COWES HARBOUR COMMISSIONERS

Sedimentary Processes in the Medina Estuary
May 2016

Report AmbCHC02
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Appendices (1-3) are in a separate report.
Executive Summary.
A thorough review of readily available data on sedimentary conditions in the Medina estuary has been completed, providing a robust understanding of the key processes that define the system.

The estuary is significantly modified from its natural condition. Within the estuary, effects of channel floor deepening have been greater than those of reclamation (narrowing), and the volume of the water held in the estuary at very high water is about one and a half times its 1802 volume. This means that the sedimentary system is unlikely to be in an equilibrium state, the enhanced water exchange increasing the potential for sedimentation. A second change relates to the 19th century building of sea walls and groynes along the coast, and the 1937 construction of the Shrape breakwater. The change to the supply of coarse littoral sediment has resulted in the complete disappearance of the (sand-gravel dominated) Shrape Spit which originally lay immediately east of the fairway, allowing strong inshore Solent tidal currents to penetrate much more into the outermost harbour area, which remains a zone of persistent bed erosion, with Holocene estuary deposits exposed at bed level.

Complex flow conditions are found in the harbour area because of the close juxtaposition of the very strong west-east oriented Solent flows and the north-south oriented estuary inflow and outflow. The works being undertaken will only have minimal effect on the latter (tidal-prism-driven flow) but they are potentially capable of significantly changing the more complex throughflow and main gyre conditions (driven by Solent flow), with implications for local sedimentation patterns and rates.

Bedload sediment transport plays only a minor role within the estuary, with localized mobile medium sand beds in the west entrance zone. The gravel component of the estuary sediments in certain areas is principally a lag (winnowed) deposit formed in situ; this bed surface layer plays an erosion-protection role. Outside the estuary medium and fine sands are very mobile along the coastal slope, and across shallow Shrape Sand. Medium sand deposits occur in the eastern part of the latter zone, which give way to fine sand on approaching the Shrape breakwater, with hydrodynamic conditions stopping the ingress of medium sand into the harbour. Although unlikely, changed patterns of flow across the Shrape sand predicted by the post-works model scenario may change this situation, which should be monitored.

Fine (suspended) sediment (fine and very fine sand, silt and clay) dominates the sediment flooring the harbour, mud (silt and clay) forming 40-90% of the bed sediment in most of the area, and fine sand about 10-20%. Most bed sediments therefore exhibit cohesive properties, increasing resistance to erosive flows. Mud dynamics appear to be characterized by a slow rate of exchange between suspended and accumulated states. Even through peak depth-averaged flows exceed 0.8m s⁻¹ on high spring tides, the turbidity change recorded is only modest, indicating no strong erosion of the bed is occurring. This phenomena is consistent with the widespread cohesive nature of the bed, and the presence of a protecting bed veneer of lag gravel at the sites of strongest flow. Similarly during periods of slack flow, turbidity levels do not markedly reduce, suggesting that the suspended load has a low settling velocity. The latter observation is consistent with the observed high clay content of the fine sediment most commonly in circulation. It is recommended that field observations should be made to clarify typical settling velocity rates.

The spring-neap variation in tidal energy is the principle driver of changing suspended sediment levels, with total suspended solids levels approximately doubling (20-40mg l⁻¹) from average neaps to average springs. It is though this change is primarily a function of the changing energy of the wider Solent system rather than a Medina-specific phenomenon. Within the semi-diurnal cycle there
are modest fluctuations that correlate to changing local tide current energy, and much larger short-term variations relating both to random effects or local non-tidal influences (e.g. shipping movement, small-amplitude wave action). The ferry turning/docking areas are particularly noted as zones of high bed disturbance. Storms have a major perturbation on the suspended solids regime (raising TSS values for short periods to ~200mg l⁻¹), but only occur infrequently. Storm effects are seen with strong winds from the west (and presumably east, though not yet recorded) which can generate Solent-wide high turbidity, probably with strong nearshore erosion along the north Wight coast. A second type of storm is associated with northerly winds. These lower height waves create a turbid body of water over the shallow Shrape sands area east of the Shrape breakwater, creating a plume of turbid water that enters the east entrance only.

Fine sediment flux into the estuary, estimated from dredging records, bathymetry changes and analysis of tidal prism/average suspended sediment concentrations all tell the same story (long term average trapping of 10-20,000 tonnes per year) but there is clearly significant intra-annual and inter-annual variation. It is recommended that future monitoring should seek to much more accurately define this flux. The turbidity monitoring sites that have been set up appear to work effectively and data collection should be continued into the foreseeable future. Using the ABPmer model to generate a one-off data-base on flow through key cross sections for a full range of tidal conditions, the turbidity monitoring data can be used to measure fine sediment flux into and out of the estuary at the precision of single tides. Combined with future high accuracy multibeam bathymetric surveys, a ‘double entry bookkeeping’ system can be set up to monitor a) the effects of works and b) the efficacy of navigation-depth-maintenance operations that may be used in the future.

The strategy adopted in this study for examining bathymetric change identified some recent variation in the patterns and rates of bed level changes inside the estuary, compared with trends seen over past decades. Erosion, not deposition, may have been more prevalent recently. Though these differences may be a function of the short time span between surveys (intra-annual variability) or changed survey methods they may also relate to the emplacement of the new breakwater. Continued bathymetric monitoring is recommended.
Sedimentary Processes in the Medina Estuary

1. Introduction

1.1. Background

The Medina Estuary (Cowes and Newport harbours, Figure 1) on the Isle of Wight is a site of significant navigation activity, notably leisure boating, ferry terminals, fishing and cargo wharves. The Cowes Harbour Commissioners (CHC) manage the lower estuary, and the Isle of Wight council (IWC) the upper reaches (to Newport).

Changes are occurring within the estuary, driven by the East Cowes Regeneration programme, which involves (on the marine side) the construction of the new offshore breakwater (completed 2015), the extension of the Shrape Breakwater, the deepening of the eastern approach channel to the harbour and the formation of a new marina inside the existing Shrape breakwater.

Sedimentation management has been traditionally practised in the estuary, with shipping channels and mooring areas (wharves, marinas) maintained to navigable depths using conventional dredging methods, with 10-20,000 wet tonnes of sediment typically being removed (to remote disposal sites) each year. In recent years the maintenance dredging situation has altered, or will be altering, due to the effects of:

- Development of new marina areas
- Construction of a new offshore breakwater across the harbour entrance
- Experimentation with non-traditional dredging methods (e.g., plough or agitation dredging).

A detailed understanding of sedimentary processes currently and historically active in the Medina estuary is important for minimising impacts during the ongoing development and for developing a strategy for sedimentation management in future years. Surveys and monitoring activity addressing this need were initiated in November 2015. Activity and methodologies are reported elsewhere. On 23rd February 2016 CHC commissioned Ambios EC Ltd to undertake a review of sedimentary processes in the Cowes Harbour areas, and that study is reported here. This study incorporates the results of the recent surveys and monitoring to date, combined with a review of previously available data.

1.2. Objectives

The objective of this study is to develop a detailed conceptual model of the suite of sedimentary processes that are currently active in the Medina estuary, focussing on the lower estuary (north of Kingston Wharf). This will combine with the East Cowes Regeneration (EIA) related mathematical modelling to provide a robust basis for development of:

- A sediment management (navigable depth maintenance) strategy for the future

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1 Ambios Environmental Consultants Ltd 2016. MEDINA ESTUARY SEDIMENT MANAGEMENT STRATEGY: MONITORING INITIATION February 2016 Report AmbCHC01
2 From scope of work provided by Ambios EC Ltd to CHC 19/02/2016
3 A conceptual model provides a descriptive framework for the organization of knowledge about the elements and interrelationships within a system, serving as a guide for observation and interpretation. Importantly, conceptual models can define the envelope of reality that mathematical models (of the necessarily simplified system) must reproduce.
• A change-monitoring programme, to understand the scale and interaction of both human-induced and naturally occurring variability in the sedimentary system of the estuary into the future.

The study will address all secondary data that has been made available, in combination with the results of recent and ongoing measurements of seabed conditions and fine sediment mobility (bed sediment analysis, bathymetric change, turbidity monitoring 1).

1.3. Report Structure
In Section 2 (Water Energy and Circulation) water movement driven by tides, surges and waves is described, based on historical tide flow measurements, ongoing wave monitoring and published mathematical model outputs (ABPmer Ltd). These are the forces that drive sediment transport processes.

In Section 3 (Geomorphometric Change) observed alterations in the form of the local seabed are described from historic hydrographic surveys (1802 to present day), against the background of the geological/geomorphological legacy of the zone. These broad patterns of change are then used to provide context for the most recent bed-level variability being observed in the estuary.

Section 4 (Bed Sediments) provides a detailed description of the nature of the sediment flooring the estuary, from grab-sample in situ and laboratory measurements. Particle populations that are mobile in the estuary are identified and quantified, their stability is discussed and potential source/sink zones identified.

In Section 5 (Sediment Dynamics) information from Sections 2-4 are brought together to provide an assessment of sediment transport processes that are present in the estuary, broadly divided into bedload and suspended-load regimes. The suspended sediment processes are then analysed in greater detail using data from the first few months of the turbidity monitoring programme that has been initiated.

Conclusions are drawn in Section 6, with recommendations made where appropriate.

1.4. Data Sources
The following list includes the most important data sources used in the production of this report. Other sources are identified in footnotes through the text.

• All reports issued by ABPmer Southampton over the period 2006 to date concerning modelling water flow and sediment transport in the Medina estuary, and associated data collected reports.
• Isle of Wight Shoreline Management Plan 2 Appendix C: Baseline Process Understanding C1: Assessment of Shoreline Dynamics December 2 Coastal Management; Directorate of Economy & Environment, Isle of Wight Council
• UK Hydrographic Office. Chart Archive (inspection of original survey drawings).
• Shoreline Surveys Ltd have provided original xyz data for all Medina surveys they have undertaken 2005 to 2015.
2. Water Energy and Circulation

2.1. River Flow

The Medina River has a total catchment area of 71km², a gauged mean flow (Upper Shide Station, at 10m ODN) of 0.4m³ s⁻¹ and a highest gauged flow of 10m³ s⁻¹. Flow variability over the past year is shown in Figure 2.

![Figure 2. Medina at Shide Gauging Station. Water levels April 2015 -April 2016. Source EA & Shoothill Ltd.](image)

Over one tidal cycle the mean river inflow would be 18,000m³, and at peak flow 450,000m³. These volumes respectively represent about 0.3 and 8% of the volume of water exchanged in the estuary on a peak spring tide (tidal prism, ~6Mm³), the percentages approximately doubling on neap tides. Thus normally freshwater forms a minor component (a few percent) of estuary waters, increasing towards the estuary head and during flood events. Salinity profiles observed during November 2015 surveys in the harbour (various sites between the entrances and Kingston Wharf) are plotted in Figure 3. River levels at this time (Figure 2) were between 7.1 and 7.3m, with only minor discharge events. Salinities at the bed were consistently at 34-35, values in the surface few metres fell as low as 31, with the majority of the lowers salinity observations occurring on the ebb.

In UK rivers, where suspended sediment loads are almost exclusively non-capacity loads, ie the rivers can carry more suspended sediment than is actually transported, sediment supply or availability exerts a greater influence on suspended sediment transport than the hydraulic conditions or transport energy. Typically 80% of the suspended solids load is delivered over 5-10 days of the year. Suspended sediment yield from the landsurface for this region of the UK (Hampshire Basin⁴) is between 2 and 10 t km⁻² yr⁻¹. Thus the Medina river may be expected to deliver some 142-710t of mud to the estuary each year, mostly arriving during <10 storm events.

Other rivers will deliver fine sediment to the region, which may enter the estuary via the mouth as part of the ‘Solent’ suspended load, and probably with their fluvial characteristics modified through their transition of that body.

Figure 3. Salinity profiles from the harbour area during November 2015.
2.2. Tides

2.1.1. Levels

Critical water levels (semi-diurnal tidal wave, storm surge) for Cowes Harbour are shown in Table 1. Levels are similar in the upper Medina Estuary, with higher low-water levels. The relationships between tidal cycle duration, range and low water level (LWL) are shown in Figure 4 (data from Cowes Yacht Haven active monitoring site). For purposes of analysis in this report the neap-spring cycle has been subdivided into five range groups (<2, 2-2.5, 2.5-3, 3-3.5 and >3.5m).

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Table 1. Water levels in Cowes Harbour (UK Hydrographic Office).


Mean sea level in this area of the UK coast is rising relative to the land (probably a mix of isostatic and eustatic adjustments) at a rate of 1.6mm per year.

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5 Surge data from: Coastal flood boundary conditions for UK mainland and islands. Environment Agency Project: SC060064/TR2: Design sea levels

6 Proudman Oceanographic Laboratory Sea Level Monitoring project, Portsmouth tide gauge data.
The semi-diurnal tide-level curve in the Solent is unusual (Figure 5), with a strong inflexion of the rising tide levels and a post high water pronounced stand (neaps) or a second (lesser) high water (on springs). Figure 5 also shows a plot of the tidal volumes (prism) generated by the rising and falling tide levels, identifying periods when strongest flows might occur (peak volume change). As some confusion surrounds the precise definition of high water, all tide times (hours) in this report are counted from low water.

![Figure 5. Semi-diurnal tide level and prism volume variation, by tidal range. Levels from ABPmer model.](image)

Volumes relate to the whole estuary prism, defined by the entrances west and east of the new breakwater.

### 2.1.2. Currents

The most recent ABPmer Mike21 flow model, validated to 2014 field measurements, is used here as the source of tidal current data. Tidal flows within the Mid and Outer zones of Cowes Harbour (Figure 6) are complex. This is due to the interaction a variety of factors that drive the flow.

1. The normal small estuary flow situation is driven by the rise and fall of the tide, the voids so generated creating responsive currents (flow 1 Figure 6). Flow tends to be along the axis of the estuary with highest currents on the flood and ebb and slack flow at high and low water (standing wave). The unusual semi-diurnal rhythm of tide-level change (Section 2.1.1) in the Solent complicates this simple pattern of flow, creating strong flood/ebb asymmetry and extended stands with slack flow.

2. There are strong, shore-parallel tidal streams in this area of the Solent (flow 2 Figure 6). These west-east aligned streams reach 4 knots (200cm s\(^{-1}\)) immediately across the entrance to the Medina estuary. They interact in a complex way with the void-driven currents, firstly because the two flows are aligned at about 90° to each other, and secondly because flow

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7 ABPmer, 2015b. Cowes Local Model Calibration, ABPmer Report No R.2517
takes the form of a progressive wave with peak velocities tending to occur at high and low water and flow reversal/slack periods at mid flood and mid ebb. The westgoing flow persists from 3 to 10 hours after LW (7 hours duration) and the eastgoing flow from 10 hours after low water through to 3 hours after low water (5.5 hours duration).

