EQUIPMENT

IS HIGH QUALITY SEDIMENT MONITORING WORTH ITS WEIGHT IN GOLD?

Dredging activities often result in the suspension of sediment into the water column in the vicinity of the activity. Sediment release to the aquatic environment and the effects of this release are often the prime environmental concern associated with dredging. As a consequence, the accurate monitoring of suspended particulate matter (SPM) concentration is of considerable importance to the industry.

If a selected monitoring contractor has staff who are inexperienced, what might the implications of this be for a project?

The three most widely used techniques for the measurement of SPM concentration associated with dredging are:

- water sampling;
- use of optical (e.g. optical backscatter) sensors (OBSs) and
- use of Acoustic Doppler Current Profilers (ADCPs).

The commonly used approach of water sampling combined with optical sensor measurements is particularly important, as the techniques:

- are well established and widely used;
- are relatively simple and inexpensive and
- provide a means of calibration for other techniques such as ADCP measurements.

Although versatile and in widespread use, there is often little consideration of the accuracy – or potential lack of accuracy – in the application of OBS and water sampling methods. This is important information for the design and implementation of very many dredging monitoring studies, the costs of which can be very substantial.

This article describes the potential error sources and magnitudes associated with water sampling and the use of OBSs for the measurement of SPM concentration. A theoretical worked example of the errors that could be expected when undertaking SPM concentration measurements in a tropical location (based on a real world dredging project) is also presented. This highlights how these errors could easily result in projects experiencing significantly increased numbers of caution and stop events, the direct cost implications of which are likely to significantly outweigh the cost of carrying out the monitoring to a good standard and checking that this is maintained.

Consequence of dredging

Sediment release to the environment as a consequence of dredging, and the effects of this release, are typically the prime environmental concerns associated with the activity. The successful implementation of sustainable dredging operations often requires an effective monitoring programme to be established, which will include the collection of measurements of SPM concentration.

Monitoring costs can be significant for dredging projects (up to 5 per cent of the contract value). Dredging is a highly competitive business so sensibly minimising the cost of the monitoring activities is important. However if a selected monitoring contractor has staff who are a little inexperienced, or not so focused or informed with respect to achieving high accuracy, what might the implications of this be for a project?

Dredging and disposal management plans for many construction projects rely on 'trigger' levels (e.g. for SPM concentration) to protect the sensitive receivers in the vicinity of the project site. Erroneous estimates of SPM concentration may thus result in excessive downtime of the dredging works due to the 'apparent' exceedance of trigger levels or, worse still, may fail to protect a receiver from excessive sedimentation. Costs associated with dredger downtime can be large, and the failure to protect the ecosystem may result in claims made against the developer for the resulting damage. Such claims not only have a commercial impact but can damage the reputation of a development or developer, as well as the wider

Erroneous estimates of SPM concentration can result in excessive dredging downtime due to an 'apparent' exceedance of trigger levels or may fail to protect a receiver from sedimentation.

industry. As a consequence the accurate measurement and monitoring of SPM concentration is of considerable importance.

While optical sensors (see Figure 1) and water sampling methods are widely used, their accuracy – or potential lack thereof – is not often considered. This is especially true when applying these techniques to monitoring in areas of low SPM concentration. The versatility and proven value of the two techniques have meant that they have been used in relatively quiescent, deeper water, lower sediment concentration environments as part of nearshore dredging studies, despite the OBS method being developed for more dynamic, shallower, higher concentration environments (e.g. the surf zone of beaches, see Downing, 2006).

An appreciation of the limitations and accuracy of the two methods is thus key to the design and implementation of many dredging monitoring studies.

Methods for measuring SPM concentration in water

There are three main techniques for measuring SPM concentration in common use:

- water sampling;
- use of optical sensors such as OBS, or turbidity sensors and
- use of acoustic techniques (calibration of acoustic backscatter from an ADCP using Sediview (HR Wallingford, 2012) or similar).

Of these techniques water sampling and the use of optical sensors (e.g. OBSs) are particularly important, as they:

- are well established (OBSs have been in use for around 35 years and water sampling for considerably longer);
- are widely applied in coastal waters (survey contractors know and routinely use these techniques);
- are relatively simple and inexpensive and
- provide data for the calibration of acoustic techniques (ADCP backscatter).

Acoustic techniques (calibration of ADCP backscatter) are more complex to implement with relatively few organisations equipped and experienced in their use. Our focus for this assessment is therefore on water sampling and the use of OBS for measuring SPM concentration. This article highlights the principal factors that affect the accuracy of SPM concentration determination when using these very commonly applied methods and evaluates the expected order of potential errors associated with each error source.

