MONITORING OF EXPERIMENT DISPOSAL MOUND AT CAPE FEAR, NC: SEDIVIEW CALIBRATION OF ADCPs AND COMPARISON WITH OTHER MEASUREMENT TECHNIQUES,

1 Introduction

The US Army Corps of Engineers (USACE) is undertaking a dredged material disposal experiment offshore Cape Fear, NC. A disposal mound has been constructed about 5 miles from the beach at Bald Head Island. The objective of the experiment is to study the manner in which the mound evolves under the influence of waves and currents. It is expected that the fines content of the dredged material will be progressively winnowed out, without giving rise to turbidity levels that could be detrimental to local marine ecology and habitat, and that the remaining material will eventually comprise beach-quality sand with less than 10% fines. If these expectations are confirmed, it is hoped that a similar mound placed closer to the shore would feed suitable beach-quality materials into the littoral system without harmful side-effects on the environment.

In order to monitor the experimental mound, the Corps have installed five Acoustic Doppler Current Profilers (ADCPs) on the bed at strategic locations on and around the mound. The ADCPs are used to measure water currents and waves. Other equipment is installed with the ADCPs to measure water quality parameters. The ADCPs are presently located:

- on the crest of the mound ('Mound Crest');
- offshore of the mound ('Outer Mound');
- between the mound and Bald Head Island ('Bald Head');
- approximately 1,500 m offshore of Oak Island ('Oak');
- in the river (River 2).

It has been suggested that the Sediview Method, developed by Dredging Research Ltd and DRL Software Ltd, could be used to obtain solids concentration data from the bed-mounted ADCPs, thus considerably enhancing the information that they provide. The Sediview Method has been widely applied to vessel-mounted ADCPs for observing natural sediment transport and the plumes generated by dredging and disposal operations. When used in this manner, calibration data can be obtained at frequent intervals during the survey and the calibration can be adjusted in response to step-changes of particle size and other environmental parameters. The main concern with the application of Sediview to bed-mounted ADCPs deployed over long periods is that step changes in the Sediview calibration may not be detected, leading to potentially significant errors. In order to investigate this application, the Corps commissioned DRL Software Ltd (through Evans Hamilton Inc) to participate in an experiment at Cape Fear in August 2001. There were two general objectives:

1) to establish the extent to which the bed-mounted ADCPs can be calibrated to provide reliable suspended solids data
2) to compare suspended solids concentration measured using water samples, an OBS turbidity meter, a LISST 25 and Sediview.

The other participants in the experiment, and their main responsibilities, were:

- Evans Hamilton Inc - deployment and operation of the bed-mounted equipment;
- Sequoia Scientific Inc - operation of a LISST 25, analysis of data;
- Virginia Institute of Marine Science (VIMS) - provision of R/V Langley, water sampling, siltmetering, water quality parameters. supply of a vessel-mounted ADCP.

The work was coordinated and supervised by Carl Miller of the Corps of Engineers.

This report presents the results of a comparison between the four main solids measurement techniques, focussing on the data obtained using the ADCPs and whether or not it is likely to be possible to develop Sediview calibrations for bed-mounted ADCPs that can be used for long-term monitoring.

VIMS also deployed a LISST 100 instrument during the experiment but the data obtained using this instrument are not included in this report. It is understood that this experiment is the first time that a LISST 25 has been used to derive particle size (Sauter Mean Diameter) and the first detailed evaluation of concentration measurements against Sediview, water samples and a turbidity meter. In addition, this is the first time that a Sediview survey has been undertaken during which (mean) particle size data have been obtained for all data used to calibrate Sediview. The experiment is thus unique.

2 Methodology

2.1 General Approach

The R/V Langley was used to deploy all of the equipment except the bed-mounted ADCPs. In addition to the water sampler, OBS turbidity meter and the LISST 25 and 100, the Langley was equipped with a 1200 kHz ADCP that was deployed from a temporary mounting near the bow of the vessel.