3. The impingement of the shore-parallel Solent flows on the west and east entrances to the harbour create jets across the outer zone (Figure 6). These jets drive a throughflow of water (flow 3 Figure 6), thus the volume of water passing across the outer zone is far larger than would be caused by just the void-driven currents alone.

4. The interaction of the throughflow jet with the void-driven currents and the Shrape breakwater configuration combine to generate a large gyre in the mid region of the harbour (Flow 4 Figure 6). This gyre can become quite strong, and is normally anti-clockwise but can reverse under certain tide states. Once again the presence of this gyre draws a much larger volume of water through the mid region that would occur under the action of void-driven currents alone.

5. Minor gyres/eddies also occur at various locations (flow 5 Figure 6), either as lee features (flow separation in the lee of a coastal protuberance) or lateral flow features, breaking off in shallow water to either side of the main, channel-axis flow. Although minor in dimensions these gyres can persist for many hours and may be significant from the viewpoint of sediment transport.

An analysis of water volume exchanges has been undertaken using a very simple box-model approaches, based on ABPmer depth averaged flow predictions (as modelled by ABPmer Ltd for the four monitoring sites that are being used to study fine sediment circulation, Figure 6) and void calculation from GIS analysis of latest bathymetric surveys. The effects of inertia, causing 15-30 minute lags between void generation and flow response have not been allowed for, but result in only minor data misfits. This simple analysis shows that at times of peak flow, the volume of water in circulation can be of the order of x2 (Outer zone) and x3 (Mid zone) the void-generated volume (Figure 7). In the Inner harbour area void volumes are similar to actually exchanged volumes. This additional exchange of water is a function of both throughflow and gyre formation (Figure 6). This mechanism of enhanced flow has important implications for sediment supply within the Mid and Outer harbour zones.

The temporal and spatial distributions in tidal currents have been examined in terms of their sediment transport potential: a critical depth-averaged tidal velocity of 0.25m s\(^{-1}\) has been used to differentiate flow conditions. Bedload sediment motion is unlikely and fine sediment has a higher potential to accumulate from suspension at flows <0.25m s\(^{-1}\) whereas some bed motion in fine cohesionless sand may occur and mud is more likely being put into suspension from the bed rather than accumulating at flows >0.25m s\(^{-1}\). Tidal cycle current velocity and direction plots at all tidal ranges for the four turbidity monitoring sites (Figure 6) have been colour shaded where the velocity exceeds 0.25m s\(^{-1}\) (Figure 8). Inspection of Figure 8 shows that:

- There is significant variability in the timing of peak flows between the four sites.
- Peak depth-averaged velocities attain ~0.8m s\(^{-1}\) at the Shrape and Cowes Yacht Haven sites and ~0.6m s\(^{-1}\) at Trinity Landing and MMC Divers sites.
- Peak velocities occur on the flood at Shrape and Cowes Yacht Haven and on the ebb at Trinity Landing and MMC Divers.
- At times of peak velocities current directions remain remarkably stable/consistent.
Simple hourly summary flow maps have been produced (Figure 9), where zones of current velocities >0.25m s\(^{-1}\) have been colour coded consistent with Figure 8. Generalised flow vectors are also plotted. These charts illustrate the complexity of the flow situation, how the peak velocity episodes link spatially, and how water circulates in-between the high-flow zones.

Figure 6. Flow types in the outer, mid and inner Cowes Harbour zones.
Figure 7. Comparison of changing tidal prism volumes (voids) and actual volume changes (based on current flows through harbour sections).

Voids (blue shaded areas, positive or negative according to rising or falling water levels) are calculated as volumes up-estuary from three estuary sections (Figure 6):
- Outer is section from Trinity Landing to Shrape Breakwater end via the new breakwater (two entrances)
- Mid is section from Cowes Yacht Haven to end of Shrape Breakwater
- Inner is section across narrows at MMX Divers site

Actual volume changes (red and orange lines) are calculated by applying half-hourly depth averaged current velocities through the sections. Velocities are from verified ABPmer model outputs for the four monitoring sites (Figure 6), Shrape and Trinity Landing data applied to the Outer section, Cowes Yacht Haven data to the western 50% of the Mid section and MMC Divers data to the Inner section. Flow direction is simply assessed as ‘inward’ or ‘outward’ across each section line (positive and negative respectively). Where actual volumes exceed void volumes (in a positive or negative sense) then additional water exchange is being driven by throughflow or gyre formation.
Figure 8. Tidal cycle flow velocity and direction plots for all tide ranges at the four turbidity monitoring sites. Periods when (depth averaged) velocity exceeds 0.25 m s\(^{-1}\) are colour shaded.
Figure 9. Hourly charts showing generalised flow vectors over a tidal cycle. Zones of flow velocity >0.25m s\(^{-1}\) are colour shaded consistent with Figure 8.
2.3. Waves

Although wave-induced water motion is capable of driving net sediment transport, in the context of the dynamics of fine sediment in small estuaries, waves are most important as agents of sediment resuspension from the bed, creating turbid water bodies that are then transported by tidal streams.

Few wave data exist for the Medina Estuary area. A review in the ABPmer East Cowes Marina EIA\(^8\) identified that there is an 8km restricting fetch for locally generated waves, and that for the northern edge of the harbour area the one year and fifty year return period of their significant wave heights is 0.8 and 1.1m respectively, with associated wave periods of 2.5 to 5s.

Three types of natural wave action can be identified as important for sediment transport processes affecting the Medina estuary.

OFFSHORE SWELL. Although the Solent is sheltered from the offshore English Channel wave climate, swell with very long period (peak periods >15s) may refract around the southern coasts of the Island and have some effect along the north Wight shorelines. This swell penetration must be particularly effective with waves from the east to south-east sector (affecting the Spithead area), though the largest swell periods are seen with seas approaching from the south and west, enabling most effective refraction. The Channel Coastal Observatory maintains a directional wave buoy at Sandown Bay, SE Wight (Figure 10), and these data are freely available for use in analysing fine sediment transport conditions observed in the Medina. Data from January to March 2016 are plotted in Figure 11. It can be seen that winter wave conditions in Sandown Bay involve peak significant wave heights (\(H_s\)) of ~4m, peak wave periods (\(T_p\)) in excess of 20s and wave direction predominantly from the south (which will include swell approaching the Island from W to SW) but going round to the SE and E at times.

SOLENT LOCALLY-GENERATED WIND-WAVES. The effectiveness of waves generated by winds from the NW-N-NE sectors on the outer harbour at Cowes has been modelled by ABPmer\(^8\), considering the situation both before and after the new breakwater construction in 2014-15. The plan distributions of 100 year return period significant wave height across the outer harbour are shown in Figure 12. The new breakwater achieves a significant reduction in wave height in its lee.

SMALL AMPLITUDE WAVES. Even the smallest of waves, in very shallow water, can significantly resuspend fine bed sediments. This action is an important process affecting sedimentation regimes over shallow mudflat areas, and is driven by local wind conditions.

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Figure 11. 2016 (January, February and March) wave data from the Sandown Bay Buoy.
Figure 12. Modelled significant wave height distributions during northerly local wave conditions, without (A) and with (B) the new breakwater.
Figure 13. Personal Weather Station (PWS) IsleofW4 data for January, February and March 2016. Daily totals (rainfall) mean or mode (wind direction) values. Wind speed (average and maximum gust) in km hr$^{-1}$. Precipitation in mm. Pressure in hPa. Note: y-scales vary between months.
Figure 14. Five minute scend values recorded at Cowes Yacht Haven during February (left) and March (right) 2016. Time-series data and tide range are plotted in the top graphs, tide-hour plots are shown in the bottom graphs.
A further potential source of wave energy is ship wake. Within the estuary speed limits will restrict these to small amplitude wave effects, as described above. Ship jet or screw scour is also possible. Outside the estuary, local observation provides that Southampton large ship traffic can cause significant wake-wave impact along the coastline east of the Medina, particularly in Osborne Bay.

It is important to have some measure of types of wave condition as controls within the ongoing turbidity monitoring programme. This is being achieved in three ways:

1. Offshore wave conditions are being recorded at the Sandown Wave Buoy (Figures 10 & 11)
2. Weather conditions are being recorded (30 minute observations by an automatic Personal Weather Station overlooking the east shore of the mid estuary\(^9\)). Wind direction, average speed and gust speed are logged (Figure 13 shows daily statistics for all data for 2016 to date). These data are freely accessible via the internet and provide a useful index (based on wind speed and direction) of when peak-energy local Solent waves and in-estuary small-amplitude waves may be occurring. The Bramble Bank met station data is also used.
3. As part of the ongoing turbidity monitoring, a pressure sensor has been installed at Cowes Yacht Haven. This records water level every five minutes. Actual, maximum and minimum values are logged for each sample. If an allowance is made for the rate of tidal rise or fall over the five minute period, the difference between the maximum and minimum levels provides an indicator of water surface variability (described here as 5 minute scend). However the instrument is deployed inside the porous wall that encloses the Yacht Haven, which will remove small amplitude wave effects. These data may record the action of larger period waves however (residual offshore swell or local Solent storm waves) that penetrate into the harbour. The scend data logged for February and March 2016 are shown in Figure 14, graphed both as a time series and by tide hour. Higher scend values show some correlation with tidal range, and a strong correlation with tidal hour (~high water). This may relate to the increased ability of waves to penetrate into the harbour area at times of highest water levels. Event checking shows that some higher scend values do not correspond to periods of high wave activity, hence other factors may be influential (e.g., violent vessel manoeuvres close to the sensor location, or interference with the sensor).

3 Geomorphometric Change

3.1 Long Term Trends

3.1.1 Geological Constraints

The Medina Estuary and adjacent coast is cut into Oligocene Osborne and Headon beds. These are dominated by stiff and very stiff grey and green clays\(^10\), but also contain sandier zones and sparse thin limestone bands. These beds outcrop in the overgrown cliffs of the coast, generally protected from erosion by seawalls, but subject to local active slips, particularly in the area east of the Medina. Harder outcrops in the Oligocene rocks are believed to define the (Chain Ferry) Narrows in the estuary.

The Medina River valley was deeply incised during the Pleistocene low sea-level stands. This incision was infilled with alluvial deposits during the Holocene period, as sea-level rose to its present

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Figure 15. Geological cross section from six boreholes approximately along the line of the Shrape Breakwater.
position. Boreholes\textsuperscript{10} (Figure 15) show that these alluvial deposits tend to pinch out along the present HWM, and increase in thickness into the estuary axis and seawards to a maximum observed depth of -20ODN (Figure 15 is a section approximately along the line of the Shrape breakwater). The alluvium generally comprises very soft grey or black slightly gravelly sandy silts and clays\textsuperscript{10}.

During grabbing surveys in November 2015 apparent outcrop of the Oligocene clay was found on the seabed sites 5 & 11 (both at about -5m ODN) and Holocene clay at sites 15, 16 and 30 (sites plotted in Figure 16). At all other grab sites the seabed was composed of Recent sediment.

![Figure 16. Grab sample locations where Oligocene (red) and Holocene (blue) deposits were found.](image)

3.1.2 The Solent Shore
Seven sets of original survey data (not compilation charts, where survey date is often vague) have been used to examine the long-term trends in the morphology of the Medina estuary and adjacent Solent shore (Table 2). The charts and their analysis are described in Appendix 1.

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</table>

Table 2. Original survey data used to characterise estuary morphology changes.
Changes that have occurred along the Solent shore are summarised in Figure 18 as:

1) A plan view of a low water spring tide-line (-2m ODN) and the -10m isobaths (towards to foot of the coastal slope) for all surveys and
2) North-south cross-sections of the coast at 500m intervals for all surveys.

These plots show the following relatively simple pattern of development.

- **High Water Mark.** The West Cowes seashore HWM has retreated only slightly in places over the period 1802-2015, and the town waterfront has undergone modest local advances as a result of seawall construction and reclamation. In East Cowes, west of 450500E, extensive seaward advance of the HWM has occurred, initially probably by beach accumulation but since the 1850s by seawall construction and reclamation. East of this to Old Castle Point the coast underwent about 20m retreat from 1802 to 1856, but has been stable since as a result of seawall and groyne construction. East of Old Castle Point both erosion and accretion occurred between 1802 and the 1930s, but since the latter date wall and groyne construction has again created stability. Groyne construction all along this coast post 1850s would have cut down sand and shingle supply to the East Cowes spit (West Shrape).

- **The low water mark (LWM, -2mODN) has retreated steadily landwards all along the coast and through the period.** Only at one point (east of Old Castle Point, 451500E marked by black arrow in Figure 18) has no apparent retreat taken place, and the Admiralty chart shows intertidal rock ledges at this point (limestone outcrop?). Just to the west of Old Castle Point (451000E), LWM retreat has slowed to almost nothing since 1856. This is an area of steep slope at the LWM, defining the east edge of Shrape Sands, and where Oligocene clay was found at -5m ODN in grab sample Site 5 (Figures 16 & 17), again indicating local exposure of geological strata.

Figure 17. Zone of low water mark stability 1856-2015, Old Castle Point.
Figure 18. Changes in the morphology of the Solent shore, 1802-2015. Plan shows -10mODN, -2mODN and HW isobaths for each survey.
Figure 19. Summary data showing gross changes in the form of the Medina estuary 1802-2015.
Figure 20. Medina estuary cross-section changes 1802-2015.
Along the West Cowes seaward shore retreat over the period 1802-2015 averaged about 0.5m yr\(^{-1}\). East of the estuary entrance the rate of retreat of the LWM was greatest to the west of Old Castle Point, averaging about 1.5m yr\(^{-1}\) at the western end of Shrape Sands compared to 0.25m yr\(^{-1}\) east of the Point. Along the Shrape shore this rate of retreat was not steady, there appearing to be strong retreat (2-3m yr\(^{-1}\)) from 1802 to 1845, little change and some accretion 1845-1930s (prior to Shrape Breakwater construction in 1937), then renewed erosion to the 1990s (2.5m yr\(^{-1}\)) with more recent slowing to ~1m yr\(^{-1}\).

The zone of fastest retreat of the LWM, towards the western end of Shrape Sands, has been associated with an overall lowering of the surface of the sands by up to 5m. This can be seen in profile 450000E in Figure 18, and seems to have occurred steadily over the period 1800 to the present day.

Towards the base of the coastal slope (-10m isobaths), erosion and accretion are seen respectively west and east of a hinge line at about 452000E (marked by a black arrow in Figure 18). East of this line the -10m isobath advanced seawards as a result of bed accumulation at a rate of about 0.5m yr\(^{-1}\) between 1802 and the 1930s (though no more recent data are available). West of the hinge there has been steady erosion. This appears to have been very rapid over the period 1802-1845, with isobath retreat rates of up to 4m yr\(^{-1}\), and reductions in bed levels in excess of 10m (see profile 450500E). Subsequently rates of retreat have dropped to >1m yr\(^{-1}\), with local areas of accretion occurring between some surveys. This variability is consistent with the presence of mobile sand shoals/waves in this zone (Section 4).

Where the main channel of the estuary crosses the coastal slope, dredging (to depths of about -5mODN) has caused depth increases over the last century (seen in profile 449500E, Figure 18, on the west edge of the channel).