Water sampling

The objective of water sampling (for the purposes of determining SPM concentration) is to obtain a representative sample of water and sediment at a precise point in time and space. The SPM concentration can be determined by laboratory analysis of the water sample.

Sampling devices broadly fall into two categories – trap-type samplers (see Figure 2) and pump-type samplers.

Water sampling is often assumed to give highly accurate results and to be the benchmark against which other sediment concentration measuring techniques should be compared. While it is true that if the method used is well-designed and executed it is capable of providing accurate and representative SPM concentrations, the potential for the production of highly inaccurate results does exist.

Common sources of such error are related to:

- laboratory analysis of water samples;
- sub-sampling of samples, or transport of samples to the laboratory for analysis;
- (for pump-type water sampling) sampler intake orientation and flow speed in the sample pipe;

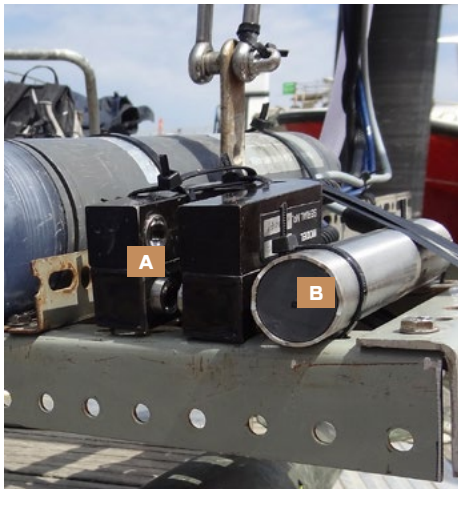


FIGURE 1

Various optical sensors mounted on a profiling rig. Transmissometers (A) and an OBS (B) .

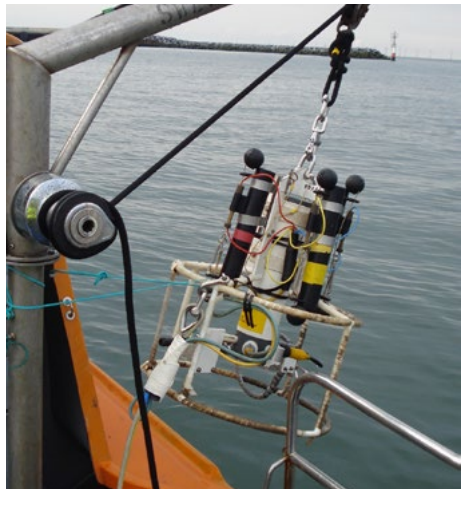


FIGURE 2

Trap-type water sampling devices mounted on a profiling rig, with electronically triggered stoppers (the black spheres which are visible).

TABLE 1

Common sources of error (and their approximate magnitudes) associated with water sampling for SPM concentration determination.

Potential Source of Error	Expected Order of Potential Error
Laboratory analysis	10% but could be higher (around 20–30% at low concentrations)
Sub-sampling or sample transfer for lab analysis	~10% but could be far higher if the field methodology is poor
Pump sampler intake orientation and flow speed in the sample pipe	~20%
'Artificial' elevation of concentration levels around the survey vessel	0 – 10s (zero to tens of) mg/l
Collision or interaction of sampling device with bed	0 – 100s (zero to hundreds of) mg/l

- 'artificial' elevation of SPM concentration levels around the survey vessel and
- collision of the sampling device with the seabed, or interaction of the sampling device with the current flows near the seabed causing the 'artificial' suspension of bed sediments.

Optical sensor measurements

Optical sensors operate by measuring the interaction of light with the suspended particles (in this case sediment) present. They are often referred to as turbidity sensors as they can be calibrated to report their data in turbidity units and, if suitable calibrations can be derived, SPM concentration.

Although still point measurement systems, optical instruments have the advantage (when compared with water sampling) that they can operate unattended and can collect data at faster sampling rates than could be achieved with water samples. They can also be lowered on a cable to acquire profiles of measurements with the data displayed in real time aboard the survey vessel. However, more data does not necessarily mean better data and, like water samples, optical sensors are subject to potential inaccuracy.

Key sources of such potential inaccuracy are:

- reporting data in turbidity units without calibration to SPM concentration;
- the calibration methodology used;
- insufficient sensor range;
- instrument bio-fouling and
- interference from bubbles.

A note on terminology

The terms turbidity, SPM concentration, total suspended solids (TSS) and suspended sediment concentration (SSC) are all used interchangeably by some parties. These terms do not all have the same meaning and therefore they should not be used interchangeably.

Measurements of turbidity are typically referenced to a standard material known as Formazin. This is an artificial suspension of milky white particles of a reproducible size, shape and reflectivity. Turbidity units are generally quoted in Formazin Turbidity Units (FTU) although Formazin Nephelometric Units (FNU) or Nephelometric Turbidity Units (NTUs) are also used. A useful summary of the differences between these units is given in USGS (2015).