The general approach to measurement was to anchor near the bed-mounted ADCP and to obtain several series of water sample profiles, working from near-bed to near-surface. The samples were taken at depth intervals of approximately 1 metre, each sample taking approximately 60 seconds. As each sample was collected, simultaneous observations were made using the ADCP, OBS and the LISST 25 and 100 instruments. Water temperature and salinity data were also obtained.

Weather conditions during the experiment were poor which, in combination with a variety of problems with equipment, resulted in less work being completed than originally planned. The Oak Island ADCP shore station was struck by lightening, resulting in failure of the ADCP and therefore no work was done at this location. No work was possible at the Outer Mound location due to adverse sea conditions. A limited amount of work was possible at the Mound Crest and Bald Head locations but sea conditions were very poor and equipment failures and conflicts limited the amount and type of data that could be obtained. Conditions at the relatively sheltered River 2 site were good and a reasonable amount of data was obtained during the ebb tide. Because of the weather problems, an additional relatively sheltered location was investigated, close to the river mouth.

2.2 General Limitations of Methodology

Accurate comparison of four different measurement techniques (and calibration of bed mounted ADCPs using boat-mounted equipment) requires a high degree of spatial and temporal synchronisation. However, perfect synchronisation is clearly impossible to achieve because each method measures different volumes of water at different locations. During this deployment, the ADCP was mounted close to the bow of the R/V Langley. All other equipment was deployed in a frame over the stern, approximately 8 metres behind the shipboard ADCP.

The most that can be expected is a broad correlation in which the trends of concentration variation are reflected by all measurement techniques and each method yields broadly similar concentrations but it would be reasonable to expect a higher degree of correlation between the three types of equipment deployed over the stern than between these instruments and the ADCPs. Perfect agreement between all four methods is quite impossible to achieve in anything other than a perfectly uniform suspension and such suspensions do not normally occur in rivers and coastal areas. Problems of spatial correlation might be expected to be most severe where:

1) concentration gradients are steepest (eg. near the bed or in very high concentration suspensions); and where
2) there is a large separation between the instruments used to make the observations (eg. between the ADCP and the other equipment deployed from the Langley and between all of the Langley's equipment and the bed-mounted ADCPs).

2.3 Method-specific limitations of methodology

In addition to the limitations arising from the impossibility of achieving perfect temporal and spatial synchronisation, there are some that are specific to the method of observation. Limitations that are relevant to this experiment, and the interpretation of the results, are briefly reviewed here.

2.3.1 Water samples

Pumped water samples are prone to error unless an isokinetic sampler is used. Isokinetic sampling is difficult to achieve and the sampler used in this experiment was non-isokinetic. When working in very fine sediments, the errors induced by non-isokinetic sampling are usually small but they become increasingly significant as particle size increases. The sample may yield higher or lower concentrations than actually exist depending on the ratio between the suction inlet and water current velocities and the orientation of the inlet relative to the current direction.

Gravimetric analysis is required to determine the solids content of the water samples,. This introduces an additional potential error source. Although the method used at Cape Fear (filtration of whole samples) is generally expected to yield concentrations accurate to within about 1 mg/L, there exists the possibility of sample contamination during testing. In addition, it is worth noting that, in the context of comparative measurements undertaken here, each water sample took approximately 60 seconds to obtain. The LISST obtained data at approximately 6-second intervals as did the bed-mounted ADCPs. The ADCP on the Langley obtained measurements at 1-second intervals. The water samples thus represent average values obtained over relatively long periods during which time the LISST, OBS and ADCP data might reasonably be expected to show some scatter about the average.

2.3.2 Turbidity meters

Turbidity meters such as the OBS provide an indirect measure of solids concentration and must be calibrated using other methods such as water sampling. The main reason for this is that they are sensitive to particle size, their response diminishing rapidly as particle size increases. There is evidence that the OBS data obtained during this experiment were biased in response to particle size.

2.3.3 Sediview

The Sediview Method requires calibration using other methods such as water samples to establish the basic relationship between backscatter intensity and solids concentration. In addition, the following parameters must be established:

- the reference level and scaling factors for each of the four transducers and RSSI (Received Signal Strength Indicator) assemblies;
- the coefficient of acoustic attenuation due to the sediment in suspension,
- the profile of water absorption coefficient at the measurement location.

