for each tidal cycle (via a 25-point running average) and to use the deviations from this changing mean as the actual volume change per 30 minutes. The error per half hour, so derived, was then equally applied to the volume passing through each of the contributing cross-sections for each polygon, to correct the total polygon value. An example plot is shown in Figure 3.

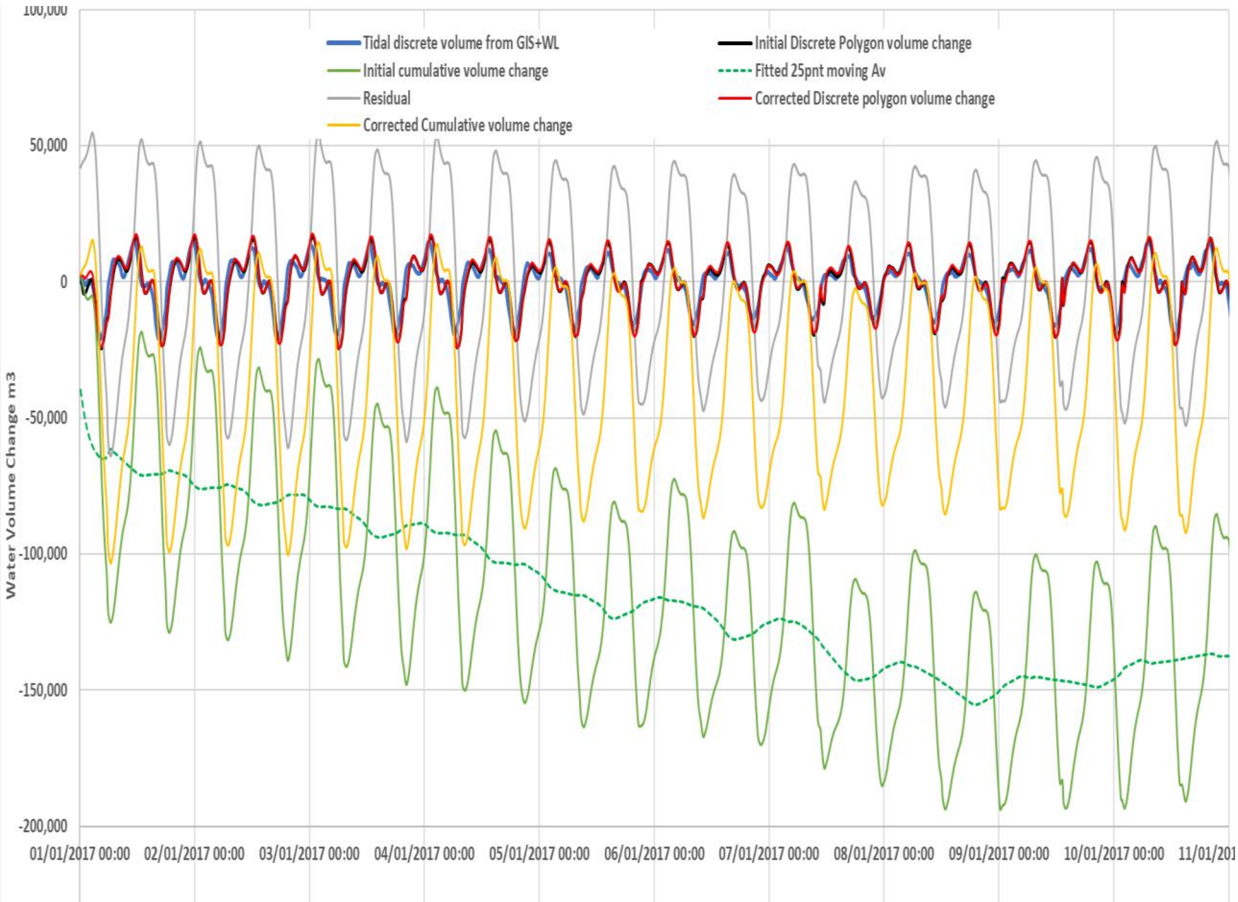

Figure 3. Example of effect of removing the (erroneous) progressive residual cumulative value from the model data. Eleven days of record are shown.

As a quality-control procedure it was possible (for polygons A-F) to apply actual tidal levels to the GIS data of the morphology of each polygon thus predicting approximate water volume changes every half hour. The summation of the profile data volume changes for the same polygon should approximately equal this volume. Odd spikes of inaccurate data (normally associated with very low neap tides, not adequately covered by the model) were identified in this manner, and these data ignored in favour of averages of adjacent good data points. Plotting of both spike-corrected and uncorrected data showed that the spikes have little influence on the overall flux measurements.

2.3 Total Suspended Solids (TSS) Data

2.3.1 Data loss

Through the year about 35% of the potential number of turbidity readings were lost for a variety of reasons. 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. A poor memory allocation problem developed slowly and not obviously in the Shrape sensor. Similarly a recurrent wiper failure at the MM Divers site proved difficult to resolve.
- Staff shortages. On several occasions servicing was missed by periods of up to a week due to staff unavailability.
- Weed/biota contamination of the optical windows. 2017 was very productive in biofouling terms and at some periods one-week service intervals should have been instigated. Staff shortages did not allow this to be possible however.

All four sensors were only operating together for about 14% of the time, and for 10% of the time only one of the four sensors was operational (Figure 4). This shortage of data made it near impossible to 'infill' missing data, as can be attempted for short gaps when three of the sensors are working. 2017 was therefore a very bad year for turbidity data, and that has made accurate sediment flux modelling near impossible. However the full flux analysis has been undertaken as part of the development of the experimental procedures.

2.3.2 Data Processing

An Excel workbook was set up 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 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. For each half hour interval (after LW) an average TSS value was calculated from the two 'cleaned' fifteen-minute readings so generated.

In order to derive a 30-minute average TSS value for each profile (ab, bc, bf etc, Figure 1) an assumption has to be made about how the TSS values vary spatially between the four turbidity measuring sites. The (simplest) model of linear variation through space was used in the analysis of

Start	*Duration*	*SH*	*TL*	*CY*	*MM*
01-Jan	14	1	0	1	1
15-Jan	4	0	0	1	1
19-Jan	25	1	0	1	1
13-Feb	4	1	0	0	0
17-Feb	5	1	0	1	0
22-Feb	8	1	1	1	0
02-Mar	1	1	0	1	0
03-Mar	24	1	1	1	0
27-Mar	11	1	1	1	1
07-Apr	6	0	0	1	1
13-Apr	14	0	0	0	1
27-Apr	7	0	0	1	1
04-May	34	1	0	1	1
07-Jun	9	1	1	1	1
16-Jun	3	1	0	0	0
19-Jun	4	1	0	0	1
23-Jun	15	1	1	1	1
08-Jul	7	1	1	0	0
15-Jul	6	1	0	0	0
21-Jul	3	0	0	0	0
24-Jul	6	1	1	0	1
30-Jul	11	1	1	0	0
10-Aug	3	1	1	0	1
13-Aug	4	1	1	0	0
17-Aug	5	1	1	1	0
22-Aug	1	0	0	1	0
23-Aug	2	0	1	1	0
25-Aug	3	1	1	1	1
28-Aug	16	1	1	1	0
13-Sep	3	1	0	0	0
16-Sep	3	0	0	0	0
19-Sep	1	1	1	1	0
20-Sep	22	1	1	0	0
12-Oct	4	0	1	0	1
16-Oct	12	1	1	0	0
28-Oct	3	0	1	0	0
31-Oct	3	0	0	0	0
03-Nov	5	0	1	1	1
08-Nov	12	1	1	1	1
20-Nov	2	0	1	1	1
22-Nov	2	0	0	0	0
24-Nov	19	0	1	1	1
13-Dec	4	0	1	1	0
17-Dec	1	0	1	0	0
18-Dec	1	1	1	0	0
19-Dec	12	1	1	1	0