The TSS content is defined as the (dry) mass of non-dissolved solids suspended in the water, and it is typically expressed in units of milligrams per litre (mg/l).The terms TSS (or SPM) and SSC are strictly speaking not the same as not all suspended solids are sediment. This can be particularly important where there is a lot of organic matter present in the water.

Sources and magnitudes of error in measurements

Estimates of the magnitudes of the errors which might occur and that are associated with each of the sources mentioned previously are discussed in this section. Where the error estimates have been based on available literature, references have been included for these sources. Where no reference is given the error estimates are based on the collective experience of the authors in the measurement of SPM concentration (>50 years).

Water sampling

Estimates of the approximate magnitudes of the errors which might occur during the collection and analysis of water samples (associated with the common error sources identified previously) are provided in Table 1.

Laboratory analysis

An understanding of the limitations in the laboratory methods used and their associated accuracies and limits of detection (LOD) is required. In this section an evaluation of the accuracies for the gravimetric method commonly used is provided.

What is meant by the 'actual' concentration of SPM in a water sample is the mass of material per unit volume, determined by filtering of the water sample to capture the particulate matter, with the mass of material captured calculated from the weight gain of the filter.

The procedures used to undertake the gravimetric analysis of water samples involve the filtration of acquired samples through glass fibre filter papers with a particular pore size. The International Organisation for Standardisation (ISO) standard ISO11923:1997 (2008) document covers such methods however there are a number of variants which are often quoted. Of these the most commonly used methods include:

- American Public Health Association (APHA) methods (APHA2540D and E), which concern the determination of TSS at 103-105 °C (APHA, 1997) and

TABLE 2

Precision and bias for ASTM Method D3977-97 B (ASTM, 2013).

Concentration added, mg/l	Concentration recovered, mg/l	Standard deviation of test method	Standard deviation of single operator	Bias, %
10	8	2.6	2.0	-20.0
100	91	5.3	5.1	-9.0
1000	961	20.4	14.1	-3.9

- American Society for Testing and Materials Standard Method (ASTM) D3977-97 (ASTM, 2013), for the determination of sediment concentration in water samples acquired from natural waters. This is used by many agencies responsible for studying water bodies in the United States.

It is generally understood that the LOD of these standard filtration methods is of the order of several mg/l since there must be a significant weight change in the filter paper following filtration. It thus follows that the volume of sample that needs to be collected would need to increase as the concentration reduces. With standard sampling procedures where a one litre sample is typically collected for analysis a LOD of 3 mg/l is quoted by the UK National Laboratory Service.

ASTM's own analysis of three pairs of samples at three different concentrations analysed by nine laboratories, shown in Table 2, reveals that with natural sediments measurement errors (when considered as a percentage of the actual SPM concentration) increase as the concentration of the suspension filtered decreases. The bias in the analysis was thought to be influenced by a range of factors, for example failure to remove all of the sediment from the containers and errors in analytical procedures such as drying and weighing (ASTM, 2013). It should be mentioned that the analysis undertaken which produced the results in Table 2 was undertaken using samples with a volume of 350 ml, and that the resultant deviations from the actual SPM concentration and standard deviations in the results could perhaps be reduced by analysing a larger sample volume.

Temperature effects

One of the key sources of variation in methodologies used to gravimetrically analyse water samples is the temperature at which drying takes place. Both the ASTM and APHA methods use drying of the filtered material in a very tightly controlled temperature range (103-105°C) to control the evaporation of water from the sample, however there are several methodologies which advocate drying papers at temperatures below 100°C, for example Van Der Linde (1998).

Salinity effects

Stavn et al. (2009) investigated the potential errors introduced by salt retention and the water of hydration in filter papers and their relevance to measurements of TSS. Perhaps unsurprisingly they found that the error in mass due to retention of salt and water by the filter was a function of the salinity of the water filtered, and that washing with volumes of distilled water failed to remove all this excess material from the filter paper.

Filter overloading

Glass fibre papers capture the particles within the fibre networks making up the full depth of the paper and manufacturers indicate a 98 per cent retention efficiency for particles larger than the nominal pore size quoted.

However it has been noted in both experimental studies and theoretical considerations that once a filter mesh becomes blocked by trapped particles the efficiency of the paper reduces. Neukermans et al. (2012) attempted to account for this by precisely controlling the loadings placed on the filter paper and by considering the procedural uncertainties in the filtration method, including the salt retention as well as filter preparation, weighing and handling. The method proposed utilises a measurement of the turbidity of the sample to control the volume of sub-sample requiring filtration and thereby the accuracy of the results obtained.