In summary, these data indicate that the shoreline zone into which the Medina estuary discharges has been undergoing quite rapid and persistent erosion since 1800. Man-induced changes post 1850 (seawall and groyne construction, aggregate removal, channel dredging) will have perturbed the natural trend, possibly with significant impacts related to the diminishing of the East Cowes spit (West Shrape).

Most change was observed prior to the 1850s, with erosion liberating of the order of 100,000t of sediment each year from the zone, much of which may have been sand and gravel. Post 1856 GIS analysis shows an average rate of sediment generation from erosion within the zone of the order of <10000t yr\(^{-1}\), much of which is liable to be clay and silt (Oligocene and Holocene deposits) that are exposed on the seabed or lie below the thin surface veneer of recent deposits (Section 4). Present sediment yield rates are probably much lower than this 165 year average, and are examined in Section 3.2.

3.1.3 The Medina Estuary
The same bathymetry data sets (Table 2) have been utilised to determine long-term changes in morphology in the estuary. This analysis revisits earlier studies\(^{11}\), extending the timeline (1802-2015 cf 1856-2006) and independently checking the conclusions drawn. No further work has been undertaken on the reaches above Folly Inn (to Newport) where the findings of the previous study are relied upon.

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The estuary has been subdivided into nine sectors parallel to Ordnance Survey northings (Figure 19), Zone B being the outer estuary Solent shore (Section 3.1.2), zones C-I covering the reaches as far south as Folly Point and the Upper zone (not re-examined here) running to Newport. Figure 19 show the summary data from the GIS examination of these zones. The years 1802, 1856 and 2015 have been used to examine whole estuary trends, more surveys are available in the lower estuary:

**THALWEG DEPTHS** (deepest channel value per sector) were similar 1802-1856, with Cowes Harbour values around -6mODN (with a pronounced bar around that depth) rising linearly to about 0mODN at Newport. This situation has not changed much in 2015 in the upper estuary (south of Sector H, ~4km from Newport), but north of this depths increase significantly, with depths attaining -10m both above and below the Chain Ferry narrows, and -11mODN where the bar used to be. Note that for all surveys since and including that of 1845 the local thalweg depth at the Chain Ferry Narrows has been between -5.0 and -5.5m ODN, and of similar cross-section, consistent with a geological control of this section. These increased depths are attributable both increased density of traffic and dredging activity.

**AVERAGE DEPTHS** have steadily increased over the period in all sectors, by a factor of up to 2-3 over the 213 year period (Figure 19, top right). Most change has occurred more recently, consistent with increasing traffic/dredging.

**ESTUARY WATER VOLUME** has also increased over the period, but only by a factor of 1.1 to 1.5 in the lower estuary (sectors C, D & E) rising to x2 in the mid estuary (sectors F to I) and falling again to x1.1 in the upper reaches\(^1\). The total upstream volume of the estuary (Section B-C) increased from about 5M to 7.2M m\(^3\) over the period 1802 to present. The difference in rates of increase between average depths and volumes is accounted for by simultaneous reduction in surface area in the lower estuary sectors (C, D & E). This has been the result of piecemeal wharf and industrial site reclamation works along the estuary banks. In the upper estuary a more variable situation is seen; over the period 1856-2015 some sector areas were stable and other slightly increased or decreased. The observed marked increase in the estuary surface area 1802-1856 may be partly due to difference in cartographic priorities between the surveys, but may also reflect increasing use of steam vessels (by 1830 all Solent crossing had steamships) within the estuary, wash and screw/paddle turbulence impact causing a new type of erosive process.

The general pattern of change outlined above is well illustrated in the cross-sections of the estuary shown in Figure 20. The southernmost profiles (I-U & H-I) show simple widening (traffic effects) with no significant deepening, the mid reaches (G-H & F-G) show the same widening but also deepening by dredging (to a narrow thalweg at about -6mODN by the 1930s then widening in later years) and the northern sections (E-F, D-E & C-D) showing the same depth changes (to -6m ODN), initial widening then (largely post-1930s) significant narrowing due to wharf construction and water’s edge reclamation. Critically, only minor change is recorded post 1992 (where data are available).

Profile B-C shows changes relating both to the estuary (described above) and the Solent sea coast (described in Section 3.1.2). On the West Cowes shore there is quote a restricted envelope of change, largely driven by industrial activity (slipways) and urban development reclamation works. On the Shrape Sands side of the estuary, the gradual lowering and retreat of the sands east of the present site of the Shrape breakwater is seen (though not affected by that structure until its construction in 1937, the survey dated that year immediately preceding the start of the works), largely driven by the process of coastal retreat described in Section 3.1.2. The 1937 survey (prior to the breakwater construction) shows clearly a marked change in the estuary profile, the 1856 and prior survey situation of a single channel close to the West Cowes shore being replaced by two
shallower channels (see also Figure 21). This significant change in morphology over the period 1850-1930 was most likely driven by the combined effects of persistent shoreface retreat and increased flow into and out of the enlarging estuary. As in the mid and upper estuary reaches, data of profile B-C show that only minor changes in bathymetry have occurred since 1992.

GIS analysis suggests that over the period 1856-2015 the enlargement of the estuary water volume (by bed and bank erosion and dredging) yielded on average some 10,000 t of sediment per year (this from the reaches north of Folly Inn). This figure is close to the recorded maintenance dredging amounts removed from the estuary in recent decades.

Figure 21. The Harbour area in 1937, immediately prior to the construction of the Shrape Breakwater, showing the well-developed east channel.

3.2 Recent Change
The broad analysis of geomorphometric change provided in the previous section gives a good but simplified summary of trends (and hence processes) that have been present over the past ~200 years. They give context to the more detailed analysis that is necessary to allow a) understanding of currently active processes and b) insightful monitoring of short to medium term change that may occur as a result of present day development projects. To achieve this more detailed appraisal it is necessary to define local zones where specific processes are active. This definition of zones can be simply initially based on erosion/accumulation history for a critical period. The decision was taken to use the period 1937 to 1992 for this ‘baseline’ analysis of local change for the following reasons:
Figure 22. GIS analysis of bed-level change 1937-1992 (left) and fitted ‘polygons containing near-uniform change’ (right). For Group definition see Figure 23.
Figure 23. Erosion/accumulation histories for Figure 22 polygons, grouped by similarity.
1) It is a substantive time period, allowing cumulative change to produce quite marked bed level changes, thus overcoming ‘noise’ introduced by survey inaccuracy.

2) Two reliable surveys of the outer/mid estuary zones were undertaken in those years.

3) By 1937 much of the large-scale change seen during the 1800s has settled, and the form of the estuary was approaching its modern state.

4) The Shrape breakwater was built immediately after the 1937 survey.

5) Several significantly influential capital dredging projects occurred post 1992 (fairway improvement, Shepard’s Wharf, Royal Yacht Squadron).

6) Six reliable surveys of the harbour, all taken by the same contractor (Shoreline Surveys), are available post 1992 to provide the ‘modern’, post baseline dataset. Five of these surveys were conducted using a single beam echo-sounder (SBES, 2007, 2008, 2010, 2013, 2015-June) and one survey was conducted using multi-beam\(^{12}\) (MBES, 2015-December).

Bed-level changes mapped for the 1937-1992 period, and twenty-seven polygons fitted by eye to zones of similar change, are plotted in Figure 22. The area of each polygon was determined, and its mean bed-level for each survey extracted from the GIS data. Time series data of changing bed levels in each polygon were produced and the polygons grouped according to similar history, four Groups emerging. These are plotted in Figure 23, and mapped in Figure 22.


The bed level changes of Figure 23 were converted into rates of bed level change by dividing the differences in levels between surveys by the survey interval. These rates are plotted in Figure 24 and Table 3. An envelope of accuracy limitation (defined by the accuracy of the survey method and the time interval between surveys, more accurate methods and long intervals producing the tightest envelope), is also identified in Figure 24, plotted relative to the linear regression line fitted to all the data points. Polygons with recent rates of accumulation or deposition that are close to the limit of or outside of this envelope are specifically identified (by descriptor and polygon number). These polygons, showing greatest recent rates of bed level change, are also flagged in Table 3. Table 3 is divided into an upper and lower part, being respectively the ‘outside the estuary’ and ‘inside the estuary’ polygons. The dividing line is roughly defined by the new and Shrape breakwaters, and the two connecting entrance sections (Figure 22).

A similar analysis was undertaken for one large polygon (South Polygon, Figure 22) to examine data in the mid estuary down to the south of Kingston Quays (to nothing 94000, just north of section G-H, Figure 20). Fewer surveys were available covering this area. The results are summarised in Table 4.

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\(^{12}\) Different results may be expected from SBES and MBES. MBES data were processed by averaging all data within 1m\(^2\) grid cells. Comparison of the 2015 June SBES and December MBES mean levels for all polygons showed a best-fit (linear regression) if 0.054m was added to the MBES values. However, at this initial stage of data exploration no ‘correction’ has been made. Scope for future correction is flagged here, if this proves desirable from other evidence.
Figure 24. Historical rates of accumulation for the four polygon Groups identified in Figure 22 and 23. Linear regression lines are fitted to the full span of the time-series data, each with a confidence zone (brown shading) based on method accuracy and survey interval, identifying where variability can be due to accuracy limitations. Polygons where recent bed-level change rates are close to or outside these limits are specifically identified (descriptor and polygon number). Data are readily quantified in Table 3.
Table 3. Polygon GIS analysis results. Extreme values are flagged by colour shading (red = accretion, green = erosion).

<table>
<thead>
<tr>
<th>Area</th>
<th>Description</th>
<th>OUTSIDE ESTUARY</th>
<th>Sediment Yield or Sequestration</th>
</tr>
</thead>
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<td># 1</td>
<td>West margin of inner Shrape</td>
<td>-19</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>Above Narrows, centre shift</td>
<td>-9</td>
<td>-2</td>
</tr>
<tr>
<td>3</td>
<td>Car Ferry dock approach</td>
<td>-20</td>
<td>-8</td>
</tr>
<tr>
<td>4</td>
<td>Inner Shrape</td>
<td>8</td>
<td>-14</td>
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<tr>
<td>5</td>
<td>Centre Outer Fairway</td>
<td>-8</td>
<td>-4</td>
</tr>
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<td>6</td>
<td>Shrape Spit</td>
<td>-15</td>
<td>-6</td>
</tr>
<tr>
<td>7</td>
<td>East Harbour Approach</td>
<td>-14</td>
<td>-2</td>
</tr>
<tr>
<td>8</td>
<td>Narrows and above, west side</td>
<td>9</td>
<td>-3</td>
</tr>
<tr>
<td>9</td>
<td>Fairway of the Narrows</td>
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<td>-9</td>
</tr>
<tr>
<td>10</td>
<td>Fairway off Shepard’s Wharf</td>
<td>26</td>
<td>-9</td>
</tr>
<tr>
<td>11</td>
<td>Car ferry copit</td>
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</tr>
<tr>
<td>12</td>
<td>Fairway off West Cove town</td>
<td>-8</td>
<td>-5</td>
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<td>Bed around Shrape Breakwater</td>
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</table>

Note: For simplicities sake tonnages calculated here and mentioned in the text have been determined by assuming a consolidated sediment bulk density of 2. Tonnages will therefore be higher than actuality. Corrections will be made, based on measured densities, when later comparing these figures with sediment flux measurements.
The data from Table 4 has been included with that of Table 3 (lower part, estuary proper), and with dredging records from the estuary areas north of Kingston (Appendix 2) to examine in detail the apparent estuary bed-sediment budget from geomorphometric analysis. The following summary observations can be made.

1. Data are inconsistent (different coverages, methods and accuracies) so caution should be exercised in interpretation. In particular, as a model of an annual cycle of erosion and deposition is common (with larger level fluctuations within the year compared to a much smaller net annual change) survey intervals of less than one year (ie the last survey undertaken) should be considered potentially misleading.

2. The estuary has increased in volume (lower bed levels) from 1800. During the first 50 years of the nineteenth century bed erosion was occurring at rates of 10-20,000t yr\(^{-1}\), probably under the influence of anthropogenic impacts but dredging amounts would have been much less than today.

3. Post 1850 dredging would have steadily increased to modern day levels, both continuing the trend to deeper bed levels but at the same time modifying the flows and causing a natural response to reinstate the natural sedimentation balance (increased potential for accumulation). Through the period 1937-1992 the estuary continued to be a net exporter of sediment, at an annual average rate of 17,627 t (Table 3), but that rate would have included an unquantified but increasing (capital and maintenance) dredging rate. In 1987 the maintenance dredging rate was just above 20,000t yr\(^{-1}\) (Appendix 2).

4. Since 1992, the estuary has IMPORTED sediment at an annual average rate of ~16,000t. Dredging (~600,000t over the period) has stayed on top of this to the extent that bed levels are on average lower now than in 1992 (the estuary has undergone net export of ~165,000t sediment over the period, Table 3).

5. Since 2013, some 40,000t of sediment have been dredged from the estuary (Appendix 2), and surveys show a net gain of 24,200t (Table 3), suggesting current annual influx of ~20,000t of sediment, slightly higher than the 1992-2015 average (~15,000t yr\(^{-1}\)) but equal to historical dredging rates.

6. Historically, bed level change rates in the region have been typically less than ±50mm yr\(^{-1}\). In the last three years, and in particular in the last half of 2015, a high percentage of the polygons showed slightly larger rates, both positive and negative (Figure 24). This suggests the possibility of some perturbation in the system, although the caution in point (1) above...
should be applied. Most change inside the estuary appears to be associated with erosion rather than deposition, though reworking the data in line with the analysis described in footnote 12 would probably create a more balanced erosion/deposition situation.

7. Bed level in the coast zone immediately adjacent to the estuary (Table 3 upper part) continues to fluctuate, with significant variability between surveys. Temporary storage and then dispersion of this sediment may be important but varying source of sediment entering the estuary.

4 Bed Sediments

4.1 Approach

Approximately 30 seabed samples are known to have been taken over the period 1980-2005\textsuperscript{13}, and further samples (25 grabs plus anchor dredges) in 2006. The latter data were collected in relation to infauna analysis\textsuperscript{14}. To rectify potential gaps in knowledge of the nature of the Medina sediments, a new survey was undertaken in November 2015\textsuperscript{15}, visiting some 50 sites, where samples were taken for laboratory analysis (principally particle-size) and some in-situ measurements were made (density, shear strength). Sampling sites are plotted in Figure 25, and the full field log is reproduced in Appendix 3.

Particle-size analysis was undertaken in the Ambios lab using marine-sediment-specific methodologies based on BS 1377. Samples were split (wet sieving) at 63um if the contained >~2% mud. Sand and gravel (>63um fractions) were dry sieved at 0.5 phi intervals (Wentworth Scale), and mud (<63um) was subject to pipette analysis on the following basis:

- Fine sediment was never allowed to dry (no grinding was necessary)
- All organic matter was removed using hydrogen peroxide
- Sedimentation was measured using sodium hexametaphosphate to prevent flocculation
- Sedimentation was conducted at particle concentrations well below the threshold for hindered settling.