The transducer/RSSI response is also adjusted (on an ensemble by ensemble basis) to take into account the effects of the temperature of the electronics chassis on the response. The calibration of the instrument performance characteristics is relatively simple and reliable but there exists the potential for significant errors if the character of the sediment in suspension changes during the measurement period. In a typical Sediview deployment, where the ADCP is mounted on a boat, calibration data are normally obtained at frequent intervals in order to check on variations during the deployment and time-variable calibrations are often developed to accommodate such variations. This is especially the case when working in or close to estuaries where sediment characteristics are often observed to change during the tidal cycle.

The Sediview computation method assumes that, where particle size varies, it tends to vary approximately linearly with concentration. In most situations, there is a distinct relationship between particle size and concentration and, as concentrations increase, so too does the average particle size. The assumption of an approximately linear relationship (but with a slope that may vary significantly from one site to another) usually holds true for a limited period of time (depending on the location) and is not a problem with vessel-mounted applications where the assumption can be checked frequently. However, with bed mounted instruments deployed over long periods of time, it is possible that ‘step changes’ may occur that would not be noticed, leading to errors. An important objective of this experiment was therefore to investigate the extent to which calibrations vary and whether or not there is any indication of step changes.

A purely practical limitation of the method arises from the presence of air bubbles in the water column. During much of this experiment, sea conditions were poor. Air bubbles are entrained in the near-surface during poor sea conditions and these will inevitably corrupt data obtained by both bed-mounted and vessel-mounted ADCPs. Vessel-mounted ADCPs will be affected more than bed-mounted ADCPs because:

- the pitching and rolling of the vessel will generate even more air bubbles, and
- the data corruption occurs in the ADCP measurement bins closest to the transducers and this will induce errors that will be carried down through the water column because of the iterative, top-down computation procedure used by Sediview; the magnitude of such errors ranges from negligible to severe depending on the degree of air bubble corruption.

In the case of the bed-mounted instruments, the air bubbles only affect the bins near the surface. Below the surface zone, the data will be good.

2.3.4 LISST

The LISST apparatus is specifically designed to avoid bias of concentration estimates arising from particle size variation. However, as noted in the report on this experiment provided by Sequoia Scientific, the computation of concentration requires the use of a correlation factor that is derived by comparison with water sample data. The correlation factor includes sediment parameters such as flocculation, density variations and particle shape. In this case, a factor of 7.8 was derived by Sequoia which was noted by them to be consistent with flocculated sediment. Most of the calibration data were obtained in the river where flocculation might reasonably be expected. It is noted later in this report that there is some (very limited) evidence that the LISST slightly underestimated concentrations at the sea sites where, perhaps, flocculation was less pronounced.

Our relatively superficial knowledge of LISST systems precludes further comment on limitations and accuracy.

3 Results

3.1 River 2 site (24 August)

The results of the first visit to the River 2 site exemplify the problems arising from poor spatial synchronisation. Before reviewing the data, it is first necessary to explain how the Langley moved, relative to the bed-mounted ADCP, during data collection. Figure 3.1 shows, approximately to scale, what happened during the measurements. The water depth plot shows the depths recorded by the Langley's ADCP and the bed-mounted ADCP for each water sample in sequence. The absolute depths are not important; they simply show that the tide was falling during the measurements. The important point is that, at the start of the measurements, the Langley's ADCP was in water about 2 metres deeper than the bed-mounted ADCP. The Langley then gradually moved into water about 1 metre shallower than the bed-mounted ADCP.