Their work suggests that in order to achieve a deviation of better than 15 per cent of the concentration of SPM between replicates in 90 per cent of cases 1250 ml of sample would need filtration at a concentration of 5 mg/l, but only 290 ml of sample at a concentration of 20 mg/l. This is clearly an important finding and in the authors' experience it is often the case that survey contractors aren't aware of the implications of the volume of sample analysed on the accuracy of the resultant SPM concentration. It is common for a 'standard' volume of 1 litre to be adopted by those designing / undertaking surveys.

Sample transfer and sub-sampling for laboratory analysis

Some laboratory methods may only require a proportion of the sample collected in the field sampler for analysis purposes and samples must invariably be removed from the sampler and transferred into other vessels for storage and transport. Sub-sampling and sample transfer both have the potential to result in concentration errors being introduced.

For example, Glysson et al. (2000) showed from an analysis of paired TSS samples that the loss of sand grains during sub-sampling by pipette or by pouring from an open container introduced a bias into a dataset.

Pump sampler intake orientation and flow speed

In the case of pumped samples, the orientation of the intake and the flow speed in the sampling hose can affect how representative the sample is, particularly when coarser sediments such as sands are in suspension. In cases where the intake nozzle is aligned with the ambient flow direction (with the opening pointing into the flow), differences between the intake velocity and local flow velocity will result in sampling errors (Rijn and Roberti, 2011). Samples with higher than ambient sediment concentration result if the velocity in the pipe is lower than that of the ambient flow speed whilst, lower-than-actual sediment concentrations are achieved if sampling at a higher velocity than that of the ambient flow.

Bosman et al. (1987) further showed that sampled SSC most closely matched the ambient SSC when the orientation of the hose inlet matched the ambient current direction (with the opening pointing into the flow) and the ratio of the velocity in the hose to the local flow velocity is 1 (see Figure 3). Errors of around 20 per cent could be expected when using an intake orientation that is normal to the current direction and an in line velocity twice the natural current speed at the site (for fine-medium sand using a 3 mm diameter hose and in local flow velocities of 1-2.5 m/s). It is appreciated that suspended sediment detected in plumes arising from dredging generally consists of silt and clay size particles, however in some environments it is possible for fine-sand sized particles to be consistently present in suspension (e.g. estuarine environments such as the river Thames).

'Artificial' elevation of concentration levels around the survey vessel

Flows resulting from vessel propulsion can and do interact with the bed in shallow water resulting in the suspension of bed sediments (see Figure 4). Effects of this can be avoided by good field practice with respect to:

- the orientation of the vessel relative to the prevailing currents and wind;
- the choice of position on the vessel from which sampling is undertaken;
- the way in which the vessel's propulsion system is used and
- good communication between the survey team and the helmsman.

It is often the case that survey contractors aren't aware of the implications of the volume of sample analysed on the accuracy of SPM concentration results.

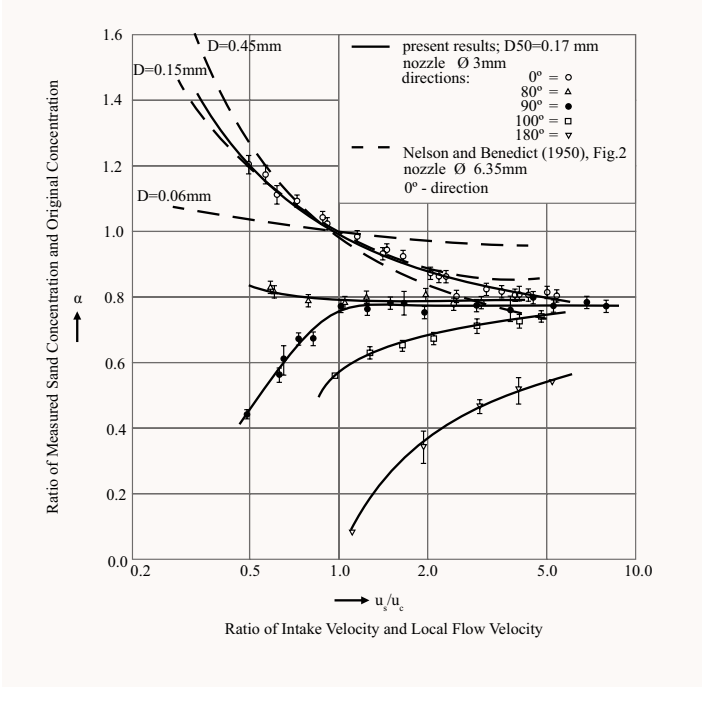


FIGURE 3

Effect of flow rate and intake orientation on sampling accuracy (Bosman et al., 1987).