	Operational Statistics	*Main Failure reason*
13.7	% of time all four sensor operational	-
9.6	% of time only one sensor operational	
77.0	% of time SHRAPE operational	Sensor memory malfunction & weed fouling
60.8	% of time TRINITY LANDING operational	Electricity supply
67.1	% of time CYH operational	Electricity supply
54.0	% of time MM DIVERS operational	Wiper malfunction & electricity supply

64.7 % of total data possible was collcted
Green equals good data collection

Figure 4. Turbidity sensor data loss during 2017.

the 2016 data, when sensitivity tests run using other models showed little difference to the flux results. If the centroid of a profile was within 50m of a turbidity measuring site, then just the data from that measuring site was used. Otherwise, the TSS concentrations from the 2 or 3 closest measuring sites were combined, weighted according to the inverse distance to the sensors (closest sensor had the greatest influence). During the analysis of the 2017 data this simple approach has been modified slightly, for four profiles (Table 1) where the presence of a recirculating gyre complicates the simple linear approach. For these four profiles, periods of the tidal cycle are identified when an 'upstream' selection process best replaces the linear gradient approach. Sensitivity testing indicated that this change provided more realistic simulation.

	Applies: Tide Hr	Inverse distance to sensor (or blank if distal) SH	TL	CY	MM	Tot
ab	All		1			n/a
bc1	>5	130	460			590
bc2	<5		1			n/a
bf	All	580	790	530		1900
fg	All	555	605	610		1770
de	All	1				n/a
eh1	<2.5,>8	210		120		330
eh2	2.5-8			1		
fh1	0-10	580	430	610		1620
fh2	>10		200	380		580
hi	All			1		n/a
ij	All			1		n/a
hl1	<2.5,>8	830		980	530	2340
hl2	2.5-8			1		n/a
ik	All			630	130	760
mn	All				1	n/a

Table 1. Model used in 2017 for calculation of Total Suspended Solids values for each profile. See Figure 1 for locations.

2.4 Calculation of Sediment Retention or Loss in Polygons

Having determined for each 30-minute tidal period through the year of 2017 both the water volume crossing each profile (Section 2.2) and the average TSS concentration of that water (Section 2.3), the suspended sediment flux across the section for each 30-minute period was calculated as the product of the two values. The retention or loss of fine sediment from each of the polygons A-G could then be calculated by combining the flux across each of the profile sections forming the polygon, adding the flux if it flowed into the polygon or subtracting it if it flowed out. This process provides a figure of sediment accumulation or loss within each polygon in dry tonnes. Tonnages can be converted in to an equivalent volume of bed sediment, using a bed dry-density[6] of 0.6 t m^{-3} in depositional polygons and 0.9 t m^{-3} in erosional polygons, allowing the sediment flux results (t) to be compared with the annual bathymetric results (m^3).

2.5 Bed Level Changes

The results of the bathymetric surveys conducted in December 2016 and December 2017 have been compared. The volume of sediment that had eroded or accreted on the Medina bed between the two surveys was determined by subtracting the data-averaged values on a 1m^2 grid from both 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 precision of multibeam surveys, at best, 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.

[6] From field data acquired during the 2015 survey. Definition of erosional or depositional condition was applied on the basis of net monthly change.

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.

As an initial step in this calibration process, a quality control procedure has been designed. 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 small 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 (Table 2 Procedures ~2 & 3).

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

QC Procedure #1: Slipway sites

Slipway	Mean level mODN			(+0.04m)	(+0.06m)
Site	1992	2015	2016	2016C	2017C
1	-0.44	-1.93	-2.11	-2.07	-1.96
2	-1.14	-2.35	-2.34	-2.30	-2.33
3	0.43	-1.58	-1.67	-1.63	-1.66
4	0.14	-2.18	-2.29	-2.25	-2.27
5	-1.52	-1.93	-2.05	-2.01	-1.98
6	-1.28	-1.49	-1.60	-1.56	-1.48
7	-1.86	-1.67	-1.62	-1.58	-1.58
8	-1.08	-1.14	-1.10	-1.06	-1.04
9	-2.41	-0.68	-0.47	-0.43	-0.61
10	-2.37	-1.11	-1.10	-1.06	-0.96
11	-2.21	-2.20	-2.05	-2.01	-1.97
12	-0.10	-0.83	-0.86	-0.82	-0.9

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

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
2015-1992	-0.21	-0.25	-0.42
2016C-2015	-0.01	0.04	-0.02
2017C-2015	-0.04	0.07	-0.06

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
2015-1992	-0.15	-0.72	-0.41
2016C-2015	-0.02	-0.03	-0.03
2017C-2015	-0.04	-0.03	-0.06

Table 2. Bathymetry Quality Control data.

Two potential problems arose during the collection of the December 2017 multibeam bathymetry data.

- The first was an apparent inconsistency in the data initially delivered by the contractors (Shoreline Surveys). On investigation it transpired that an unusual setting had been used in the multibeam equipment during just one day, in order to improve the survey footprint in a difficult area. This new setting had not been correctly allowed for and it was calculated that a 27cm error had been introduced. The data were corrected and the discrepancies, in zones of data overlap, appeared to be resolved. However this correction was all done as a post-processing procedure, and no rerun of any data was undertaken. Whilst it is reasonable to assume that the corrections were very accurate, the potential of some low-level residual error must be recognised. The day of error was largely concentrated in the southern part of the Medina, above the Chain Ferry Narrows. This issue will be referred back to later in the report.

- A new chain ferry was installed at Cowes during 2017. There were initial problems with how the ferry landed at either terminal, with changed pull on the ferry chains. The bathymetric survey showed that the shallower areas of the bed in Chain Ferry Narrows were significantly modified as a result of the changed ferry/chain behaviour. This may have resulted in some change to the bed levels within the polygons used for quality control (Table 2). In view of this, greater precedence was given to the slipway QC points rather then the Chain Ferry Narrows QC area (Table 2).

The quality control procedure suggested that all bathymetric levels recorded during the 2017 survey should have 0.06m added to them to be consistent with the 2015 baseline levels. This compares favourably with the +0.04m correction applied to the 2016 dataset. The bed volume change from December 2016 to December 2017 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.

2.6 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 [7] 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, although with clear evidence that improvements in the developing methodology were required. However, the fine sediment flux data for 2017 is recognised as flawed due to the low success rate for turbidity data collection, so the bathymetric volume changes have not been tuned to sediment flux values (process (1) above) for

[7] 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.

the year 2017. Calibrating the flux data, in order to reveal some idea of the patterns of accumulation through the year, has however been attempted. The calibration process is summarised in Table 3, and the resulting accumulation rates, by polygon, from the sediment flux analysis, is plotted in Results section. Conversion of the bathymetric change data volumes to tonnes was undertaken per sub-polygon, using a dry density of 1.6 in sand areas, 1.0 for dredged mud, 0.9 for naturally eroded mud and 0.6 for accumulating mud.

ZONE	Poly	Change 2017 Bathy		Change Flux	Flux Correct
		m3	*t*	*t*	
Approaches	**O**	2409	3,854	nd	-
Outer harbour	**A**	-1500	-369	-1,100	0.336
	B		-1,690	12,000	-0.141
	C		108	900	0.119
	D		-130	200	-0.651
	E		-6	3,000	-0.002
	F		1,232	350	3.520
Upper estuary	**G**	3300	2,409	-400	-6.023

Table 3. Conversion of bathymetric change volumes to dry tonnages and comparison with modelled sediment flux tonnages.