The here-reported particle-size of the clay/silt fraction of the sediments therefore represents the true mineral characteristics of the sediment, unaffected by flocculation.

\textit{In-situ} shear strength was only measured in gravel-free sediment. Measurement was made on the surface 1cm of an undisturbed grab sample (0.1m\textsuperscript{2}) immediately after retrieval using a specialised shear vane\textsuperscript{15}. In situ sediment density was again only undertaken on gravel-free sediment by taking a 5cm deep small core from the grab sample immediately after retrieval (to secure a set volume), the solids content of which was determined in the laboratory.

4.2 Sediment Description

4.2.1 Gravel

Two types/sources of gravel (sediment >2mm diameter) are found in the area (Figure 26):

\textsuperscript{15} P. Bassoullet, P. Le Hir 2007. \textit{In situ measurements of surficial mud strength: A new vane tester suitable for soft intertidal muds. Continental Shelf Research} 27, 1200–1205
1. Flint shingle, originally from Cretaceous strata but today largely sourced through the erosion of derived Tertiary deposits, is a common beach and river channel floor sediment in the region. Largest deposits are present along the upper beach, moving westwards under longshore drift (as evidenced by accumulation east of groynes).

2. Biogenic gravel, dominated by old native oyster and slipper limpet (Crepidula) shell. Much of this shell is iron stained and rotten, suggesting lack of modern sources (the once thriving Solent oyster fishery was shut down by Bonamia disease in the 1980s).

Away from the littoral zone, most gravels are a mixture of these two types of material.

Figure 25. November 2015 grab sites. 0-44 Smith McIntyre grab (0.1m²), 101-105 van Veen grab (0.05m²), 201-204 CEFAS (dredging licence) samples only. The Change Polygons (Figure 22) are shown.
Figure 26. Gravel types.

Top: Shingle beach east of the Shrape Breakwater.

Middle. Rotten native oyster and Crepidula shell, offshore from the old bar zone.

Bottom. Shell and flint gravel mix (bed of the narrows)
Figure 27. The distribution of gravel (%) determined from grab sampling. Field descriptions are also shown. [Note that gravel content differs slightly in places between the contours and the shading. The former are plotted from particle-size analysis data, but the small samples collected may make these data unreliable. The colour shading is from field visual estimates of the gravel content, which is probably more representative although a less precise method.]

Gravel dominates the sediment in two zones, in the north-west at the foot of the coastal slope (seawards of the old bar) and in the Chain Ferry Narrows area (Figure 27). These are zones of strongest currents, and the sediment is most likely a residual deposit, formed during the erosion of pre-existing deposits/surfaces, winnowing processes removing all finer material. In a zone trending
along the axis of the estuary gravel forms a secondary component within mud deposits, often present at low density within the deposit at depth but forming a lag veneer of gravel at the surface again as a result of winnowing processes. These gravels will have been derived both from in-situ biological activity, and through reworking of old estuarine channel floor deposits within the Holocene buried-channel fill (Section 3.1.1).

In some places, the appearance of the finer gravel particles in particular (unencrusted, bright) suggests frequent gravel motion (under tidal or storm wave action).

4.2.2 Sand
Sand (sediment with grain diameters between 0.063 and 2mm) is ubiquitous throughout the bed deposits of the area. Within the mid/inner estuary the contribution of sand to the total bed sediment rarely exceeds 20%. Seaward of the Shrape breakwater however sand becomes the dominant bed sediment component, forming 90-100% of the bed in two separate zones (Figure 28). This Figure also shows how the type (modal grain-size) of sand varies through the region. Fine sand (with a modal grain diameter of between about 180 and 63um), which is principally transported as suspended load, is present throughout the whole region apart from in three shallow intertidal samples on the east side of the outer Shrape Sand area, and two samples around the east outer area of the harbour west entrance. Medium and coarse sand, which is transported as bedload (forming bedforms such as ripples, megaripples and sand-waves) is present on the east outer Shrape Sand, and around and offshore of the harbour entrance area, extending southwards into the harbour along the east side of the fairway, the zone originally the west edge of the Shrape Spit. Bedforms associated with these deposits are seen in aerial photos (Figure 17) and multibeam imagery (Figure 29). Small local patches of coarse sand are also found within the estuary, probably derived from decomposing shell.

The medium and fine sand grains found through the estuary seem to be of similar mineralogy (quartz dominated, Figure 30). Coarse sands are usually dominated by shell fragments.

4.2.3 Mud
Mud (sediment <63um grain diameter) is the principle component of the Medina estuary sediments (Figure 31):

- Within the estuary along the axis of flow, mud comprises 30-50% of the bed sediment
- Only around the car ferry terminal and the western end of the new breakwater does mud concentration drop to ~10% of the sediment.
- Mud content of the sediment rises to ~90% along the sides of the estuary upstream of the Narrows, all along the West Cowes waterfront and inside the Shrape breakwater (zones of slacker currents, Figure 9).
- Mud content is also high on the bed of the East Entrance (70-80%), connected to the Inner Shrape mud zone. This is a zone of strong tidal currents Figure 9
- Outside the estuary (entrances/breakwaters) mud content of the bed falls to 30-0%

The nature of the mud, as defined by the relative contributions of silt (material 63-4um) and clay (material <4um) varies strongly through the region (Figure 32). Two end-member types are present.
Figure 28. The distribution of sand (%) determined from grab sampling. Sand type (modal size of grain diameter distributions) is also shown (modal diameters in phi units per site, see conversion chart below, general areas of medium and coarse sand cross hatched).

<table>
<thead>
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<th>um</th>
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<td>-2</td>
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</tr>
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<td>2000</td>
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<tr>
<td>-1</td>
<td>1400</td>
</tr>
<tr>
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Figure 29. Megaripple zones (circled in black) indicative of active bedload transport of medium/coarse sand deposits. Source Boskalis multibeam data, 2015)

Figure 30. Microscope images of typical medium sand (top) and fine sand grains, showing quartz grains and iron stained shell fragments.
Figure 31. The distribution of mud (%) determined from grab sampling.
Figure 32. Clay material (<4um) as a percentage of the mud (<63um) fraction.
High clay, low silt (80:20). This particle population is most evident offshore, on the coastal slope off the old estuary bar zone, and in deeper water off East Outer Shrape (off Old Castle Point). These are areas where the grab sampling proved outcrop of green Oligocene deposits (Figure 16, sites 5 & 11). Particle-size analysis of Oligocene deposits taken from the onshore coast landslip sites inshore of the Shrape showed similar clay/silt ratios (two samples, 77:23 & 63:37), suggesting these geological strata may be important sources of this mud type. These strata outcrop along wide areas of the Isle of Wight shores, and it is likely that Solent-wide sources are important contributors, rather than just local erosion.

Low clay, high silt (10:90). This particle populations distribution is centred off the outer end of the Shrape breakwater, with also an up-estuary zone to the side of the Channel. These areas are coincident with grab samples of an appearance that indicated an (eroding) bed comprised of Holocene estuarine clays (Figure 16, sites 15 & 16, and also site 42 from the mid estuary). The clay silt ratios in these samples were 7:93, 7:93 and 19:81 respectively. Small estuaries preferably accumulate silt rather than clay \(^{16}\), the latter material of fluvial source tending to escape offshore due to its much slower settling properties. The presence of this material in the estuary sediments may reflect modern fluvial inputs, but as these are very low (Section 2.1) and as the primary area of this material is coincident with outer estuary bed erosion zones, the latter is probably the primary source.

The relative presence of these two sources of material is considered further below in relation to detailed particle-size distributions.

4.3 Bed-sediment Groups

The discrete particle-size distributions of each of the 49 analysed sediments are plotted in Figure 33. The distributions are grouped according to their similarities. The grouping criteria are as follows (note a few samples could fit in more than one group).

**Group A.** Sediment dominated by the presence of mud, the latter material exhibiting a strong mode at the fine silt grain size (8 phi, 4um) and a low clay content (<4um). This material is interpreted (Section 4.2.3) as estuarine-derived material, probably largely sourced from eroding, in-estuary exposure of Holocene deposits. Minor contributions of fine sand and gravelly (shell) material are sometimes present.

**Group B1.** Sediment dominated by high clay content, low fine silt content and a minor mode at the medium silt size (6 phi, 16um). No sand or gravel is present (indicating recent deposition from suspension). This sediment is interpreted (Section 4.2.3) as sourced from coastal/nearshore erosion of Tertiary clays present in the Solent.

**Group B2.** Similar mud (silt: clay ratio) as Group B1, but lower overall mud content and showing presence of fine and very-fine sand particle populations, as well as some minor gravel content. Interpreted as having a similar source to Group B1 but occurring in higher energy environments, permitting regular fine sand ingress from suspension and intermittent dispersion of shell debris/fine gravel.

**Group AB.** Sediment is predominantly mud and shows characteristics of a mix of Group A & B types.

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**Group C1.** Well-sorted medium sand grain populations (mode >180um) consistent with regular tidal or wave transport as bedload. Little or no mud or gravel content.

**Group C2.** Well-sorted fine sand population (mode ~125um) with no gravel and little mud, consistent with fallout of suspended sand from adjacent high-energy tidal/wave current areas.

**Group D.** These sediments are gravel dominated (shell and shingle) and contain 0-47% mud as matrix/interbedded material. The mud content shows consistency with Group B type sediment.

When compared with the extents of the change polygons (based on 1937-1992 bed level change patterns, Section 3.2) there is quite a good agreement generally within polygons, though some polygons need dividing into two and minor boundary misfits are evident. These polygons have therefore been used to convert the point (grab sample) data into region data, as shown in Figure 34.

The sand groups (C1 and C2) are confined to zones outside the estuary, (West Outer Shrape and a small zone at the west of the new breakwater are medium sand, C1, and the East Outer Shrape and the East Coastal slope (2) are fine sand).

The gravel dominated group (D) is confined to the axis of the outer estuary (off West Cowes through to the Narrows) and channel floors in the mid estuary, and to deeper areas along the lower coastal slope.

The estuarine mud A group is centred on the Inner Shrape and the zone of the original Shrape Spit to the north and west, with an outlier in the Cowes Yacht Haven area and the shore just to the north. There is a secondary zone of group A deposits in the more stable bed areas upstream of the Narrows.

The offshore mud sourced B1 group is found principally along the West Cowes shore/fairway area, the southern end of the small boat channel and along accumulating sites away from the channel axis above the Narrows. The B2 group is found patchily within the estuary but forms a large elongate zone along the top of the coastal slope outside the estuary.

The AB mixed group occurs patchily through the estuary, with the largest zone through the southern Cowes Yacht Haven into Shepard’s Wharf.

The Groups most relevant to this study are A, B1, B2 and AB, producing the mud deposits that require dredging from Fairway and marina zones (Figure 31). By associating these groups with the change polygons, some idea can be gained of the relative mobility of the two mud types within the estuary. Polygon bed level changes over the period 2013-2015 were chosen for this purpose, the most recent data available that spans a period of greater than one year and thus avoiding seasonal influences. The results for just the A and B Groups are shown in Table 6. Although a simplistic and imprecise model, the results suggest that both Groups are actively mobile in roughly equal proportions, the inference being that Group A sediments are probably largely sourced from erosion of local Holocene estuarine mud deposits, and Group B sediments are coming from Solent-wide erosion of Tertiary clays.

The precise location of erosion and deposition areas through the second half of 2015, when the grab sampling took place, is shown in Figure 35 (two survey bed level differences).
Figure 33. Discrete particle-size distributions, grouped by distribution characteristics (see Group key in Figure 34).
Figure 34. Sediment particle-size type groups applied to 1992-1937 change polygons.
Figure 35. Bed level changes June-December 2015.
Table 5. Simple sediment budget for Group A and Group B1, B2 polygons, tonnes per year 2013-2015 (data from Table 3)

4.4 In Situ sediment properties

4.4.1 Density

A bed density measurement was made during the November 2015 grab survey if no gravel was present in the sediment. A sample of known volume was taken and dry density determined in the laboratory. Bulk density was then calculated from dry density using standard formulae and seawater/quartz densities. Dry density distribution is shown in Figure 36, and bulk density is plotted against mud content (%) in Figure 37. The latter figure shows clearly how bed density is controlled primarily by sand content, then at a secondary level by degree of consolidation (accumulation history), the latter typically about ±10% about the sand-content-dictated mean value. Bulk density reaches a peak value of ~2.0 t m\(^{-3}\) in consolidated sand, and a minimum value of ~1.35 t m\(^{-3}\) in unconsolidated sand-free mud. A value of 1.5 t m\(^{-3}\) should be used for relating bed level (volume) changes to solids flux (suspended sediment monitoring).

Highest dry density values (>1.0, Figure 36) are found at and seawards of the outer limits of the estuary due to the lower mud content of the sediments and the consolidating effect of wave action. Lowest dry density values (~0.6) coincide with the quiet mud accumulation zones (marinas) along the West Cowes shore.

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Figure 36. Distribution of dry density values for the surface 50mm sediment layer. Gravel areas are blanked.

Figure 37. Plot of bed sediment bulk density against mud content.
4.4.2 Shear Strength

Bed shear strength measurements were made during the November 2015 grab survey if no gravel was present in the sediment and if the grab was sufficiently full to allow clean vane insertion. Data are plotted in Figure 38, with gravel sites being assigned a >1.5kPa value. Lowest bed strength is found in the soft mud areas of Cowes Yacht Haven and Shepard’s Wharf; low values are associated with the immediate sub-littoral zone all along the West Cowes waterfront, indicative of accumulating conditions. Low strength is also seen along the western areas of the Inner Shrape and the adjacent small boat channel. Mud zone strength above the Narrows is not generally as low. The mud-floored area between the two breakwaters does not exhibit low strength (sites 15 & 16, figure 16), neither does site 44 above the Narrows. In Figure 39 the relationship of shear strength to both mud content and bulk density is plotted. The expected underlying trend between high mud/low density and low shear strength is evident, but there is a wide scatter about the linear regression line, which is caused by the differences between accumulating and eroding mud beds (eroding sites 15, 16 & 44 and accumulating sites 24 & 32 are identified to illustrate this point).

Figure 38. Measured in situ bed shear strength. Gravel sites have been allocated a value >1.5kPa.
Figure 39. Plots of sediment mud content and bulk density against bed shear strength, illustrating marked variability between eroding (15, 16 & 44) and accumulating (24 & 31) sites. See Figure 25 for site locations.

As well as differentiating between eroding and accumulating mud zones, knowledge of bed shear strength and bulk density is also important for assessing thresholds of erosion, through established (laboratory and field) relationships.