FIGURE 4

Elevated SSC as a result of sediments being mobilised by a vessel's propulsion system.

TABLE 3

Common sources of error – and their approximate magnitudes – associated with the use of optical sensors such as OBSs for SPM concentration determination.

Potential Source of Error	Expected Order of Potential Error
Reporting data in turbidity units without calibration to mg/l	100% (although could be more, or less)
Calibration methodology	0 - 100%, although examples of errors of around 1000% do exist
Sensor range and resolution	100s – 1000s (hundreds to thousands of) mg/l
Bio-fouling of instrument	0 to ultimately the full scale range of the instrument e.g. 1000 mg/l.
Interference from bubbles	0 – 100s (zero to hundreds of) mg/l

Collision or interaction of sampling device with the bed

Often there is a requirement to measure near-bed sediment concentrations and under such conditions the sampler or other part of the sampling equipment (e.g. bomb weight shown in Figure 1) can either collide with the bed or disturb current flows near the bed, generating an 'artificial' sediment plume which changes SPM concentration in the vicinity of the sampler and potentially in the sample retrieved.

The potential for such occurrences can be minimised by careful positioning of the sampler using the survey vessel's echo-sounder and placing a depth sensor or an altimeter on the sampling equipment with a real-time data display. Mounting an OBS with a real-time display on the sampling equipment can also help to decide when a sampler should be activated.

Optical sensor measurements

Estimates of the magnitudes of the errors which might occur during the collection of optical sensor data (associated with the common sources identified previously) are provided in Table 3.

Reporting results in turbidity units without calibration to mg/l

On occasion workers have reported readings that are directly output by turbidity sensors (typically in units of NTU or FTU). For the reasons discussed previously, such units should not be accepted as a valid quantification of SPM concentration. The concept is well explained by Downing (2006).

During a recent study undertaken by HR Wallingford, calibrations to convert from turbidity readings in FTU to concentrations in mg/l were established through a series of laboratory experiments. A subset of the results of the experiments is shown in Table 4. The results highlight the range in calibration coefficients that can be obtained when using the same sensor in a variety of material types. A much larger multiplier value (slope) was derived for material with a lower content of fines (material c) – the response of the sensor being lower when recording data in a suspension of generally coarser particles relative to a suspension of finer material with the same SSC. The applied calibrations are shown graphically in Figure 5.

Calibration Methodology

Two possible choices are available by which a calibration can be undertaken. The first is field-based, whereby an attempt is made to perform an in-situ calibration of a sensor, through the collection of water samples which are coincident in both space and time with the optical data. The second takes place under laboratory conditions by preparing a suspension of particles which are representative of what the sensor may be experiencing in the field and recording the sensor response as the concentration is varied.

The main problems are associated with deficiencies in the execution of either approach, such as unrepresentative sampling in time and space. Space in this context includes the use of the bed sediment laboratory dilution approach when not appropriate.

A comparison of the different calibration methods used during a dredging study in a temperate estuary in the UK was recently undertaken by HR Wallingford. OBS data, water, and grab samples were collected at 11 different sites spanning 20 kilometres of the estuary. Each site was occupied for a period of 13 hours with OBS data collection and water sampling carried out throughout each occupation. For the OBS data collected at each site, two

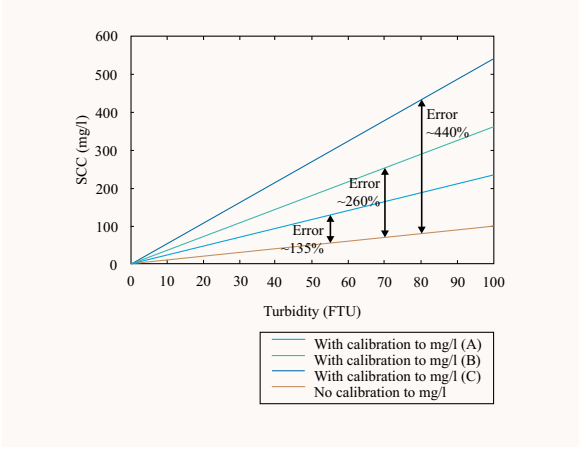


FIGURE 5

A graphic illustration of the magnitude of errors quoted in Table 4.