From Table 3 it can be seen that for Polygons A, C, D & F the bathymetry-derived and flux-derived tonnages are of a similar magnitude. The slightly greater difference in polygon G (upper estuary) may be explainable by the very different estuary bed areas used by each approach. Also, inaccuracies arising from the problem due to changing the multi-beam set-up in this area (discussed in 2.5) may also account for the discrepancy, which equates to only a 1cm bed-level error [8]. The large differences for polygons B and E is likely to reflect inaccuracies due to the large gaps in the turbidity dataset, and as seen with the 2016 analysis, the need for further refinement of the sediment flux methodology.

3. Results

3.1 The 2017 Turbidity Regime.

3.1.1 Annual Variability

The fortnightly[9] mean values and standard deviations [10]of TSS data collected from all sites are shown in Figure 5. 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[11] deleted. The dredging period (6-20th February) was also classified as a 'storm period'. Thus the variation in TSS seen in this data set should be

[8] Because of the potential for bathymetric error in Polygon G, the correction value used to align the flux tonnages has been halved in the final plotting.

[9] Data averaged over a spring neap cycle (lowest neap to lowest neap).

[10] About 70% of all observations lie within the range Mean $\pm$ one Standard Deviation.

[11] 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 Sandown Bay wave condition >1.5m Hs and 10s period.

caused only by season variation in regional TSS condition, regular tidal variability and shipping effects.

- 'Just storm data', from storm event and maintenance dredging days only.

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

a) There is a seasonal variation in the all-site means No Storm data from about 20-25mg l^{-1} in the winter at the beginning of 2017 to 5-10 mg l^{-1} in summer (falling in late April), then rising again to about 20mg l^{-1} in the following winter.
b) Late May showed a spike increase over the typical summer No Storm mean values (to ~20 mg l^{-1})
c) The standard deviations associated with these No Storm means are generally low (normally <10 mg l^{-1}). However higher values were evident, notably at Shrape, during the first part of the year (pre-April) and with peaks again in late May and early September.
d) The 'all data' mean values including storms were similar to 'no storm' values throughout the latter part of the year, but higher January-March, peaking at 40mg l^{-1}.
e) Storm-induced increases in TSS were most evident at the Shrape site.
f) The 'All-site mean' data for both all data and 'no-storm' data for 2017 were broadly similar to the 2016 values. January to March means in 2016 were slightly higher overall but did not reach the peak value of 40mg l^{-1} attained in 2017. Summer values were very similar between the two years. November and December means were slightly higher in 2017.

This (most simplified) dataset analysis confirms the conclusions reached from the 2016 analyses that seasonal variability in regional water quality (turbidity) is the major control of the TSS regime seen in the Medina, and that for 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 6 shows the individual fifteen-minute TSS data averaged by tidal hour and grouped by tidal range, for each site. Figure 7 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 values 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 (Figure 6). This effect is not very marked however, particularly over neap tides.
e) Late ebb elevated TSS concentrations were seen at CYH and particularly 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 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 months.
- The local accumulation of this material initially provides a readily eroded source of fine sediment that the tidal currents (especially on spring tides) rework to generate the local turbidity regime in the winter and early spring. Through the late spring, summer and autumn this new material became both dispersed into the most sheltered mud accumulation zones and consolidated into the seabed, thus being removed from the active local TSS recirculation system.
- The tendency for a landward gradient in the mean TSS values (highest at Shrape, lowest at MM Divers) is consistent with the conclusion that the Solent is the prime source of turbidity.
- Significant inter-annual variability in the supply of fine sediment to the estuary may be a feature of the TSS regime. Through the first few months of 2016 spring tide reworking of fine sediment was relatively active compared to neap activity. This difference was not strongly seen in the patterns of turbidity through the winter of 2016-2017, suggesting a lower level regional input at that time. Offshore Wight wave data (Sandown Bay[12], timeseries 2008-2018, Figure 8) indicate that regional seabed and coast erosion as a result of storm wave action may have been slightly less during 2017 winter periods compared to 2016, and at a modest level generally, consistent with the turbidity situation recorded in the Medina.

In general the characteristics of the turbidity regime in terms of tidal influences, as observed in 2017, support the conclusions reached from analysis of the 2016 data [1, 3]. However the data show a slightly more random situation than was observed in 2016, and this is probably largely attributable to the large data gaps in the 2017 dataset.

3.1.3 Storm, shipping and dredging effects.

The following comments are based on analysis of just the ‘storm day’ dataset. 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 2017 dataset. Storms clearly elevated TSS values at Shrape (Figure 5) but do not appear to have had a significant impact at the other sites. Shipping effects were not noticeable from the general pattern of the data (compared with 2016 when a turbidity peak appeared to coincide with high August yachting activity). Dredging occurred between the 6th and 20th February, a stormy period generally, and plumes from this activity may have contributed to the TSS mean peak (~43mg l^{-1}) seen at Shrape through the mid-February spring-neap cycle (Figure 5).

3.2 Fine Sediment Flux

3.2.1 2017 Quantitative Summary

From comparison of the annual bathymetric surveys (Tables 3 & 4, Figure 9), the estuary as a whole[13] naturally gained approximately 1,500 dry tonnes of mud during 2017, and in addition was dredged of a further 12,500 t[14] of spoil. The outer harbour naturally lost ~850 dry t and the upper estuary (whole area above the chain ferry narrows) gained ~2,400 dry t (there is some evidence the latter figure may be less, Section 2.5).

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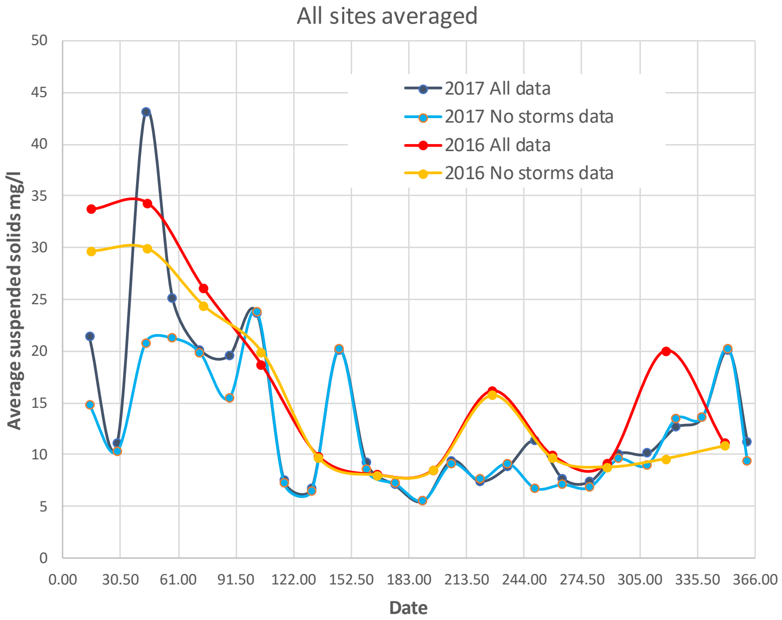
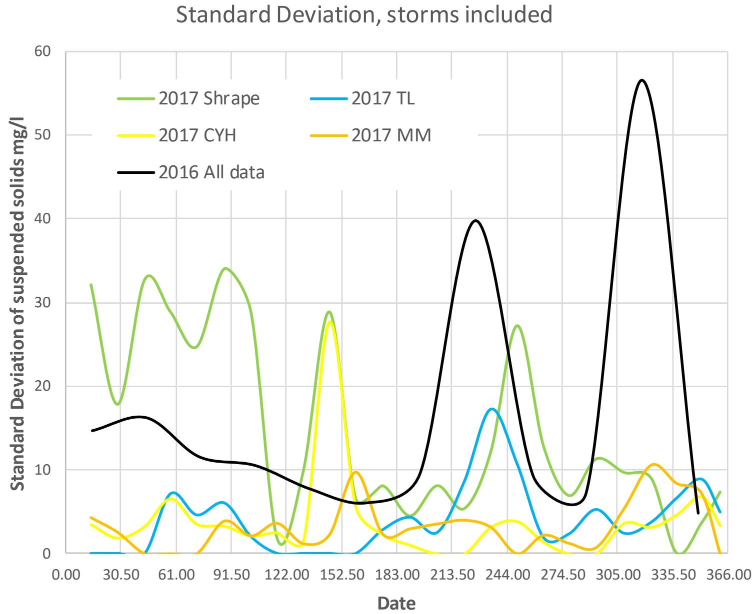
[12] Although the Sandown Bay dataset had a one-month data gap within November-December 2017, inspection of other proximal sites in the English Channel confirm a modest level of wave activity during that period.