5 Sediment Dynamics
5.1 Sand and Gravel Transport
5.1.1 Definitions
In the natural marine environment particles finer than about 100um tend to agglomerate due to the presence of organic matter coatings (biological activity), modifying their dynamic behaviour. In this section only non-cohesive particle motion is considered, down to 63um (the Wentworth lower range limit of sand). Description of the sediments present in the Medina estuary and adjacent coastal zone (Section 4) identify:

- near ubiquitous (only absent from the wave-scoured west-central Outer Shrape) fine and very fine sand populations (particle population modal size 63-150um, 2.5-4phi),
- locally present (mostly outside the estuary) medium sands (modes 180-500um, 2.5-1phi),
- locally present coarse sands (500-1000um modes, 1-0 phi, and
- gravel. The gravel is typically mixed shell and shingle, coarse sands again have a typically high shell content) and other sand is essentially quartz.

A mineral density of 2.65 t m\(^{-3}\) can be usefully applied to all these particles.

Note that the classic Wentworth boundary between medium and fine sand (250um) is modified in this report to 180um, to simplify description of analysis. This is because in quartz sand 180um is a much more natural boundary when considering sand dynamics. The relationship between particle dimensions and seawater viscosity changes at about this size, particles finer than about 180um are more readily maintained in suspension. This means that once set in motion fine sand (<180um diameter) tends to move immediately into suspension, not undergoing bedload transport (Figure 18).

Medium sand (>180um) is transported as bedload once the critical threshold of motion is exceeded, and requires further energy to place it into suspension.

Figure 40. Relationships between particle-size (x-axis) and Friction velocity (y-axis), defining threshold and modes of motion.

Sand and transport measurement in the sea is difficult and rarely undertaken. No information is available about measured sand transport for the Medina area generally. It is normal practice to consider sand and gravel transport from knowledge of the energy of tide and wave currents affecting a sediment, using standard relationships established (mostly from laboratory studies) over the last century. Various predictive approaches exist, in this report the analyses reviewed in Soulsby and Wainwright 1987 are relied upon. Figure 40 summarises the key relationships. The y-axis in this report is Friction Velocity ($U_*$, measured in cm s$^{-1}$). The equations relating Friction Velocity to current velocity are:

$$ U_* = \left( \frac{\tau_0}{p} \right)^{0.5} \text{ cm s}^{-1} $$

$$ \tau_0 = pC_{100}^* (U_{100}^2) \text{ Nm}^2 \text{ or kPa} $$

where:

$\tau_0$ = Bed Shear Stress

$p$ = seawater density (1026 kg m$^3$)

$C_{100}$ = Drag Coefficient, taken as 0.002 for featureless sand/mud

$U_{100}$ = current velocity 1m above the bed.

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In this report \( U_{100} \) is equated to depth averaged velocity, which is an approximation which will cause over-estimate of the bed shear stress by up to about 10% in the deeper waters of the estuary.

Current velocities (depth averaged) relied upon for estimating bed shear stresses are those described in Figure 8 for four key sites in the estuary. Critical velocities identified in this figure are 0.25, 0.5 and 0.8 m s\(^{-1}\), being respectively the critical threshold of motion for fine/medium sand, the maximum velocity achieved at all sites and the maximum velocity reached at any site. These velocities, converted to Friction Velocities using the above equations, are plotted onto Figure 40. Vertical (x-axis, particle-size) lines are 180um (upper limit of fine sand), 250um (typical medium sand from the area) and 2000um (lower limit of gravel) – coloured red, light blue and purple respectively.

Wave currents (orbital) do not generally tend to create suspension conditions, except within the surf zone, and have a different set of threshold effects. The latter are summarised in Figure 41 for a 1m 5s wave, the largest wave likely to be found in the Medina, and then only in the immediate entrance areas (Section 2.3).

![Figure 41. Seabed disturbance effects for a 1m 5s (red) and 0.5m 4s (green) wave at a range of water depths.](image)

5.1.2 Bedload

Bedload movement is effectively restricted to medium and coarse sand and gravel.

**GRAVEL.** Gravel transport is thought to be low inside the estuary for the following reasons.

1) A depth averaged tidal velocity exceeding 0.75m s\(^{-1}\) is required to initiate motion in the finest gravel, and significantly greater to effect significant transport rates or move larger gravel material, as constitutes most of the Medina gravel deposits observed. Sources\(^{20}\) indicate that this velocity is only reached/exceeded in the zone north and west of the end of

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the Shrape breakwater, and in the Chain Ferry Narrows on the ebb, and then in both places only for short periods on spring tides.

2) Low wave penetration into the estuary reduces the likelihood of weaker tidal currents being able to transport gravel that is being simultaneously disturbed by wave action. Figure 41 indicates that gravel disturbance is possible only during severe storms (waves approaching 1m height). Effects would only be felt in the entrance zones due to restricted wave penetration (Figure 12).

3) Active gravel motion produces ‘clean’ (bright, unencrusted) material. This description fitted only the surface veneer of gravel deposits observed within the estuary. The matrices of gravel deposits were commonly mud-filled. Therefore the gravel is a lag deposit, immobile and scoured bright at the surface by the passage of sand grains. Deep deposits of bright gravel, indicating a mobile gravel layer, were not observed within the estuary.

Gravel transport is therefore unlikely to be an active mechanism within the estuary. Gravel produced by in situ biogenic activity, and/or released from eroding, relict estuarine deposits may be subject to minor motion and concentration under extreme energy conditions and under the effect of gravity, with the deposits so-formed kept clean at the bed surface by the abrading/winnowing action of currents.

Outside of the estuary, to the north and into deeper water, wave action will not be competent to move gravel but the Solent tidal currents peak at 1.5 ms⁻¹ and therefore are capable of driving shore-parallel gravel transport. The extensive and deeper bright-fine-gravel sampled from this region attests to active transport.

COARSE AND MEDIUM SAND. As coarse sand deposits are uncommon in the estuary, and largely made up of shell fragments (usually platy and decomposing, enhancing mobility) the focus here is on medium sand, although conclusions drawn are largely applicable to coarse sand as well.

Inside the estuary, medium sand populations are only found on the east side of the fairway off West Cowes, on and along the western margin of the original Shrape Spit (Figure 42). These medium sand deposits are mostly associated with a substantial mud/gravel component in the sediment, and have been grouped as A or D types, not C1 (medium sand) deposits (Figure 34). Detailed multibeam images in this zone show no bedforms, apart from where the zone meets the west end of the new breakwater (grab site 10), and where the mud content drops to zero (at the entrance section). Thus although currents in this zone have the capacity to drive bedload transport of medium sand, it would seem likely that the high gravel/mud content of the sediment here inhibits sand motion (increasing sheltering and cohesive effects respectively). The medium sand content seen is likely to simply be sand yielded from the erosion of the historic/Holocene deposits that occupy this area, exposes as a result of recent channel deepening and widening (Polygons 8 & 18 have a history of steady erosion, Figures 22 & 23). No contiguous medium/coarse sand bedload pathway is evident within the estuary.

At site 10, on the east side of the West Entrance, immediately south of the new breakwater, the bed is well sorted medium/fine sand (modal grain diameter 180um) with no mud, and megaripples are present. This C1 Group site is however linked to an offshore fine sand pathway (polygons 17 & 21), and only just penetrates into the estuary. This localised pocket of medium sand may rely on the newly emplaced breakwater as its principle source of sand, and therefore be a temporary feature. However medium and coarse sand populations are present in the in the coastal slope area to the north and west of the Medina West Entrance (Figures 28 & 42), as subsidiary populations in gravel dominated sediments, and intermixed with fine sand populations too. These complex deposits too
may be the source of the site 10 sand. Stronger wave action at site 10, inhibiting mud deposition, may also play a role in permitting a local area of medium sand mobility.

The main area of medium sand occurrence is outside the estuary on the central and east Outer Shrape Sand (Polygon 27). The envelope containing these well-sorted medium sand populations is shown in Figure 42. This zone is likely to continue eastwards beyond Old Castle Point to encompass a source zone; littoral sand driven westwards along the East Wight coast may be the principle supply.

Figure 42. Areas of medium sand occurrence in the outer estuary and nearshore zone, and areas of fine sand occurrence in the nearshore zone (fine sand is ubiquitous within the estuary). December 2015 bed morphology is shown.

The well-sorted nature of these sand grain populations (Group C1 Figure 33), the absence of mud or gravel and the presence of large (~40m wavelength, <1m amplitude) near shore-normal straight crested bedforms (Figures 17 and 42) all indicate active sand transport under combined wave and tide current conditions. Over the period from 3 hours before to 3 hours after HW, when the Outer Shrape intertidal is best covered in water, the flow is consistently to the west. It can be speculated that prior to the construction of the Shrape breakwater, strong tide flow periodically enhanced by wave action carried medium sand all the way into the estuary. The construction of the breakwater in 1937 is likely to have pushed the strongest flows offshore. Modelling of the baseline situation undertaken by ABPmer (Figure 43 Map A21) shows that at times of peak west-going tidal flow just before HW, the Outer Shrape Sand area is a zone of slack currents. Thus with the construction of the breakwater the Shrape Sand may have become a relict feature, with tides unable to carry medium sand to its western extremity. Occasional strong waves may weakly continue this original movement, but it seems that the eastern extremity of the sands is now comprised of fine ‘fallout’ sand, able to drift in from adjacent areas, replacing the original active bedload vector. Before 1937 the levels across Polygon 27 were accreting, and Polygon 20 was stable, but both regions have been eroding steadily since (Figure 23). This change is consistent with a reduced ability of the tide to carry sand westwards across this area, as well as reflecting a probable reduced source of littoral sand due to

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extensive coastal protection works during the 1856-1937 period. Importantly, there is no evidence that the medium sand deposits of the Outer Shrape area have been moving into the estuary in recent decades.

Figure 43. Modelled baseline (A) and post works (B) depth averaged current flow just before HW. Area of predicted change causing concern is circled in red.

The ABPmer modelling for the post works situation\(^\text{22}\) (Figure 43 Map B) indicates a substantial change in flows across the Shrape Sands area (Polygons 20 & 27), with much stronger flows that might erode and feed a renewed supply of medium sand into the estuary. Particle-tracking of 300um sand was undertaken as part of the modelling studies, showing no extensive sand transport. However, as the sand deposits here are largely 180-250um modal grain size, this change is flagged as a potential negative impact of the development that should be watched.

\(^{22}\) The charts of Figure 43 are from the EIA report, but most recent iterations of the model show a similar situation.
5.1.3 Suspended Sand Load

FINE SAND and VERY FINE SAND (referred to jointly from now on as fine sand) is ubiquitous throughout the estuary, forming up to 40% of the sediment in areas of the outer estuary and typically 10-20% elsewhere. There is a major offshore source of fine sand, a fallout from the sand transport occurring under the very strong Solent flows. This material drifts laterally from the zones of very strong east-west-east flow to the north of the subtidal coastal slope, and accumulates (often together with mud) along the top of that slope (Polygons 17, 21, 22 & 25, Sediment Groups B2 and C2). All four of these polygon areas have been steadily accumulating over recent decades, indicating a strong feed of this material from offshore. The red envelope in Figure 42 defines this source zone for the estuary. The mud commonly associated with the fine sand in this area never appears to exceed ~34%, and it therefore a matrix fill, consistent with the active erosion and deposition of combined mud and fine sand particles. Similarly the shear strength does not exceed ~1.1kPa in clean fine sand areas, or 0.6 in mud and fine sand areas, values consistent with active rather than relict deposits (sediments interpreted as eroding Holocene deposits have mud content >80% and shear strengths of 1.1 kPa). It is worthy of note that the latter eroding Holocene muds in the outer and mid harbour areas do have a fine sand content, but only about 10%, which combined with their rate of yield probably makes them an unimportant source of fine sand compared with the offshore supply.

In the northern half of the Western Entrance for a period of a few hours on the flood, and across the whole Eastern Entrance for three hours on either side of HW (Figures 8 & 9), depth-averaged flow will exceed the critical threshold of motion for fine sand (0.25m s\(^{-1}\)) and with an extensive swathe of settled source material on the coastal slope outside the entrances there is high potential for inflow of significant quantities of this material. The mud content of the settled deposits outside the Eastern Entrance may raise its erosion threshold, but with flow exceeding ~0.5m s\(^{-1}\) for much of the time the potential remains high. At times of strongest flow fine sand will become evenly distributed through the water column, and very fine sand will be so-dispersed all the time (Figure 40) creating rapid transport with the water body. The sand is likely to interact with/be bound into flocs of the finer suspended particles, resulting in a suspended load that is more responsive to changing current conditions (settling faster from the water column at times reduced turbulence/velocity).

Fine sand clearly plays an important role in the estuary sediment regime, probably accounting for about 20% of the weight of the mobile sediment in the estuary

5.2 Mud Transport

5.2.1 Overview

In contrast to sand and gravel dynamics, mud transport can be practically measured in the field. The commonest approach to this measurement is to use optical backscatter sensors (OBS) which use a nephelometric method to determine turbidity as a surrogate of total suspended solids (TSS), the latter measured gravimetrically (sample filtration).

**CALIBRATION.** Sensors are calibrated to a uniform artificial suspension (particles slow settling and of uniform colour and size). This first level of calibration (to Nephelometric Turbidity Units, NTU) gives assurance of quality control of the optical data. A second level of calibration is required to relate sensor NTU values to TSS (expressed as mg l\(^{-1}\)). Variability in the colour and effective particle-size (Figure 44) of natural mud suspensions makes this an imprecise process, yet it is the best method available and is widely relied upon. NTU to TSS calibration has been undertaken for Medina estuary sediments in two ways.
1. Making OBS measurements in the field and simultaneously collecting water samples (undertaken over seven days of survey in November). The method has the advantage of sampling natural suspension conditions but suffers from the two water samples (optical, water bottle) not being from exactly the same point.

2. Collecting a typical mud from the harbour floor and resuspending it in seawater, stirring, allowing sand/macroflocs to settle for a short period then collecting a ‘standard’ that can be diluted to various concentrations for calibrations (silt and clay mixture). However the sediment sample(s) chosen may not be representative and the suspension-generation process may not mimic natural conditions.

Results of the calibration are reported elsewhere. There was good agreement between the methods used giving confidence that the Medina suspended sediment tends to be a uniform mix of particle types and sizes and gives a near-consistent backscatter response. However the potential inconsistency should be borne in mind, particularly with stations that are over different seabed types (eg clean fine sand or eroding relict clay).

During calibration (method 2) the opportunity was taken to make a simple measure of the settling rate of the Medina mud, by simply switching off the stirrer during an OBS sensor calibration at 500mg l\(^{-1}\) and logging the decrease in backscatter with time (readings taken at five minute intervals). The test showed the settling velocity of the particles to decrease exponentially with time, initial settling rates were of the order of 0.15 mm s\(^{-1}\) (~0.5m hr\(^{-1}\)) and the median settling rate was 0.033 mm s\(^{-1}\) (~0.1m hr\(^{-1}\)). The temperature was 18°C. Published median settling velocities for UK estuaries are commonly an order of magnitude higher, though the result was just within the envelope of scatter of Severn Estuary readings. As a single result in a non-dedicated test, conducted on sediment where the very coarsest elements (fine sand, macroflocs) had been previously allowed to settle out and be removed, this data should be treated with caution. Further study is recommended. However,

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23 Campbell Scientific App. Note Code: 2Q-T Written by John Downing. Effects of Sediment Size on OBS® Measurements

24 Ambios Environmental Consultants Ltd 2016. MEDINA ESTUARY SEDIMENT MANAGEMENT STRATEGY: MONITORING INITIATION February 2016 Report AmbCHC01
the result is mentioned here as other evidence to be discussed suggests the local suspended sediment does exhibit slow settling characteristics.