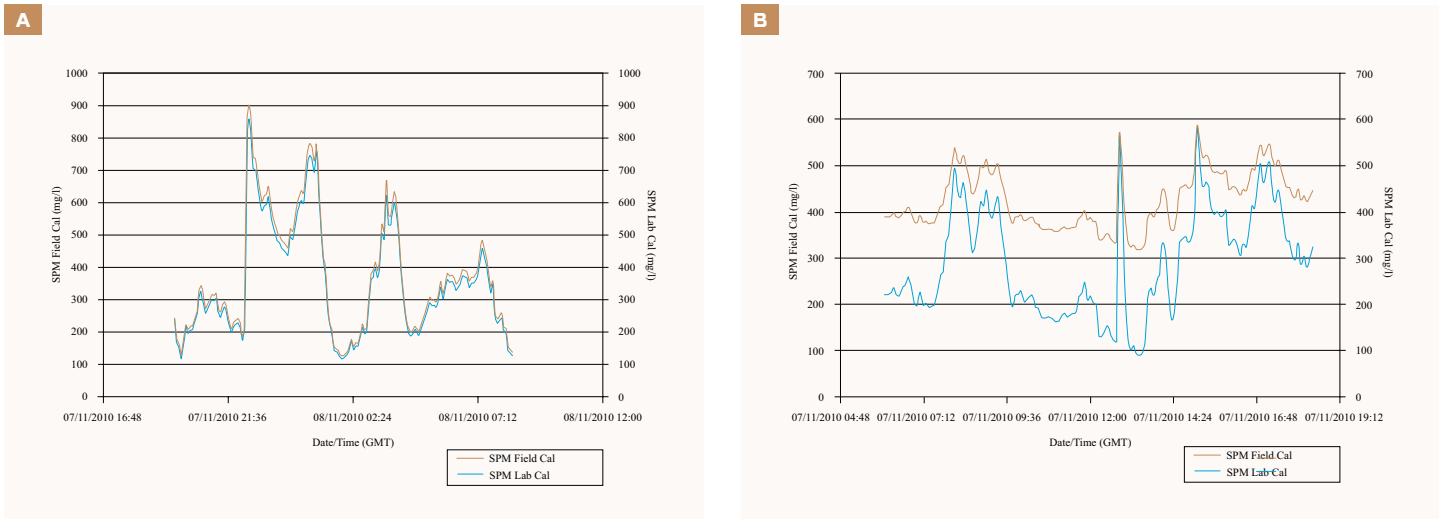


FIGURE 6

In-situ (or field) and lab-based calibrations applied to OBS data collected at two sites within a temperate estuary. Graph (A) represents Site 6 and graph (B) represents Site 8.

calibrations were derived, one using the in-situ water sample method, and the other using the sediment dilution laboratory approach. Results from two of the sites are presented in Figure 6, highlighting that sometimes a calibration based on local sediment deposits may agree well with field-based techniques, however at other points in time or space the disagreement can be considerable. A difference between the resultant values of SPM concentration of up to around 200 mg/l is seen during periods of lower concentrations at Site 8.

It must be stressed that the laboratory calibration approach can never easily or fully represent processes in the field, such as environmental factors (e.g. ambient light, temperature, etc.) and a population of particles in suspension that will vary in time due to flocculation or resuspension processes.

Sensor range and resolution

In order to measure the full range of sediment concentrations encountered an optical sensor must be capable of measuring over several orders of magnitude. In order to select the most appropriate sensor for the environment in which measurements are to be made, ideally a reliable, albeit approximate, estimate of the maximum concentration that is likely to be encountered is required. Without this information it is possible for:

a. instrument range to be exceeded during the data collection, leading to over-saturated and unrecoverable measurements (see Figure 7) or;
b. resolution of the measurements to be compromised (if the available sensor range is much greater than the maximum response obtained during the deployment).

Figure 7 shows a time series of SPM concentration derived from two co-located OBSs deployed over a 13 hour period of time with the same calibration approach used to calibrate both sensors. The measurement range of Sensor A is lower than that of Sensor B. The graph shows good correlation between the two sensor models at times when concentrations are lower than about 400 mg/l. However at other times the range of Sensor A is exceeded, leading to an underestimation of SPM concentration of 1000s of mg/l.

The picture is further complicated by the fact that some sensors will, beyond a certain limit of SSC, report decreasing readings with increasing SSC. Figure 8 shows an example OBS response for a particular model of sensor. In section A of the graph, good estimates of SSC are achieved. In section C the light scattered back to the sensor diminishes with increasing concentration as light

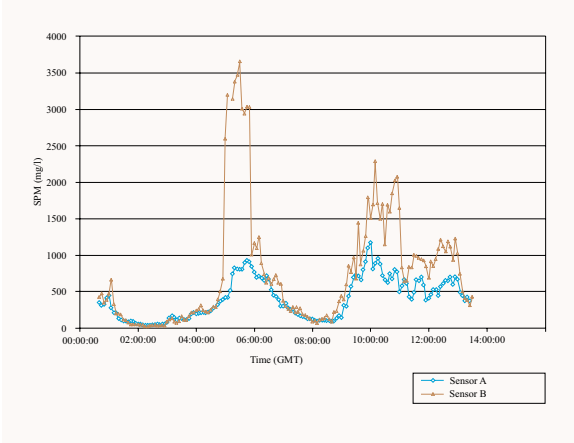


FIGURE 7

Comparison of instrument responses from two different models of OBS with different sensor ranges.