[13] Excluding the harbour approaches, seawards of the breakwater. A further ~3800t of sand accumulated in this zone through 2017.

[14] Using a 1.0 t m^{-3} dry density





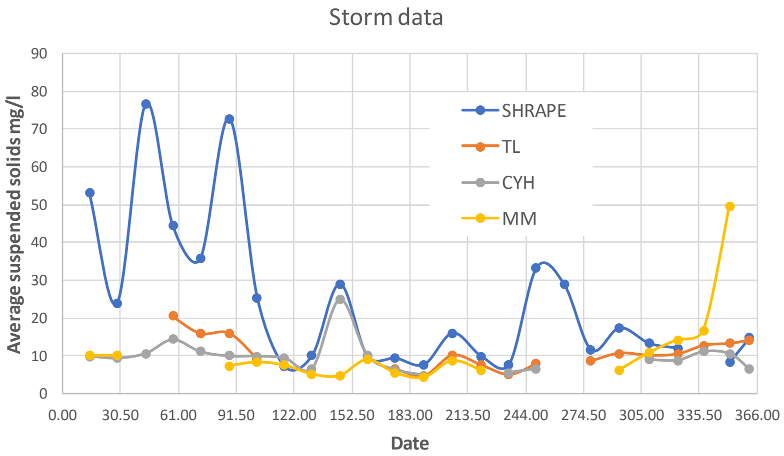


Figure 5. Total Suspended Solids time series, 2016 & 2017.

Top left – data from all four sites averaged per neap-spring cycle. 2016 and 2017, 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 2017.

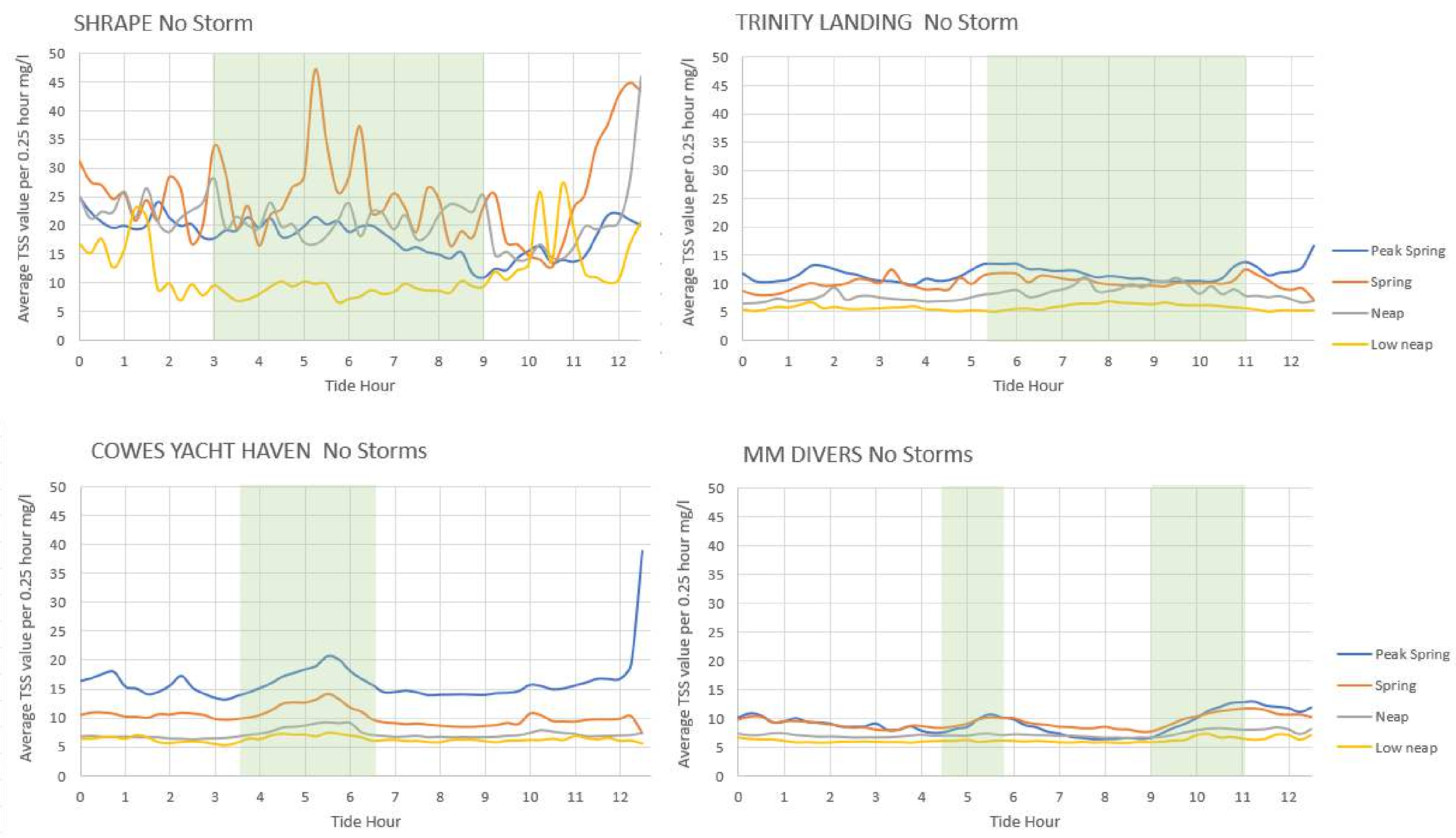


Figure 6. Fifteen-minute data values for each site, averaged by tide hour (after LW) and sorted by tide range (spring-neap). No-storm data only. Green zones indicate periods of strongest tidal currents.