FIELD CAMPAIGNS. Two types of observation have been undertaken with the methodologies fully described elsewhere 23. Manual surveys were carried out during November and December 2015 at 10+ stations (Figure 45), with hourly full water column profiles taken over a spring and a neap tide. Similar profiles were also taken during the November 2015 grabbing survey (sites shown in Figure 25). Subsequent to these surveys, autonomous turbidity measuring stations were set up at four sites (Figure 45) in January 2016 and it is planned to continue monitoring here into the foreseeable future. Two sensors (SH and TL) are suspended from floating platforms and monitor the bottom 50% of the water column, two sensors (CY and MM) are fixed at about 1m above the bed. Readings are taken at five minute intervals. A pressure sensor (wave/tide-level monitor) is also installed at the CY site.

Figure 45. Turbidity monitoring sites.
Numbered red dots are manual survey sites.
Four red circles are long-term monitoring sites.

In this report the focus has been on all turbidity data from the November-December 2015 manual surveys and the fixed site monitoring data for just for February 2016. The monitoring data began on the 19th January and continues (through the Shrape sensor was lost on 24th February and replaced May 5th). Analysis of data from the four monitoring sites will continue on a regular basis, following the methodologies developed in preparing this report.
5.2.2 Water column turbidity variability

Profiling data is available from the manual OBS surveys of November and December 2015. Summary diagrams of the profiles, showing all profiles logged at each site per survey, are provided in Figure 46. A simple rig was used to ensure that the sensor never came closer than 0.5m to the bed and in consequence normally avoiding spurious data caused by bed sediment disturbance. Descent/raise rates were 0.2m s\(^{-1}\), allowing sufficient time for instrument response.

The data show that very good vertical mixing was the norm, with no marked variation through the water column and no well-developed near-bed nepheloid layer. The observed vertical variability:

- Was often greatest between the near-surface layer and the deeper water column, with a lower turbidity near the surface. This may be due to minor salinity stratification effects (figure 3) in the surface layers, or possibly a spurious sensor acclimatisation feature.
- Sometimes was seen between the falling and rising sections of the profile (the sensor was left on bed for a little while, the operation nominally taking ~2 minutes), indicating that small scale horizontal variability in turbidity was greater than vertical variability.
- Sometimes showed local spikes, probably due to floating weed fragments etc.
- Occasionally showed strong vertical variation, such as at stations 6 & 7 during the neap tide survey and Station 9 on the mid-range tide survey. The form of the latter plot suggests either the presence of a nepheloid layer, or possibly strong dragging of the rig across the bed and the spurious effect of bed resuspension.

These data clearly demonstrate the normal absence of either a near-bed nepheloid layer or an upwards decreasing turbidity gradient. This observation is important in the following ways:

1. There is justification for the use of a two-dimensional mud transport model, and also the use of single level long-term monitoring sensors (which are mounted in the bottom half of the water column but at variable heights above the bed).
2. Absence of vertical variation in turbidity is consistent with a highly mixed water body, and hence suspended sediment population, thus giving confidence in the use of a single NTU-TSS calibration relationship.
3. Vertical turbidity uniformity suggests that strong bed erosion did not occur at most of the profile measurements made during this spring/neap surveys. As profiles were taken at 10+ sites in the outer harbour, and for every hour of the tidal cycles, this suggests that bed resuspension by tidal currents does not regularly strongly resuspend seabed sediment in the area. High wave action did not occur during any of these surveys.
Figure 46. Vertical turbidity profiles. The spring (3.8m range) and neap (2.2m range) tide data were each collected over two consecutive days, the mid-range (2.5m) data over just one day (not a full 12.5 hour tide).

5.2.3 Time-series analysis
A TSS time-series plot for February 2016 is shown in Figure 47, presented as a centred one-hour moving average. Coincident water level and wave/weather plots are also shown. Although not
shown, plots for January, March and April have a similar appearance. The same TSS data are shown in Figure 48 presented as 30 minute averaged data, colour coded by tide range. The following basic characteristics of the turbidity regime are illustrated by these plots.

- TSS typically varies in the range 10-100mg l⁻¹. Average and standard deviation data for February are shown in Table 6, grouped by tide range.
- The strongest trend in the data variability relates to the spring neap cycle, with average concentrations approximately doubling between lowest and highest ranges (Table 6, 20-40mg l⁻¹).
- Modest semi-diurnal tidal cycle variability is evident, greatest on spring tides but not showing highly consistent patterns between sites or through time, the latter suggesting influence of local non-tidal controls of turbidity.
- Intermittent high TSS events occur, likely to be storm driven, but they do not occur frequently (only 2-3 days in February 2016).

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Table 6. February 2016 Total Suspended Solids (TSS) average and standard deviation data, grouped by tide range. Standard deviation relates to 30 minute averaged data.

These general characteristics are explored further by looking at ten individual semi-diurnal tidal cycles in detail. The TSS plots (five minute data readings) are shown in Figure 49, together with summary weather plots for the day. The locations of these tides within the monthly cycle is shown at the foot of Figure 48. River levels were generally stable through the month at around 7.1m with two minor flood events (~7.4 m) on the 8th and the 13th. The four sites are taken to represent the following key points in the estuary.

MM. Interface between the harbour and the estuary upstream of the Narrows

SH. Eastern Entrance

TL. Western Entrance, though on the early flood the opposite (NE) side of the entrance may have very different conditions

CY. The Cowes Yacht Haven/Red Jet terminal area

On the TSS plots, the periods of strong tidal flow (Figure 8) are identified by coloured box overlays.
Figure 47. Time series for February 2015. Top: Turbidity data is one hour centred moving average, water level is 5 minute reading. Centre: Offshore wave conditions south of Wight. Bottom: Local weather conditions at Newport. Red boxed areas are the two stormy periods of the month with marked impacts on turbidity.
Figure 48. Time series of 30 minute averaged turbidity per site, coded by tide range. High readings A-E are late ebb (11-12 hours after HW) turbidity at Shrape on a top spring tide. Red-boxed areas are storm conditions (see Figure 47).
Figure 49A. Individual tidal cycle time-series (1). Weather plots show (top to bottom) air temperature, wind speed, wind direction and rainfall.
Figure 49B. Individual tidal cycle time-series (2). Weather plots show (top to bottom) air temperature, wind speed, wind direction and rainfall.
Figure 49C. Individual tidal cycle time-series (3). Weather plots show (top to bottom) air temperature, wind speed, wind direction and rainfall.

02/02/2016. LW at 10:50. Wind WSW force 2-5. Low neap. The envelope of most TSS readings is 15-50 mg l\(^{-1}\). Levels at the two entrances are similar outside the peak flow periods, and levels rise a little at both sites during peak flow, SH being slightly higher until the late ebb. The MM site is lowest throughout the tide, rising to equal the outer harbour levels on the late flood. CY levels are higher than all other levels on the flood, peaking at 90 mg l\(^{-1}\). Levels at CY fall to equal general levels in the harbour during the ebb. Most of the records at all sites show moderate levels of variability within the timescale of one hour (typically \(\pm 10\) mg l\(^{-1}\)) given the modest variation over the whole tide, indicating that local/random processes are important. Generally the distribution is explained well by offshore suspended sediment sources being important and there being a slight response to increased flow strengths. The situation at CY on the flood is not immediately explainable.

05/02/2016. LW at 01:35. Wind SW force 2-4. Neap. The envelope of most TSS readings is 15-40 mg l\(^{-1}\). Levels at the two entrances are similar outside the peak flow periods, and levels rise a little at both sites during peak flow, SH being slightly higher until the late ebb. The MM site is lowest throughout much of the tide, rising to equal the outer harbour levels on the late flood, and to exceed harbour levels at times of peak flow periods, but only towards the end of those periods. The few high MM peaks may be spurious\(^{25}\). CY levels are higher than all other levels on the early and late flood, peaking at 50 mg l\(^{-1}\). Levels at CY fall to equal general levels in the harbour during the ebb. Most of the records at all sites show moderate levels of variability within the timescale of one hour (typically \(\pm 10\) mg l\(^{-1}\)) given the modest variation over the whole tide, indicating that local/random processes are important.

\(^{25}\) There was a problem with the mounting of this sensor in until rectified in March 2016, causing spurious high values occasionally. Most of these have been subjectively edited out.
processes are important. Generally the distribution is similar to the 02/02 low neap tidal cycle, but with slightly higher overall levels, and is explained well by offshore suspended sediment sources being important and there being some response to increased flow strengths. The situation at CY on the flood is not immediately explainable. The slight increase in overall TSS concentrations compared to the (lower energy) low neap tide may be a function of the prevailing wind/wave conditions determining turbidity levels in the Solent rather than locally. On the 2\textsuperscript{nd} the wind strength as slightly higher and had a more westerly component, possibly increasing wave activity within the Eastern Solent. Also on the 2\textsuperscript{nd} offshore waves were higher and had a very long peak period (>20s) which may have increased swell penetration into the Solent area. Both these influences may account for a slight increase in the Solent water turbidity levels.

15/02/2016. LW at 09:13. Wind N-NW force 4-5. Spring. The envelope of most TSS readings is 20-60 mg l\textsuperscript{-1}. There is a moderate onshore breeze which clearly causes turbidity along the coast outside the estuary. This breeze dies away though the ebb. At TL the effect of the local wave action is simply seen as slightly higher than normal early flood TSS levels, which mask any increase into the peak tidal flow period. Levels at TL decrease through the ebb. The situation at CY mirrors that at TL, with only occasional spikes where CY levels exceed those at TL. At SH the early flood levels are similar to those seen at TL and CY, but after 2 hours the levels rise to peak at ~100mg l\textsuperscript{-1}. At 3.5-4 hours after HW there is a marked drop in the SH levels to about 30mg l\textsuperscript{-1}, after which SH levels generally follow those seen at TL/CY. Small waves breaking over a shallow muddy foreshore create a water-body of muddy water which the wave-driven water circulation system tends to pin against the shore. The situation seen on the flood at SH is best interpreted as the inflowing tide being initially fed by this turbid wave-created shallow water body, but at about 3.5 hours after LW the seaward margin of this body passes inshore of the outer end of the Shrape breakwater, thus no longer being able to feed the tide flow into the harbour. This “LW +3.5hour cut off” is seem repeatedly in the SH records. At the MM site conditions are quite different to those described in the previous paragraphs; there is significant short term variability in the TSS level, with minimum values equalling or being slightly lower than harbour values, but peak values, particularly on the flood, being very much higher (attaining 100mg l\textsuperscript{-1}). The most likely interpretation of the MM flood tide situation seen here is relates to the ability of the NW breeze/waves to penetrate the harbour through the east entrance, the small amplitude waves breaking on the East Cowes shore north of the Narrows, and across the southern part of the inner Shrape mudflat, to generate a local turbidity zone which the flood tide carries into the upper estuary (this turbidity not seen at the TL, CY or SH sites). The periods of flood and ebb peak tidal flow are not reflected in the turbidity values, which is surprising considering an effect was seen on neap tides. The absence of effect on the flood may be due to wind driven effects on the velocity distribution within the water column, the northerly breeze accelerating surface flow and hence reducing flow at the bed.

15/02/16. LW at 2143. Wind near calm. Spring. This tide follows immediately on from the previous, has a slightly lower range but with calm wind/wave conditions. The envelope of most TSS readings is 20-60 mg l\textsuperscript{-1}, and the general distributions of turbidity are different to those seen on the previous tide, emphasising the potential effects of northerly winds. Lowest levels of TSS are seen at SH, there being only a slight response to peak flow conditions (this low level may reflect temporary exhaustion of mud sources on the outer Shrape zone due to the wave scouring during the previous tide). Levels at TL are similar to SH on the first of the flood and last of the ebb, but through the rest of the cycle they are higher than SH, being highest with the onset of peak flow conditions. Conditions at CY generally lie between the levels seen at TL and SH, apart from during the initial 2-3 hours of the flood when (as seen previously) they are much higher than SH/TL, peaking at 70mg l\textsuperscript{-1}. Conditions at
MM again show a lot of short term variability, but the effect of the peak-flow period is very marked, with strong turbidity values (~80mg l\(^{-1}\)) associated with the times of highest flood and ebb currents. This strong response may reflect a temporary abundance of erodible fine sediment in the in-harbour source areas due to the effects of the wind/wave action seen during the last tide.

11/02/2016. LW at 06:15. Wind S force 0-2. Top Spring. The envelope of most TSS readings is 20-80 mg l\(^{-1}\). During the first three hours and last hour of the tide the TSS levels at all sites are very similar at around 40-60mg l\(^{-1}\), consistent with the highest energy tidal condition producing a well-mixed high-turbidity condition both in the Solent and the estuary. During the periods of peak flow however inflow levels at SH tend to fall off (to around 20mg l\(^{-1}\)) whereas levels at CY and TL remain higher, suggesting bed sediment reworking within the harbour is occurring. At MM TSS levels flowing into and out of the upper estuary generally follow peak flow periods. The unusual feature of this tide cycle is the peak in turbidity seen at SH on the last of the ebb, attaining ~140mg l\(^{-1}\). This late ebb peak is seen on several tides around this time (labelled A-E in Figure 48). It is likely that this is a ‘top spring’ feature, the very low tidal levels reached toward slow water (see Figure 47) allowing the ebb flow to erode the unstable, accreting outer edge of the inner Shrape mudflat and cause this plume. Similar conditions occurred (low ebb tide level) on the 23\(^{rd}\) and 24\(^{th}\) February, when a late ebb plume (less marked) also occurred (Figures 47, 48 & 49C).

08/02/2016. LW at 04:00. Wind W force 4-8. The envelope of most TSS readings is 25-80 mg l\(^{-1}\). The TSS levels at all sites was approximately the same all through the tide, showing indolence due to periods of peak currents, and with small-scale variability masking small and varying differences between the sites. High CY levels on the early flood, previously noted, were present. The strongest feature of the tidal cycle turbidity distribution was a marked peak at SH on the late ebb (~160mg l\(^{-1}\)). At this time a westerly gale was blowing, with refraction causing wave breaking on the shallow outer Shrape area creating a zone of high turbidity that would have been pulled into the slow eddying flows at the SH site at this time.