TABLE 4

Magnitudes of error associated without calibration to mg/l.

Material	**% fines**	**% gravel** (shell fragments)	**Brief material description** (based on PIANC, 2016)	**Slope** (m) **value in linear regression equation** (y = mx)	**Linear regression coefficient of determination** (R^2)	**Error with no calibration to mg/l**
a	36%	0.1%	sandy SILT	2.35	0.9947	135%
b	15%	0.1%	silty fine SAND	3.61	0.999	261%
c	5%	6.7%	slightly silty, gravelly fine SAND	5.40	0.9967	440%

TABLE 5

Estimates of errors associated to the collection of water samples as part of a theoretical project.

Error source	**Estimated minimum error** (general case, not specifically this worked example)	**Estimated maximum error** (general case, not specifically this worked example)	**Estimated error for worked example**
Laboratory analysis[1]	3 mg/l	30%	+3 mg/l
Sample transfer / sub-sampling	0	50%	0 mg/l
Pump sampling inlet orientation and flow speed	0	90%	-2 mg/l
Vessel bed disturbance	0	20 mg/l	+5 mg/l
Instrument bed disturbance	0	200 mg/l	+2 mg/l

Notes:
1 - the error magnitude associated to laboratory analysis is based on a typical minimum LOD of 2-3 mg/l.

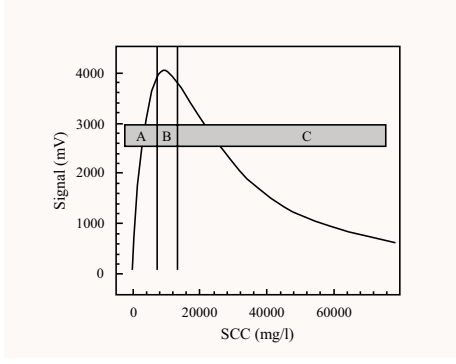
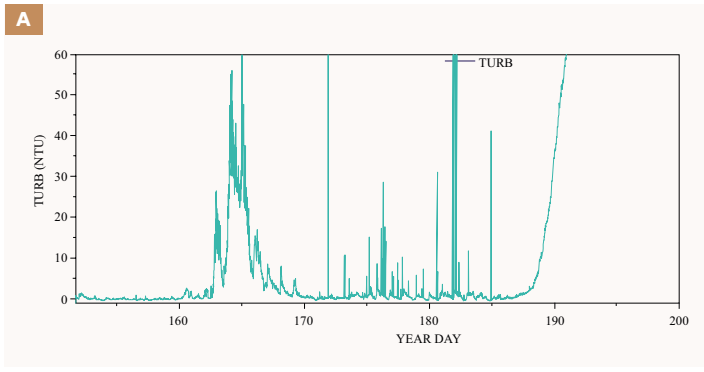


FIGURE 8

Example OBS response to a wide range of SSC (after Downing, 2006).



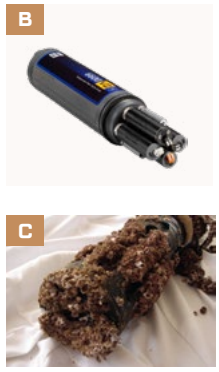


FIGURE 9

Bio-fouling observed on an OBS and corresponding turbidity readings made during the deployment (A) (ACT-US, 2006). OBS pre-deployment (B) and post-deployment (C).

TABLE 6

Estimates of errors associated to the collection of optical data shown as part of a theoretical project.

Error source	Estimated minimum error (general case, not specifically this worked example)	Estimated maximum error (general case, not specifically this worked example)	Estimated error for worked example
No calibration to mg/l	0%	500%	0 mg/l
Poor calibration methodology (lab)	0	500%	+10 mg/l
Insufficient sensor range	0	4000 mg/l	0 mg/l
Biofouling of instruments	0	4000 mg/l	+2 mg/l
Interference from bubbles	0	200 mg/l	0 mg/l

attenuation, as opposed to backscatter, becomes the dominant optical process. This transition occurs in Section B (Downing, 2006). Although this response is specific to a particular model of sensor used in a specific environment, the general behaviour is applicable to a range of OBSs.

Biofouling of instruments

Sensors not equipped with effective protection against bio-fouling (e.g. a wiper system) and not regularly serviced may have their optical face fouled with marine growth over time, resulting in inaccurate measurements being collected (see Figure 9). The time-scale over which fouling occurs is, typically, days / weeks dependant on productivity and environmental factors but the potential error ultimately covers the full range of the sensor (e.g. 1000 mg/l).