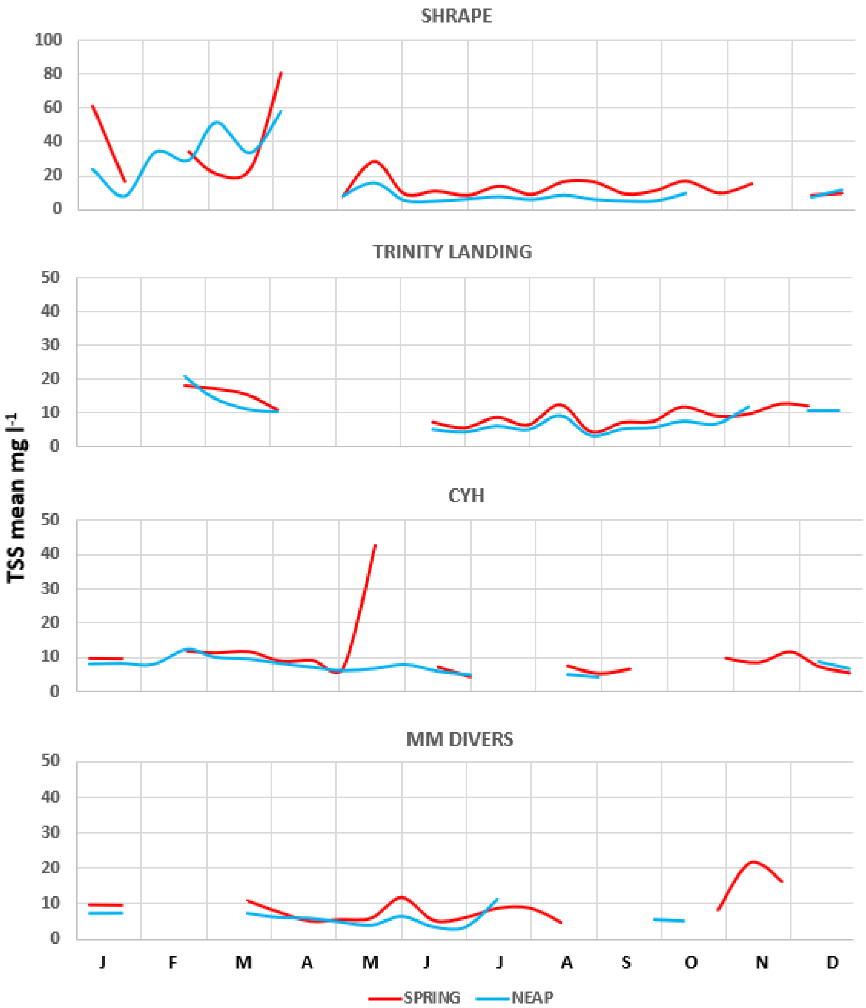


Figure 7. Spring and neap (>2.5m< range) TSS values averaged over each spring/ neap cycle.

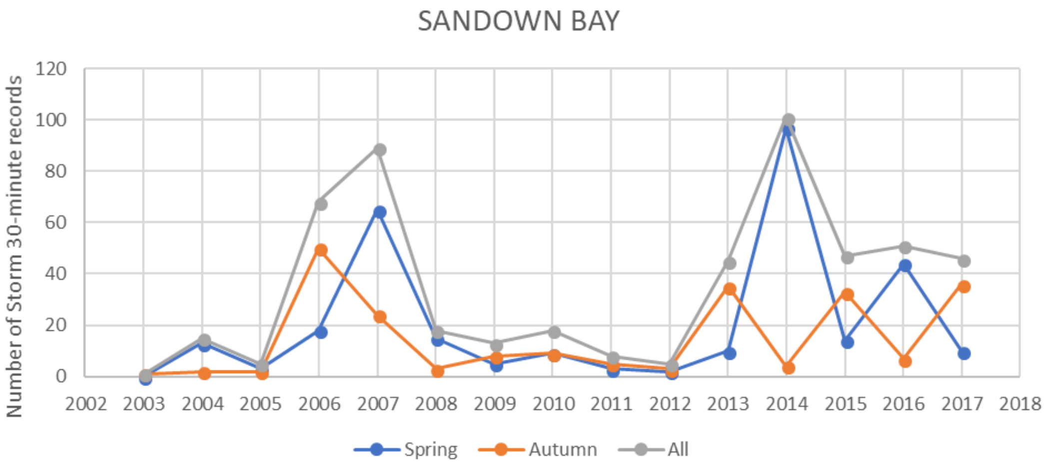


Figure 8. Frequency of occurrence of severe storms, 2003-2017, at Sandown Bay data buoy, south-east of Wight. Data courtesy of Channel Coastal Observatory.

The loss from the outer harbour is unusual, as historically (past 20-30 years) the whole estuary has naturally imported about 10,000 dry tonnes of mud (counteracted by dredging). The loss situation was found in 2016 as well. Inspection of individual polygon data from the outer harbour (Table 4) shows that the two historically recognised depositional zones (polygons D and F) together accumulated some 1,000 m^3 of mud in 2017 (D showing little change), which is near-normal, but that this was offset by erosion of about 2,000m^3 of sediment from polygons A & B, which may be attributable to the modification of tidal flow caused by the emplacement of the new breakwater in 2014-5. Polygon E (Fairway) too had eroded in 2016 but in 2017 this zone was stable.

In the upper estuary, above the chain ferry narrows, flux measurements (for the whole upper estuary) showed a net loss of about 400t of fine sediment. The bathymetry data, just for the subtidal estuary north of Folly Inn, showed a gain of 2,400t (after dredging has been allowed for). Comparison of the flux and bathymetry data suggests that the intertidal and southernmost subtidal estuary zones therefore lost about 2,800t. However the possibility of a slight (1cm) discrepancy in the bathymetric data for this region in 2017, and/or the low level of turbidity data recovery for the MM divers site (~50% success) make it impossible to accurately evaluate the precise situation here.

Despite the shortcomings of the 2017 data collection programme it is possible to conclude that the Medina estuary as a whole saw only a modest level of fine sediment influx during the year, consistent with a relatively low level of regional sediment supply as indicated by English Channel wave recorders (low storminess index, Figure 8).

3.2.2 Seasonal Variability

Examination of the calibrated sediment flux data allows time series plots to be produced for each polygon (Figure 10). However the large data gaps during the year make these plots very unreliable in detail, so no detailed appraisal of the seasonal changes has been attempted.

3.2.3 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 [15] (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 and 2016-17 changes are listed. The same 2017 data are plotted in the three charts of Figure 9.

The key 2016 accumulation areas (>0.03m deposit, ordered by bed level change) are:

- Cowes Yacht Haven south (13.2) 0.10m 1435m^3
- East Cowes Marina (30.3) 0.10m 3654m^3
- Cowes Yacht Haven north (13.1) 0.04m 303m^3
- West Margin off Shrape Flats (9.2) 0.03m 573m^3
- *West Cowes shore (14.3) 0.03m 256m^3*

The key erosion areas were all dredged zones. The only other areas showing more than 0.03m of erosion were (ordered by bed level change):

- Eastern Fairway side-slope (17.2) -0.04 -230m^3
- East harbour entrance (19a) -0.04 -688m^3