08/02/2016. LW at 15:50. Wind W force 7-4. This tide follows on from the previous. The envelope of most TSS readings is 25-140 mg l\(^{-1}\). This tidal cycle is very unusual for its very high flood tide TSS levels, the ebb tide is more typical of a normal spring tide. The large perturbation in turbidity (one of two during the month, Figures 47 & 48) was caused by gale force westerly winds causing large Solent waves which broke along the coast west and east of Cowes. The first half of the flood brought in Solent water at very high concentrations (100-140mg l\(^{-1}\)) through both entrances, and similar levels were seen at the CY site. With decreasing wind conditions from about LW + 2 TSS levels at SH, TL and CY steadily reduced together through the full tidal cycle. In contrast, TSS levels at site MM were normal at the beginning of the flood but steadily rose (with one pronounced spike) to equal the outer harbour levels at LW + 5.5 hours, the time of peak tidal inflow. From that point MM levels decreased in tandem with the outer harbour levels, although also showing a second maxima coincident with the ebb peak flow period.

13/02/2016. LW at 07:33. Wind E going N force 4-6. The envelope of most TSS readings is 25-125 mg l\(^{-1}\). The large perturbation in turbidity (one of two during the month, Figures 47 & 48) was caused by strong winds from the E – N sector causing wave breaking along the outer Shrape shallows. Strongest winds occurred over the HW period and were from the NE. The most marked effects were seen at SH, where on the flood tide (LW +2 to LW +3.5) TSS values increased steadily to ~150mg l\(^{-1}\). The “LW +3.5hour cut off” described from records above was dramatically seen at this point, reducing TSS levels to 50-60mg l\(^{-1}\), then at LW +5.5 high turbidity was again seen, attaining values of ~200mg l\(^{-1}\) at HW then reducing steadily through the ebb. Turbidity levels at TL increased to
about 150mg l\(^{-1}\) on the ebb, as a function of the throughflow coming across from SH. Interestingly, levels at CY and MM although high (typically 30-60mg l\(^{-1}\)) did not approach the SH/TL maximum levels. This suggests that much of the material being placed in suspension at the latter sites was fine sand, which settled out from the flood currents running into the harbour, the highest turbidities therefore not reaching the CY/MM sites. High turbidity was seen again at SH on the very last of the ebb.


The envelope of most TSS readings is 20-50 mg l\(^{-1}\). These tides have been included as they are the only other period during February that had northerly winds, albeit light. The examples show minor effects of elevated TSS levels at Shrape under these conditions. The top spring example shows a case of late ebb elevated turbidity at SH referred to in the 11/02 example.

In summary, these case studies show that there is considerable variation around the basic tide-flow driven system of turbidity. This sources of this variability can be categorized as follows:

- Gale-force westerly (and probably easterly winds) possibly coupled with high groundswell penetrating from offshore (peak periods >15s) can elevate suspended solids levels along the north Wight coasts, causing significant elevations in the TSS levels entering the harbour.
- Northerly strong winds breaking over the shallow outer Shrape zone generate a nearshore body of turbid water. This can be pulled into the outer harbour by the west-going streams entering the east entrance. The access of these streams to the turbid water body is sometimes cut off, as the wave-driven littoral currents pin the turbid water body against the shore, and as the tide rises beyond approximately the mid-tide level it seems the turbid water area becomes separated from (its outer margin lies inshore of) the strong-tide zone just outside the Shrape breakwater. There is a suggestion that these north wind episodes are when fine sand is effectively carried into the harbour area.
- Small amplitude waves generated in the harbour (eg by strong southerly or north-easterly winds) can generate a turbid body of water over the inner Shrape mudflat area, this turbid water can then be carried seawards or into the upper estuary by the tide.
- On lowest spring tides, current and wave action effective along the outer edge slope of the Inner Shrape mudflat can cause erosion and generate a turbid plume of water that passes out through the eastern entrance.
- There are random small scale variations in the system.
- Pre-conditioning plays a role. Periods of non-regular high energy (eg a storm) can both temporarily exhaust sediment source areas, and create new temporary supply zones of readily erodible mud, thus respectively decreasing or increasing regular suspension transport load through subsequent tide(s).
- TSS levels at CY are often, on the flood, higher than the TSS levels in the ‘source zones’ of the two entrances (SH/TL). On the ebb a similar situation is seen but with TL levels higher than source zones (MM, SH). This implies marked local resuspension within either the central outer harbour area or along the central West Cowes shore. Vertical profile data (Section 5.2.2) do not show evidence of regular, strong bed erosion that might be expected if such action was commonplace. Another explanation might be regular shipping activity, where screw or jet action violently disturbs the seabed, tending to near-instantly create a highly turbid water column i.e. not generating vertical TSS gradients but horizontally patchy turbidity. The turning of the Red Jet just north of the CY site would be a likely source of such disturbance, and bathymetry surveys clearly show zones of localised bed scour and accretion.
associated with this activity (Figure 35). To test this hypothesis the February 2016 five
minute turbidity readings at the CY site were averaged for Red Jet operational times (06:00
to 24:00) and non-operational times (00:00 to 06:00). The results (Table 7) show that during
Red Jet operational periods TSS levels at the CY site are three times that of the non-
operational periods, and standard deviations double the value. These data suggest that the
Red Jet turning may be responsible for much the elevated turbidity levels seen in this zone.

<table>
<thead>
<tr>
<th>Time</th>
<th>00-06</th>
<th>06-24</th>
<th>00-06</th>
<th>06-24</th>
</tr>
</thead>
<tbody>
<tr>
<td>mg l⁻¹</td>
<td>11.91</td>
<td>30.27</td>
<td>6.92</td>
<td>11.39</td>
</tr>
</tbody>
</table>

Table 6. Average and standard deviations for five minute TSS readings during February 2016,
grouped by time of day (Red Jet non-operation and operation periods).

5.2.4 Tide Hour Plots
In the previous section the apparent strong influence of tidal cycles (semi-diurnal and spring-neap)
was broadly recognised from the time-series data, and the focus of analysis was identifying the non-
tidal effects that blur the effects of tidal rhythms on the turbidity distribution. In this section the
blurring is accepted and the analysis focusses on identifying the average tidal effect within the
scatter of points. This has been achieved graphically, by plotting the tide-hour against TSS values,
and by grouping the plots by tidal range, for each of the four sites. In Figure 50(A-C) this is done
using the individual (5 minute) TSS readings for the months of January, February and March 2016. In
Figure 51 thirty minute data averages are used in similar plots, just for the month of February. The
latter removes small scale local variability, and random variability, and provides a clearer view of the
underlying tidally-driven rhythms. Simple linear regression lines have been fitted to each group of
data, to reveal the base trend through the tidal cycle. These lines are an approximate indicator of
sediment flux; if the line is horizontal sediment levels on the flood balance sediment levels on the
ebb, a higher initial value decreasing through the tide suggests the site is importing more sediment
than it is exporting, and vice versa with a line with a lower initial value, the site exports more than it
imports. For each site the period when depth averaged currents exceed 0.25m s⁻¹ are colour shaded.

The following observations can be made from these figures:

- There is not a marked difference in the TSS distributions between January, February and
  March (particularly bearing in mind that January had only about 10 days of data). Detailed
  analysis of monthly differences in conditions will be undertaken once more months of data
  have been collected. The most noticeable differences related to the highest TSS values,
  thought to relate in infrequent storm events. The regular tidal influence seems to be
  dominant.
- Although there is some evidence of slight increases in TSS values associated with the
  periods of strongest flow, this is minimal, and is even more difficult to recognise in the 30-
  minute averaged data of Figure 51. The absence of a marked increase in TSS values
  associated with flows >0.25m s⁻¹ suggests that strong bed resuspension is not taking place
  at these times. Most bed mobilisation effect is noted on spring tides, and at the onset of
  high currents at TL and towards peak or late higher current condition at CY and MM. Little
  effect is noted at SH.
- The 30 minute averaged data shows much less variability through the semi-diurnal tidal
cycle than the raw data indicating that short term fluctuation, with infrequent higher TSS
readings, is an important aspect of the turbidity regime. The 30 minute data (Figure 51)
show little systematic variability in TSS values through the tidal cycle, and only modest differences between sites.

Figure 50A. Individual (5 minute) turbidity readings at the Shrape site, plotted against tide hour and colour coded by tide range. Linear regression lines fitted to data from each range group. Colour shaded zone indicates period with depth averaged velocities >0.25 m s\(^{-1}\) (see Figure 8).
Figure 50B. Individual (5 minute) turbidity readings at the Cowes Yacht Haven site, plotted against tide hour and colour coded by tide range. Linear regression lines fitted to data from each range group. Colour shaded zone indicates period with depth averaged velocities $>$0.25 m s$^{-1}$ (see Figure 8).
Figure 50C. Individual (5 minute) turbidity readings at the Trinity Landing site, plotted against tide hour and colour coded by tide range. Linear regression lines fitted to data from each range group. Colour shaded zone indicates period with depth averaged velocities >0.25 m s\(^{-1}\) (see Figure 8).
Figure 50D. Individual (5 minute) turbidity readings at the MMC Divers site, plotted against tide hour and colour coded by tide range. Linear regression lines fitted to data from each range group. Colour shaded zone indicates period with depth averaged velocities >0.25 m s\(^{-1}\) (see Figure 8).
Figure 51. Thirty minute averaged turbidity readings at all sites and for all tidal range groups, plotted against tide hour. Colour shaded zone indicates period with depth averaged velocities >0.25 m s\(^{-1}\) (see Figure 8). The grey envelope relates to the TL Top-tide plot and is copied to all other plots to help visual comparison.
In contrast to the semidiurnal/inter-site situation, there is a marked variation in TSS levels through the spring-neap cycle.

The trend-lines fitted to the plots show only minor variation between the months. The February lines (seen most clearly in Figure 51) suggest that, CY site aside, there is a balance between flood and ebb sediment levels, with a slight tendency for the estuary to become a net sediment trap over neap tides. The CY site shows a much stronger tendency to trap sediment on all tidal ranges. These fitted lines can however only be used as an index of balance, the true sediment flux is a more complex situation as tidal prism volume variations do not vary linearly through the tide.

In summary, examination of the semi-diurnal and neap-spring variations in TSS values suggests that, as individual semi-diurnal distributions vary little, the processes primarily responsible for turbidity lie out in the Solent, and neap-spring variations in turbidity are generated in the Solent rather than in the Medina estuary. For this to be occurring the Solent suspended particle populations must typically exhibit quite slow settling behaviour. This Solent source provides for an approximate doubling of the suspended load between neap and spring tides. Deposition and resuspension does occur within the estuary, as evidenced by the increase (above Solent levels) of TSS values on the flood at CY, and the trap-format trend-lines at CY on all tidal ranges and other sites on neaps. This model is consistent with the observations, based on settled sediment analyses and bathymetric change (Table 5) that a Solent derived (clay rich) particle population is an important source for the flux of fine sediment into the estuary, but that a locally generated (silt rich) population also circulates within the estuary, and notably dominates the seabed in the CY zone (Figure 34).

5.2.5 Bed erosion and sedimentation
A simple and practical way to get a first estimate of erosion and deposition activity for silt/clay is to determine the water flow vectors and then examine the changes in the suspended sediment concentration along those lines. An increase in suspended sediment level between two points along the flowline indicates that resuspension of bed material has taken place to feed the suspended load, and a decrease indicates that there has been deposition from the flow. This has been undertaken for the outer harbour area, looking at conditions on a neap (2m range) and spring (3.5m range) tide. Flow lines are taken from the ABPmer model for the post-breakwater condition (currently prevailing) and 30-minute averaged TSS data from the four monitoring sites are taken as representing typical suspended load conditions for that vicinity. The latter assumption seems reasonable given the generally low degree of variability between sites at any given point in time (Figure 51).

Plots were prepared for each site for each 30 minute interval of the semi-diurnal tidal cycle, and TSS values were plotted against tide range (Figure 52). Best-fit trend lines were fitted to the data from each site, representing average TSS/range relationships at 30 minute intervals through the tide. It was found that an exponential equation provided best-fit, of the form:

$$TSS \ mg \ l^{-1} = A*e^{(B*range)}$$

where $A$ & $B$ are constants.

$R^2$ values indicate that these exponential relationships represented about 20-70% of the variability in the data, which is reasonable for a natural system. The TSS values were calculated from these equations for a 2m and a 3.5m tide for each site. The ABPmer model water flow-lines, the calculated half-hourly average TSS readings and the periods of strong current velocity (>0.25m s$^{-1}$) were plotted on hourly neap and a spring charts, shown in Figure 53. Generalised zones of apparent erosion and deposition were subjectively coloured blue and brown on each chart.
Figure 52 (and previous two pages). Half-hourly plots of tide range against 30 minute turbidity averages for February 2016, plots colour coded by site. Exponential best-fit lines are fitted to data from each site. Data from storms (8th and 13th February) have been removed.

The following observations can be made from the erosion/deposition zone plots of Figure 53:

- The erosion/deposition areas identified only relate to the main flow zones within the harbour. Quiescent areas on the margins of the estuary (notably marinas or deepened mooring areas) area likely to be much more persistent zones of deposition. However it is useful to be able to identify the closest central-harbour erosion/deposition zone in order to assess the principle sources and mechanisms affecting the marginal sites.

- In general the north-west harbour zone (within the triangle between TL, SH and CY) emerges as the principle zone of erosion and the south-east harbour zone (within the SH, CY & MM triangle) the principle zone of deposition. This agrees with the pattern of bed level change seen inside the estuary post 1992, with Group 1 and Group 4 Change Polygons (associated with recent accretion) tending to occupy the south-east harbour zone (Figures 23 to 24).

- An erosion node is clearly centred just to the north of the CY monitoring station for much of the time, and even during periods when water flow in the area lies below the minimum threshold value for any bed disturbance (0.25m s\(^{-1}\)). This node coincides with the Red Jet turning area, providing further indication that this shipping activity plays an important role in the present day fine sediment regime of the harbour. Similarly the maintenance of an erosion-dominated fairway to the Red Funnel Car Ferry terminal, and a scour pit at the terminal, both within the ‘deposition dominated zone’ identified by the monitoring, suggests that the car ferry too is playing a key role in the fine sediment transport patterns.

- The role of the gyre in enhancing sedimentation in the harbour (flow #4 in Figure 6) is clearly seen in these charts. Analysis undertaken for this report (Figure 7) suggests that the presence of the gyre increases the volume of water moving through the central harbour (and hence suspended sediment source) by up to a factor of three over the normal tidal prism change volumes, thus significantly enhancing the potential for higher sedimentation within the bounds of the gyre. Ebb flows modify this accretion focussing principal deposition into the small boat channel and the western margin of the Inner Shrape mudflat (polygons 9 & 10, Figure 23).
Figure 53. Hourly (from LW) charts showing, for neap and spring tides, the zones of potential erosion and deposition based on an analysis of changing suspended sediment concentrations along water flowlines. See key notes on the third page of this diagram.
Figure 53 cont. Hourly (from LW) charts showing, for neap and spring tides, the zones of potential erosion and deposition based on an analysis of changing suspended sediment concentrations along water flowlines. See key notes on the third page of this diagram.
Figure 53 cont. Hourly (from LW) charts showing, for neap and spring tides, the zones of potential erosion and deposition based on an analysis of changing suspended sediment concentrations along water flowlines. See key notes on the third page of this diagram.
Figure 53 cont. Hourly (from LW) charts showing, for neap and spring tides, the zones of potential erosion and deposition based on an analysis of changing suspended sediment concentrations along water flowlines. See key notes on the third page of this diagram.
Figure 53 continued. Hourly (from LW) charts showing, for neap and spring tides, the zones of potential erosion and deposition based on an analysis of changing suspended sediment concentrations along water flowlines.