Preventative measures such as coating instruments in copper can help to limit marine growth. Pumping water to a cell or isolated chamber where the sensors are located can limit the influence that bio-fouling will have on the data readings, whilst treating the water in the cell can prevent further fouling.

Interference from bubbles

Bubbles generated by waves, motion of the survey vessel, dredger overflow, propellers, etc. have the potential to result in inaccurate optical sensor readings, to the extent that measured SPM concentrations may be twice the actual concentrations (VBKO, 2003).

Worked example using a theoretical project

Tables 5 and 6 show estimations of the errors that could arise during the measurement of SPM concentration in a typical tropical location. The theoretical example is based on a real world dredging project in the Australasia region. Baseline SPM concentrations are assumed to be 10 mg/l, with 'caution' and 'stop' (stop dredging) thresholds of 20 mg/l and 30 mg/l. The errors presented take into account the potential error sources and error magnitudes identified in the previous sections and the authors' experience of measurements of SPM concentration undertaken in these environments (and during the project this example is based upon).

It is assumed in the estimates shown in Table 6 that a calibration to convert from turbidity to SPM concentration has been applied, and therefore that the estimated error associated with this source is zero. It should be recognised however, that even if the during-dredging monitoring has been undertaken properly there remains the potential for 'apparent' exceedances to occur as a result of poorly executed baseline monitoring. The error estimate associated to the calibration methodology assumes that a laboratory-type calibration is undertaken, although it is not-well executed, resulting in an over-estimation of SPM concentration by 10 mg/l.

Discussion

Table 5 shows that the estimated errors associated with water sampling, when combined, could result in apparent values of SPM concentration that are near the 'caution' threshold of 20 mg/l when actual concentrations are in fact not much greater than baseline levels (10 mg/l).

Sensors not equipped with protection against bio-fouling and not regularly serviced may have their optical face fouled with marine growth over time, resulting in inaccurate measurements.

In the case of the errors associated with the optical measurements (Table 4), the example shows that a poorly executed calibration has the potential to result in significant numbers of 'apparent' threshold exceedances.

It should be noted that water samples are used to calibrate OBSs so there is potential for interaction between sources of error.

Summary

All data used during a dredging project must be fit for purpose with the levels of uncertainty clearly quantified and accounted for. The onus is thus on developers, contractors, regulators and the stakeholder community to ensure that all monitoring undertaken is based on sound methodologies and best possible practice, with this being particularly important for a key parameter such as the concentration of SPM.

In both temperate and tropical environments, where natural suspended sediment concentrations may either be large or small, it can be seen that high quality suspended sediment measurements really do matter. In a tropical sea, even the 3 mg/l LOD typical of standard methods of gravimetric analysis can represent 30 per cent of the sediment concentration signal which we are attempting to measure.

Thus poor measurement practice can easily result in projects experiencing very significantly increased caution and stop threshold exceedances. The direct cost implications of such are likely to significantly outweigh the cost of carrying out the monitoring to a good standard and checking that this is maintained.

It is also possible that monitoring errors may result in underestimation of concentration thereby not protecting the environment as intended.

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A worked example in a tropical location shows estimated errors, when combined, could result in 'apparent' trigger level exceedances.

Dr Jonathan Taylor
With a bachelor's degree in Geology and a PhD in coastal and estuarine sediment dynamics, Jonathan has held university research positions in coastal physical oceanography. He has broad expertise in coastal and offshore oceanographic and geophysical surveying, and has worked on many coastal management issues including the co-ordination of coastal zone engineering/management studies and marine environmental assessments with particular emphasis on the application of monitoring to dredging operations.

Neil Crossouard
Prior to joining HR Wallingford, Neil graduated with an MSc in Geophysics from the University of Southampton and was involved in vessel-based high resolution marine geophysical and hydrographic surveys. As a Scientist in the Dredging Group with 10 years' experience in marine monitoring and surveying, he is routinely involved in the analysis of environmental monitoring, oceanographic, hydrographic and geophysical datasets. On a recent Marine E-tech research expedition, he measured flows and sediment plumes in water depths over 1000 meters.

Dr Mark Lee
Currently Group Manager of HR Wallingford's Dredging Group, Mark has a background in marine monitoring and surveying with a focus on dredging-related projects. For over 20 years, he has specialised in coastal oceanographic surveys and coastal and fluvial sediment transport measurements, and worked on projects in the sectors of ports and shipping, construction, energy, oil and gas, and water. He has undertaken extensive vessel-based and shore-based marine survey work as a Surveyor and Party Chief, and as a Client Representative

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