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

Site polygon	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*	
17.1	Coast slope north of breakwater	70,772	729	2,106	2.9	3.0			70	0.0	0.1			
17.3	Coast slope eastern sector	25,891		-41		-0.2			227	-5.5	0.9			
19b	East Harbour Entrance	40,949	-297	-862	2.9	-2.1			-489	0.6	-1.2			
12	Shrape Breakwater zone	12,492	-945	1,081	-1.1	8.7			-348	-0.3	-2.8			**Harbour Approaches**
20.1	Solent shore: West Shrape	59,892	-403	-38	0.1	-0.1			1,463	-38.5	2.4			(outside new breakwater)
20.2	Solent shore: Mid Shrape	83,360		441		0.5			1,451	3.3	1.7			
20.3	Solent shore: East Shrape	40,663		1,059		2.6		*No*	103	0.1	0.3		*No*	
21.1	Main Fairway entrance	5,032	-106	-15	0.1	-0.3		*dredging*	-61	4.1	-1.2		*dredging*	
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	
14.1	West side of Fairway entrance	18,126	-653	-908	1.4	-5.0		*No*	-265	0.3	-1.5		*2,057*	
14.2	Trinity Landing & RYS	12,712	-440	-1	0.0	0.0		*dredging*	-2,225	2225.0	-17.5		*m3 dredged*	
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	**POLYGON A**
17.2	Eastern fairway sideslope	5,338	-204	-158	0.8	-3.0			-230	1.5	-4.3			
18a	Outer harbour mid-zone	41,299	54	-1,054	-19.5	-2.6			-369	0.4	-0.9			
16	East thalweg, inner entrance	7,616	-238	-51	0.2	-0.7		*No*	-92	1.8	-1.2		*No*	
8.1a	Fairway off West Cowes	20,792	-145	-494	3.4	-2.4		*dredging*	-499	1.0	-2.4		*dredging*	
19a	East Harbour Entrance	17,611	-1	-874	>100	-5.0	-2,631	-2,631	-688	0.8	-3.9	-1,878	-1,878	**POLYGON B**
14.3	West Cowes shore private area	8,244	-75	-81	1.1	-1.0			256	-3.2	3.1			
8.1b	Fairway off West Cowes	14,330	-504	-625	1.2	-4.4			-113	0.2	-0.8			
8.2	Shore off Fountain Quay	7,876	-194	-11	0.1	-0.1		*No*	-465	42.3	-5.9		*1,636*	
8.3	Red Jet inner	2,116	186	51	0.3	2.4		*dredging*	-854	-16.7	-40.4		*m3 dredged*	
8.4	Red Jet outer	1,920	-76	-275	3.6	-14.3	-941	-941	-437	1.6	-22.8	-1,613	23	**POLYGON C**
18b	Outer harbour mid-zone	16,709	-147	-492	3.4	-2.9			-174	0.4	-1.0			
9.1	Venture Quay and Small Boat Channel	27,461	304	-616	-2.0	-2.2			-548	0.9	-2.0			
9.2	West margin off Shrape Flats	17,300	1,050	1,680	1.6	9.7		*No*	573	0.3	3.3		*No*	
10.1	Outer Shrape Flats	11,993	71	597	8.4	5.0		*dredging*	217	0.4	1.8		*dredging*	
11	Inner Shrape Flats	34,196	-16	1,361	-87.7	4.0	2,530	2,530	76	0.1	0.2	144	**144**	**POLYGON D**
8.1c	Fairway off West Cowes	35,126	-1,237	-1,977	1.6	-5.6			-1,016	0.5	-2.9			
5.1	Shepard's Wharf	8,228	-590	892	-1.5	10.8			-4,291	-4.8	-52.2			
5.2	Fairway off Shepard's Wharf	4,358	16	-30	-1.9	-0.7			-1,999	66.6	-45.9			**Outer Harbour**
5.3	Fairway south of Shepard's Wharf	8,068	15	-325	-21.1	-4.0			-361	1.1	-4.5			(inside new breakwater)
6	Fairway off Car Ferry Terminal	11,261	-86	-749	8.7	-6.7			-228	0.3	-2.0			
7	Car Ferry Terminal	4,928	-47	-290	6.2	-5.9			-33	0.1	-0.7			
10.2	Embayment off Maritime Museum	2,576	-38	50	-1.3	1.9			-21	-0.4	-0.8			
4	Fairway north of Chain Ferry	4,958	-5	-226	41.3	-4.6		*No*	-58	0.3	-1.2		*7,378*	
2a	North of Chain Ferry west bank	8,430	-90	-253	2.8	-3.0		*dredging*	-26	0.1	-0.3		*m^3 dredged*	
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	Polygon E
13.1	CYH north	8,204	-90	439		5.4		*No*	303	0.7	3.7		*1,064*	
13.2	CYH south	13,764	-165	2,008		14.6		*dredging*	1,435	0.7	10.4		*m3 dredged*	
13.3	Corinthian YC	4,320	24	256		5.9	2,703	2,703	-972	-3.8	-22.5	766	**1,830**	**POLYGON F**
1	South of Chain Ferry channel centre	17,639	-31	-601		-3.4			-268	0.4	-1.5			
2b	South of Chain Ferry west bank	18,536	174	-224	-1.6	-1.2			-487	2.2	-2.6			
3b	South of Chain Ferry east bank	9,874	-1,398	-46	0.6	-0.5			56	-1.2	0.6			
30.1	West bank south of UKSA	17,408	324	553	2.1	3.2			129	0.2	0.7			
30.2	Channel off East Cowes Marina Village	61,493	-284	-754	0.2	-1.2			-781	1.0	-1.3			**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			
30.4	Medina Wharf	10,596	-144	-285	1.3	-2.7		*20,500*	-264	0.9	-2.5		*414*	
31	Estuary off Kingston Wharf	70,069	-668	-2,364	2.2	-3.4		*m^3 dredged*	-174	0.1	-0.2		*m3 dredged*	
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**	**POLYGON G**
	TOTALS	**1,215,341**	**-8,219**	**-22,226**			**-22,226**	**-1,726**	**-6,760**			-6,760	**5,789**	