**KEY.**  
Flow-lines (from ABPmer model) as shown as black arrows. 
Suspended sediment concentration at each site is shown, one figure for each half-hour (a single figure indicates values the same for each half hour). 
The red circle symbol indicates that flow at that time at that location was >0.25m s\(^{-1}\).  
Blue zones = erosion, brown zones = deposition.

### 5.2.6 Sediment flux

At the most simplistic level, an idea of the total fine sediment load moving into the estuary annually can be gained by taking a typical neap and spring tide, looking at the volume of water (tidal prism) that moves in and out of the estuary on each tide, applying typical spring and neap suspended sediment concentrations (Table 6, Figure 52) and assuming that a set fraction of the load so calculated will be trapped in the estuary. As the difference between flood and ebb suspended sediment levels is only just noticeable (Figure 51) a trapping efficiency of just 10% has been applied. The other figures used are shown in Table 7, and the calculation shows an annual influx of ~9500t of mud to the estuary. This equates to the average maintenance dredging rate since 2005, but is about half the maintenance dredging rate through the previous 20 years. As it is likely that non-tidal influences on Solent suspended sediment levels (probably the main source of mud moving into the Medina) will sporadically increase the flux of sediment into the estuary, as will wave effects on the Shrape intertidal at the estuary entrance, the 9500t annual figure should be seen as a minimum figure, consistent with the long-term dredging history, and the influx figure from bathymetry analysis (~16,000t yr\(^{-1}\), Table 3).

In reality the complexities of estuarine flow conditions can significantly modify flux rates, although an envelope condition of no more than about 20,000t per year influx might be difficult to explain. With the existence of long-term monitoring sites in the estuary, and a detailed and accurate model of water volume exchange available (from ABPmer) there is scope for developing a useful tool for measuring flux per tide based on actual TSS measurements. The assumption has to be made that the
Table 6. Simple calculation of potential total mud flux into the estuary per year.

Turbidity values measured at each of the four sites are representative of conditions across an estuary section. Given the modest differences seen between the site turbidity regimes (Figure 51) this is not an unreasonable assumption, if care is used in defining the estuary sections. This tool has not been developed at this time due to the need for modelling data input from ABPmer, but can be economically and effectively introduced in the future. This tool will enable the flux per tide to be measured, allowing the effects of spring-neap changes on flux to be quantified, as well as non-tidal effects (principally storms).

The need for ABPmer model input, predicting the water exchange in the lower Medina estuary, in order to measure fine sediment flux, relates to the complication of the throughflow and the tidal gyres, as described in Section 2.1.2. A much simpler situation exists for the estuary above the Chain Ferry Narrows. Here the volume of water passing into and out of the upper estuary can be determined by applying (monitored) water level to the GIS model of the bathymetry of the estuary. This record of volume change can be put together with the TSS record at the MM Divers monitoring site to give a measure of suspended sediment flux. This has been done for this report for the February and March 2016 data and results are shown in Figure 54.

These flux data show a steady entrapment of mud by the upper estuary, negative flux values are rare. Storms strongly perturb the regular tidal flux, causing both increases and decreases in the flux rate that appear to persist for a while after the storm event. The effects of storms may be both the delivery of increased suspension levels to the flood tide feed, or the generation of turbidity in the upper estuary (wind/wave and rain effects) that enhance sediment loss on the ebb. The flux rate varies, the monthly values being 200t for February and 570t for March. Projected to annual rates these figures suggest that 2500-7000t may be passing into the upper estuary, or one eighth to one third of the expected total entrapment of mud in the whole estuary annually (~20,000t). The harbour reaches of the Medina estuary are therefore more important mud sink areas than the upper estuary. More detailed analysis of the flux data will be undertaken once the whole-estuary flux can be determined, and once more TSS data have been accumulated.

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Table 6: Potential Total Mud Flux into the Estuary per Year

<table>
<thead>
<tr>
<th>Volume of tidal prism</th>
<th>Average TSS</th>
<th>Suspended sediment load</th>
<th>% trapped</th>
<th>Tonnes trapped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring tide (3.5m)</td>
<td>5,260,000</td>
<td>40</td>
<td>210.4</td>
<td>7271</td>
</tr>
<tr>
<td>Neap tide (2m)</td>
<td>3,300,000</td>
<td>20</td>
<td>66.0</td>
<td>2281</td>
</tr>
</tbody>
</table>

Total Tonnes Accumulated per year 9552
6 Conclusions

A thorough review of readily available data on sedimentary conditions in the Medina estuary has been completed and has enabled a good understanding of the key processes that define the system. Recommendations made are summarised in Table 7.

Seven important themes emerge that need to be recognised in future sediment management plans.

1) Because of the close juxtaposition of very strong west-east oriented Solent flows close inshore along this coast and the north-south oriented estuary inflow and outflow, a set of complex tidal current patterns persist in the harbour area. Above the Chain Ferry Narrows normal estuarine conditions prevail, with flows responding to changes in the tidal prism. In the harbour area these prism responses act in conjunction with throughflow and gyre formation, both driven by the Solent current. Although the works being undertaken (notably the breakwater) will only have minimal effect on the tidal prism they are potentially capable
of significantly changing the throughflow and main gyre conditions, with implications for sedimentation patterns and rates.

2) The estuary has been modified significantly from its natural condition. Changes (mapped over the period 1802 to date) fall into two categories. Firstly the tidal prism has been changed, as a result of narrowing of the mid estuary region (through reclamation) and the deepening of the fairways and berthing areas (the former as a result of estuary narrowing, shipping activity and dredging, the latter as a result of capital dredging projects). The effects of deepening have been greater than the narrowing, and the volume of the water held in the estuary at very high water is about one and a half times its 1802 volume. This means that the sedimentary system is unlikely to be in an equilibrium state, the enhanced water exchange increasing the potential for sedimentation. Over the last ~25 years maintenance dredging rates of about 20,000 wet tonnes per year have been necessary to maintain a status quo (this figure excludes capital dredge tonnages). The second change relates to the 19th century building of sea walls and groynes along the coast, and the 1937 construction of the Shrape breakwater. These changes will have both cut the supply of littoral sand and gravel, travelling under wave action westwards towards the estuary, and reduced the supply of (primarily fine) sediment from cliff erosion and landslip dispersion. The change to the supply of coarse littoral sediment (probably compounded by the extraction of shingle for aggregate/ballast) has resulted in the complete disappearance of the (sand-gravel dominated) Shrape Spit which originally lay immediately east of the fairway (Figure 18), allowing the inshore tidal currents to penetrate much more into the outermost harbour areas. As a result, the bed of the outer harbour (inshore of the new breakwater to just south of the end of the Shrape breakwater) has been and remains an area of persistent bed erosion, with Holocene estuary deposits exposed at bed level in some areas.

3) Fine sediment (fine and very fine sand, silt and clay) dominates the sediment flooring the harbour, mud (silt and clay) forming 40-90% of the bed sediment in most of the area (Figure 31), and fine sand about 10-20%. This means that most bed sediments are cohesive, and will have a quite high and time-varying resistance to erosive flows. Two distinct mud populations have been identified, one with a clay:silt ratio of about 10:90, the other around 80:20. The low silt material is typical of estuarine conditions, and is associated with the present upper estuary deposits and eroding Holocene estuary sediment. It is likely that there is a local exchange between in-estuary sink and source sites. This movement may largely be driven by infrequent storm events. The high clay material is interpreted as deriving from erosion of the Oligocene deposits that form the north shore of Wight, which are principally clay-rich sediments. An offshore Solent-wide source for this material is proposed.

4) Bedload transport only plays a minor role within the estuary, away from the shallow west edge of the new breakwater and the adjacent channel floor, where megarippled medium sand deposits are found. The gravel component of the estuary sediments, occurring in many areas, is principally a lag (winnowed) deposit, formed by in situ biogenic activity (slipper limpet and oyster shell) or derived from old channel-floor deposits of flint gravel (of river or littoral origin). This bed surface layer plays an erosion-protection role. Outside the estuary medium and fine sands are very mobile along the coastal slope, and across shallow Shrape Sand (between the Shrape breakwater and Old Castle point. Combined tide and wave action has in recent history formed an extensive deposit of medium sand in the eastern part of the latter zone, which gives way to fine sand on approaching the Shrape breakwater. Thus hydrodynamic conditions appear to inhibit the ingress of medium sand into the harbour, as would have occurred previous to the construction of the Shrape breakwater. Changed
patterns of (stronger close inshore flow) across the Shrape sand predicted by the model to happen post works (Figure 43) may change this situation and should be monitored.

5) There appears to be a slow rate of exchange of mud between suspended and accumulated states. At the four turbidity monitoring sites set up, tidal currents exceed the lowest threshold value at which bed erosion may occur (depth averaged velocity of 0.25m s\(^{-1}\)) for a protracted single period of uniform flow direction at Trinity Landing (TL), Cowes Yacht Haven (CY) and Shrape Breakwater End (SH) sites, and for shorter peak flood and peak ebb periods at the MMC Divers site. Even through these flows peak at ~0.8m s\(^{-1}\) on high spring tides, the turbidity change recorded is only modest, indicating no strong erosion of the bed is occurring. This phenomena is consistent with the widespread cohesive nature of the bed, and the presence of a protecting bed veneer of lag gravel at the sites of strongest flows, both factors inhibiting erosion. Similarly during periods of slack flow, turbidity levels do not markedly reduce, suggesting that the suspended load has a low settling velocity. The latter observation is consistent with the high clay content of the fine sediment most commonly in circulation. A single sample, atypical measure of settling velocity made showed a median rate of 0.03mm s\(^{-1}\) which is very low compared to UK published data. The ABPmer sedimentation model uses a value of 0.02mm s\(^{-1}\). It is recommended that field observations should be made to clarify these data.

6) The spring-neap variation in tidal energy is the principle driver of changing suspended sediment levels, with total suspended solids (TSS) levels approximately doubling (from 20-40mg l\(^{-1}\)) from average neaps to average springs in a consistent way. It is though this change is primarily a function of the changing energy of the wider Solent system rather than a Medina specific phenomenon. Within the semi-diurnal cycle there are modest fluctuations that correlate to changing local tide current energy, and much larger short-term variations relating either to random effects or local non-tidal influences (e.g. shipping, small-amplitude wave action). The Red Jet turning area is particularly notes as a zone of high bed disturbance. Storms have a major perturbation on the suspended solids regime (raising TSS values for short periods to ~200mg l\(^{-1}\)), but only occur infrequently (a few times per month, each event typically strongly affecting turbidity over one day but with flux effects that may persist for days (as a result of storms generating or removing local sediment sources). Two types of storm effect have been recognised. The first occurs with strong winds from the west (and presumably east, though not seen yet) which can generate Solent-wide high turbidity, probably with strong nearshore erosion along the north Wight coast. Large groundsea may penetrate from offshore (~20s peak periods observed) exacerbating erosion along these shores. The second type of storms is associated with northerly winds. These lower height (smaller fetch, no groundsea) waves seem to create a turbid body of water over the shallow Shrape sands area east of the Shrape breakwater, creating a plume of turbid water that enters the east entrance only\(^{27}\).

7) The strategy used in this study to use 1937-1992 bed level change zones to define polygons for investigation of present day bed level change appears to have worked well. Four groups of polygon have been identified, Groups 1 and 4 representing modern areas general tending to accretion and Groups 2 and 3 areas tending to erosion. Rates of change over the last century have typically lain within the range ±50mm per year. However comparison of bed

\(^{27}\) A plume seen at this locality much more frequently, and often under quite calm conditions, is not recognisable in the TSS data. This might be a surface water phenomenon, with discoulouration due to decomposition of the extensive deposits of brown algae that persistently accumulate along the shoreline east of Cowes.
levels between the two 2015 harbour wide surveys does not show (in some polygons) recent
continuation of established trends in terms of rates or typical erosion/deposition zones,
which may reflect a perturbation of the system. Erosion seems to have been more prevalent
during this period. These data need to be used with caution however, due to changed survey
method between surveys and the short inter-survey interval (~5 months). Continued
monitoring is recommended. The successfully-used polygons should now be modified
slightly to meet CHC monitoring requirements, i.e. subdivided to look at individual sites of
interest (e.g. marina/berth/channel/scour-pit).

8) Fine sediment flux into the estuary, estimated from dredging records, bathymetry changes
and tidal prism/average TSS level analyses all tell the same story (long term average trapping
of 10-20,000 tonnes per year) but there is clearly significant intra-annual and inter-annual
variation. Future monitoring should seek to much more accurately define this flux. The
turbidity monitoring sites that have been set up appear to effectively capture the TSS
regime, and data collection should be continued into the foreseeable future. If the ABPmer
model is used to generate a one-off data-base on flow through key cross sections for a full
range of tidal conditions, the TSS data can be used to measure fine sediment flux into and
out of the estuary at the precision of single tides. Combined with future high accuracy
multibeam bathymetric surveys, a ‘double entry bookkeeping’ system can be set up to
monitor a) the effects of works and b) the efficacy of navigation-depth-maintenance
operations that may be used in the future.

| 1. | The monitoring (water level and suspended sediment) set up at four sites in January 2016 should be continued for the foreseeable future, with the facility for flux measurement added if possible. There may be scope for individual sites (eg marina operators) to set up their own compatible monitoring and to join in the programme. |
| 2. | Some limited observations of in situ suspended sediment settling velocities should be made using an Owen tube or similar rig. |
| 3. | Intertidal sand east of the Shrape breakwater should be monitored by bathymetry and bed-sampling surveys to check the potential for changed mobility. |
| 4. | The bathymetry change-history polygons set up in this study need to be modified (subdivided) to address specific local site conditions (eg marinas, ferry operations) and should be used as a basis for all future analyses using new bathymetric data (using GIS methods). |
| 5. | Bathymetric surveys should be shared between all harbour users and conducted as frequently as is practical. A ‘standard line’ should ideally be set up (with a fixed uniform seabed feature) that can be run by all bathymetry contractors at the time of each survey. |
| 6. | The effects of shipping on harbour sedimentation are apparent, and it is recommended that thought is given to ensuring best-management of operational practices. |
| 7. | An annual review of sedimentation conditions could be issued by the Harbour Commissioners. |
| 8. | A strategy should be developed for future management of sediment/navigation depths in the Medina Estuary, based upon both modelling and field observation. |

Table 7. Recommendations made in concluding this study.

Appendices (1-3) Are in a separate report, and include UKHO map data, Medina dredging records and the field log from the November 2015 grab survey.