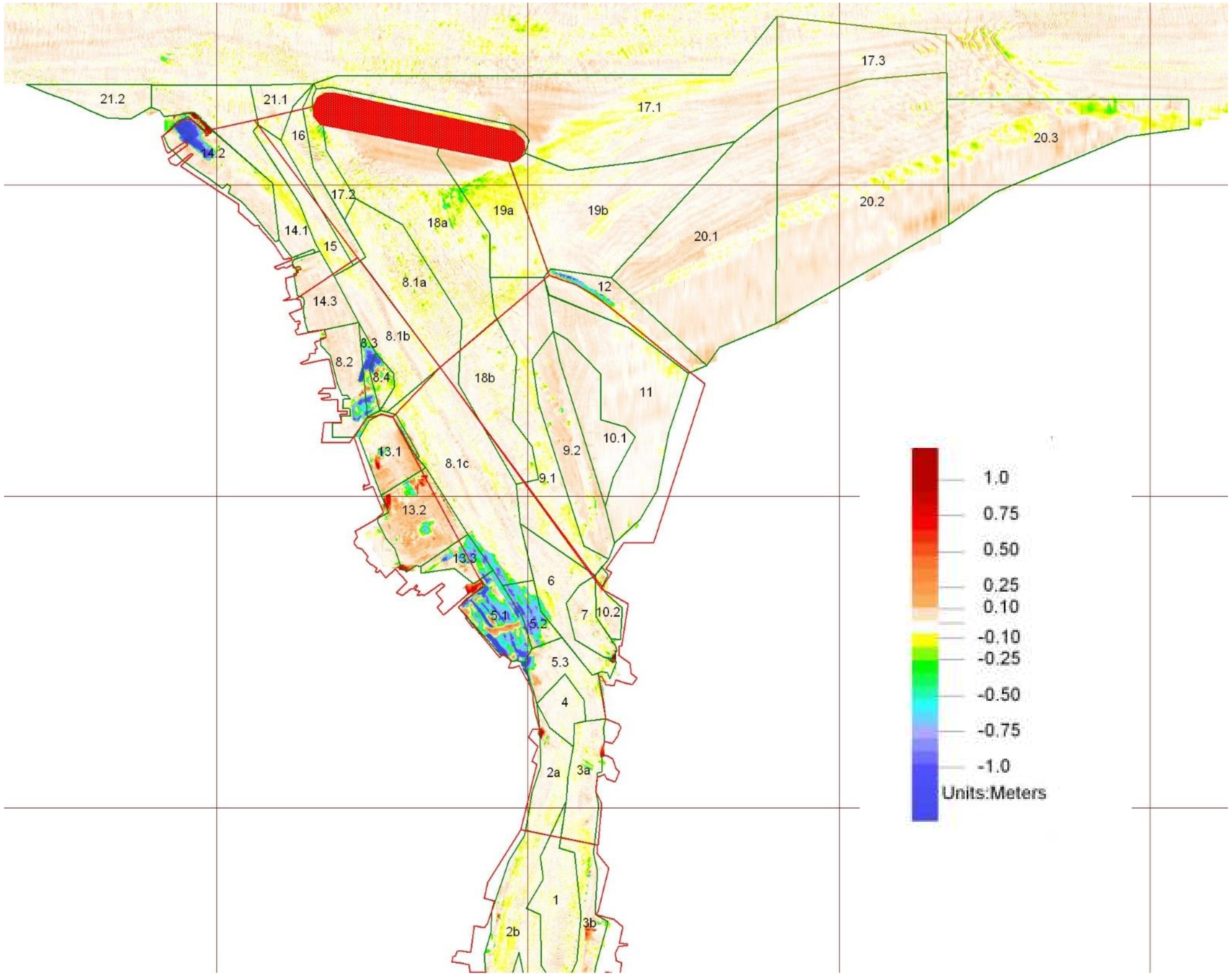
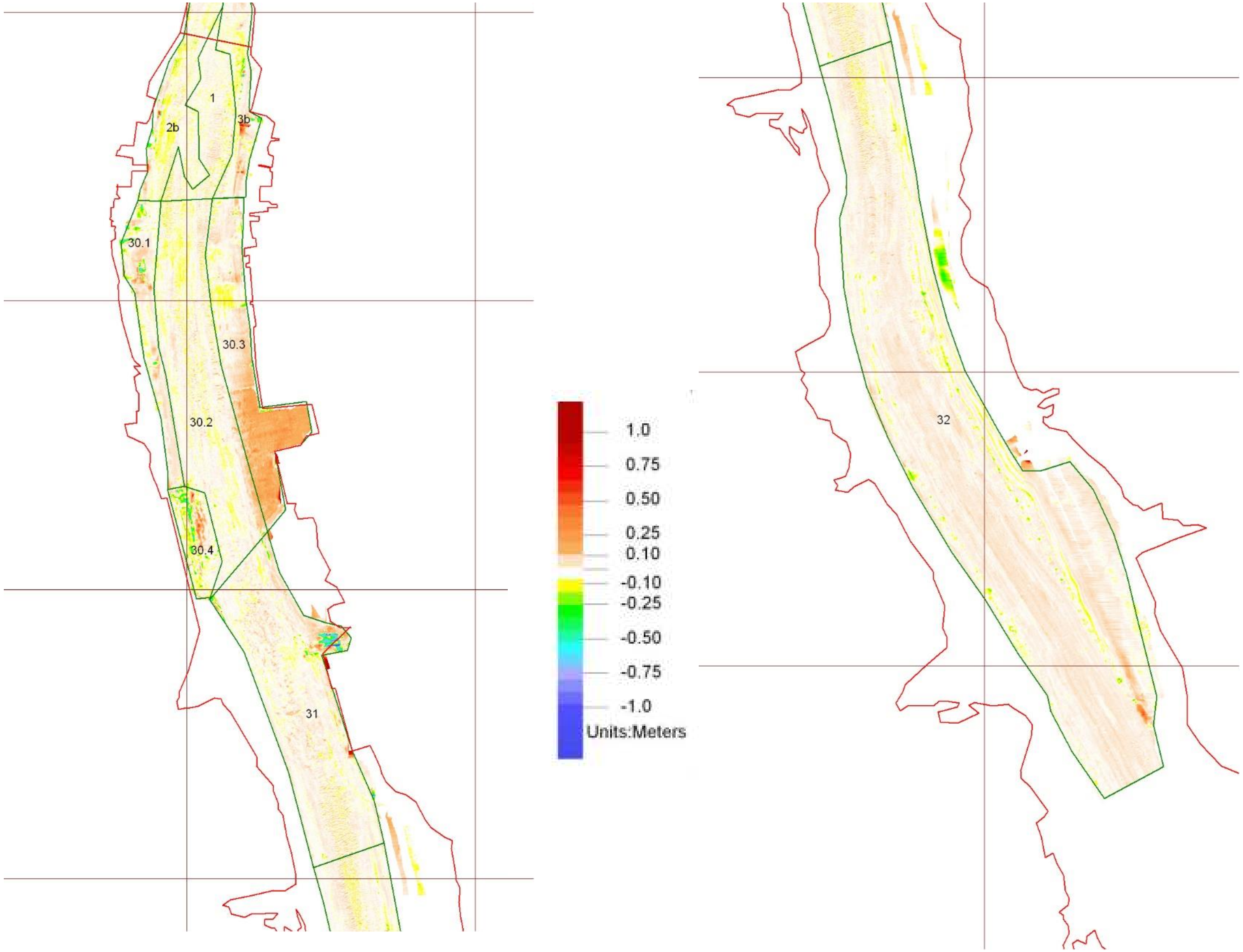


Table 4. (Previous page) Bed level changes between 1992, December 2015, December 2016 and December 2017, by estuary zone (see Figure 4 for zone location). Change 2016-2017 is compared to the history of change 2015-2016, change 2015-16 is compared to 1992-2015 annual rate.

Figure 9. Chart showing change in bed levels from December 2016 to December 2017 (left and continues overleaf).


1
2b
3b
30.1
30.3
30.2
30.4
31
32
1.0
0.75
0.50
0.25
0.10
-0.10
-0.25
-0.50
-0.75
-1.0
Units:Meters

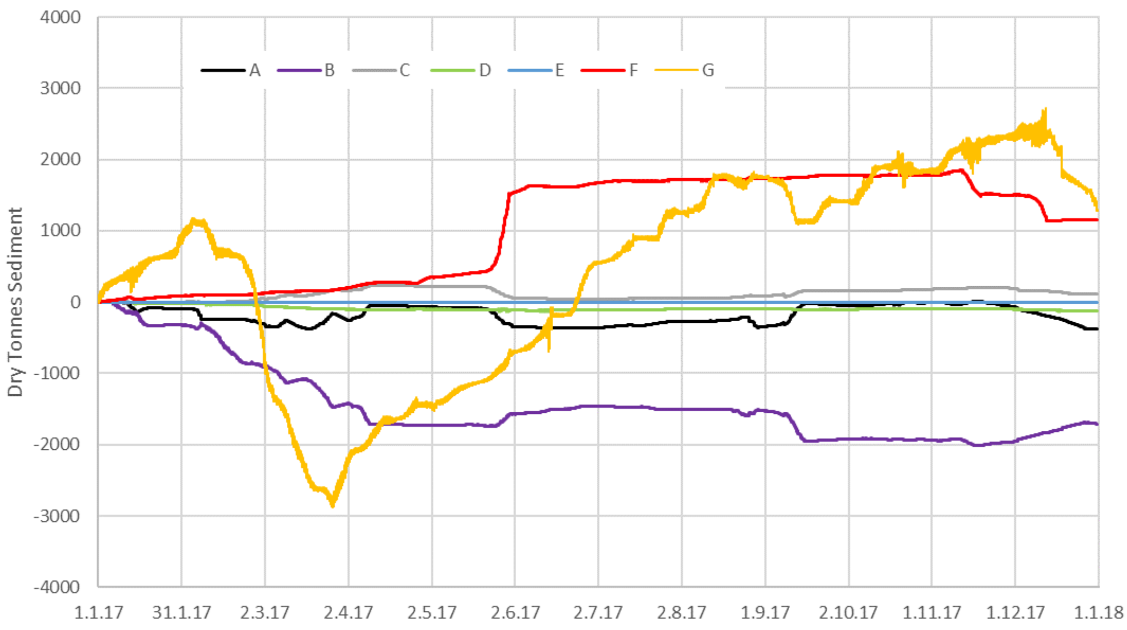


Figure 10. Seasonal variation in accumulation and erosion by polygon (see Figure 1 for polygon locations), as traced by fine sediment flux data calibrated to annual change as mapped by bathymetric survey. Table 3 shows the actual 31/12/2017 flux measurements.

The sites in italics in the above lists show a marked 2016-17 change to the historical pattern/rate of change (Table 4). The most notable 2017 changes to the 2016 rates are as follows (dredge sites excluded):

a)	*Solent Shore: West Shrape (20.1). Stable/slight erosion, now accreting*	*x 39 fold*
b)	*Coast slope: East sector (17.3). Stable/slight erosion, now accreting*	*x 6 fold*
c)	*Solent Shore: Mid Shrape (20.3). Deposition accelerated*	*x 3 fold*
d)	*Main Fairway Entrance (21.1) Erosion accelerated*	*x 4 fold*
e)	*West Cowes Shore (14.3) Erosion, now accreting*	*x 3 fold*
f)	*South of Chain Ferry, west bank (2b) Erosion accelerated*	*x 2 fold*

Increased sand deposition along the coast in areas a), b) & c) in the above list may be the result of increased current velocity in this zone off West Shrape, a response to the new breakwater emplacement. This change in current strength was predicted by the ABP model [2] and may be increasing sand mobility into the zone. The new erosion seen at d) is also likely to be breakwater related, an extension of the general erosion seen south and east of the breakwater since its construction. The new deposition on West Cowes private shore e) may be related to the dredging that took place in the adjacent deeper water areas in February, due either to modified sediment dynamics or simply spillage. The accelerated erosion seen at f) immediately south of the Chain Ferry could be related to the changed pattern of operation of the new ferry introduced this year, although this link may be tenuous.

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4. Conclusions and Recommendations

Although there were some problems with the 2017 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 year of monitoring. 'Non-storm-day' turbidity is highest autumn/winter/spring, with average suspended sediment concentrations decreasing upstream, both characteristics of the regime being indicative of an offshore for the mud as originally concluded. 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, and essentially only over spring tides. This again confirms the importance of a winter-season mud input, and exhaustion of mobile fine sediment through the summer. Erosion of mud from the seabed (probably under combined winter wave and tidal action) is now occurring in the zone south and east of the new breakwater (polygon B), and most likely due to the changed dynamics introduced by placing the breakwater (strengthening the local tidal flow and modifying wave dispersion patterns). The rate of erosion has slowed from rates seen in 2016, the first year after breakwater construction, although new erosion is now occurring at the western end of the breakwater. Mud eroded from these areas will be supplementing the material coming in from offshore.

During 2017 the estuary accumulated some 1600 dry tonnes of mud (Table 5), with some 900t being eroded from the lower estuary (north of the chain ferry narrows) and 2,400t accumulating upstream of the narrows. The latter figure has to be treated with some caution however, as the bathymetry monitoring only extends as far south as Folly Point. The mud flux data, though a probably unreliable this year, suggests that there was an overall slight loss of mud from the upper estuary as a whole in 2017 (Table 3). It is recommended that a turbidity monitoring site is established in the region of Kingston Wharf to tighten this aspect of the data collection.

ZONE	Poly	92-15 *t*	2016 *t*	2017 *t*
Approaches	**O**	-1,600	5,590	3,854
Outer harbour	**A**	-1,300	-1,300	-369
	B	-500	-2,370	-1,690
	C	-650	-860	108
	D	700	1,190	-130
	E	7,005	-3,200	-6
	F	1,785	1,600	1,232
	Tot	7,040	-4,940	-856
Upper estuary	**G**	4,604	-180	2,409

Table 5. Historical summary of erosion and accumulation in the Medina Estuary, 1992-2017.

Dredge quantities are allowed for, including capital dredge campaigns '92-'15.

The accumulation seen in various localities will have been partly fed from erosion zones within in the estuary, with the surplus (~1,500t) coming in from offshore (~1000 t) and from river input (~500t [2]). As has always occurred, the main zones for mud accumulation in 2017 were East Cowes Marina and Cowes Yacht Haven (sub-polygons 30.3 and 13.1/13.2 respectively) where some 10cm of mud accumulated, on average, over the year. Interestingly polygon D (Shrape Flats inside the breakwater, sub-polygons 9.2, 10.1 and 11), normally a site of significant mud accretion, showed near-stability in

2017. This appeared to be as a result of low rate of mud input rather than step-erosion caused by storm events (Figure 10).

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[16]. As in 2016, 2017 saw much less material entering the estuary (Table 5). This will partly result from the erosion in the outer harbour area initiated by the new breakwater emplacement, but probably largely reflects two years of modest regional sediment supply. Storm wave records from south of Wight show that the winters of 2016 and 2017 were not marked by high storm intensity, but equally they were not exceptionally calm periods. However, these wave records can only be an index of the intensity of fine sediment supply from the offshore/Solent region, and other factors may play on important controlling role. In this respect the setting up of a turbidity sensor site in the mid-Solent area would provide a useful source of information about this crucial input.

The eastern approaches to the harbour (sub polygons 20.1 & 20.2) have seen a marked change in the sedimentary regime since the winter of 2015-2016. This is a zone of sand transport, and a previous situation of ongoing low-level erosion has changed to one of modest accretion. The ABP modelling foresaw increased tidal flow through this shallow, partly intertidal zone as a result of the breakwater emplacement. This increased flow seems to have enhanced the transport of sand into the zone, under combined wave and tide currents. There is no evidence as yet that any of this sand passes westwards around the breakwater tip and into the harbour, but this possibility should be monitored.

The following recommendations are made:

- Continuity of methodology should be flagged as critical when undertaken annual bathymetric surveys. Changing equipment between parts of a survey should always be avoided, and every effort should be made to keep continuity from year to year.
- The turbidity sensor sites should be upgraded to 'report' via the internet (real-time output), so that data collection problems can be dealt with quickly. This change is in hand. CHC should also ensure that mechanisms are in place to ensure problems are fixed quickly. Critically, access to real-time data will facilitate licensing agency approval for any dredging trials that may take in the future, allowing precautionary 'stop' controls to be operated.
- Installation of a fifth turbidity sensor at the southern end of Easy Cowes marina, or close to Kingston Wharf, will allow a) better understanding of the dredging needs at ECM and b) comparison of flux and bathymetric data in the zone between the Chain Ferry Narrows and Kingston, increasing confidence/precision in the quantification of mud transport in that zone.
- A turbidity sensor could be usefully set up in a mid-east-Solent area, to accurately show inter-annual variability in the regional zone of high winter suspended solids that feeds the local estuaries.
- A simple current meter system should be deployed in the centroid areas of each of the flux-polygon profiles (ab, bc, bf etc Figure 1) to check cross-profile flows, as part of the process of improving the precision of fine-sediment flux measurements (this is in-hand).

[16] The calculation of ~12,000 dry tonnes per year shown in Table 5 as the 1992-2015 average necessarily embraces the potential for inaccuracies due to assumptions that have to be made about the density of the large volumes of capital dredging that have taken place. A better (~10,000 tpa) figure is derived by simply fitting polynomial regression lines through maintenance dredging data alone.