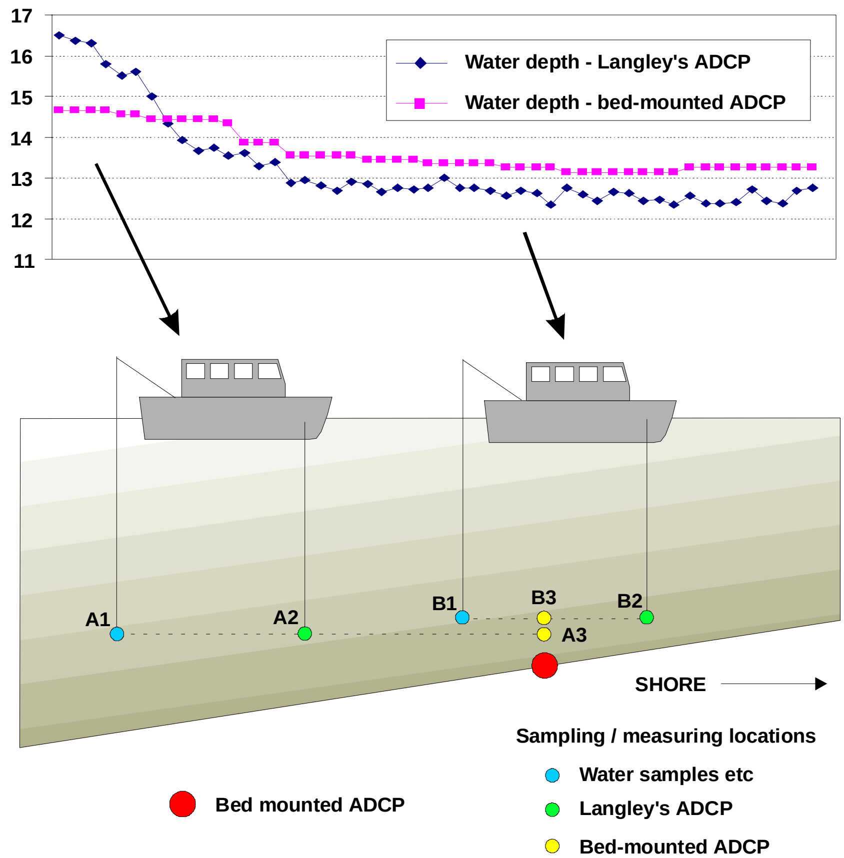

Figure 3.1. Interpreted movement of the R/V Langley - River 2 site, 24 August

The bed-mounted ADCP was located on the nearshore slope of the river bed. Due to the combination of wind and tidal current, the bow of the Langley was closer to the shore than the stern. While the water depth under the ADCP (near the bow) at the time of each sample is known, the water depth at the stern, where the sampling equipment and LISST were located, is not known but it will almost invariably have been deeper than that under the ADCP. At the start of sampling, the Langley's ADCP was located slightly offshore of the bed-mounted ADCP, profiling in water about 2 metres deeper than that at the location of the bed-mounted ADCP. The result is that, when obtaining data at given depth, the Langley's ADCP (at Position A2 in Figure 3.1) will have been sampling closer to the bed than the water sampler, OBS and LISST (at Position A1 in Figure 3.1). Because the concentration gradient is relatively steep close to the bed, the ADCP concentrations at a given depth will tend to be higher than those measured by the equipment deployed over the stern. The bed mounted ADCP (at Position A3) will, in turn, have been measuring even higher concentrations.

As the ebb tide gained speed, the Langley appears to have moved into shallower water. It passed the bed mounted ADCP during the later part of profile No S636 and continued to move into shallower water until the end of Profile S637, at which point the water depth under the Langley's ADCP was about 1 metre less than the water depth at the location of the bed mounted ADCP. At that point, the location of the Langley appears to have stabilised. The Langley's ADCP (Position B2 would have recorded higher concentrations than the bed mounted ADCP (Position B3) which, in turn, would have been higher than the concentrations recorded by the equipment deployed over the stern of the Langley.

Figure 3.2 shows the data obtained by the Langley's ADCP compared with the concentrations measured by the LISST 25, water sampler and OBS. In this (and all other similar plots in this report) the sampling/measurement intervals during each profile are indicated by the letters A-NN, A being the near-bed sample. Successive samples were taken at approximately 1 metre intervals towards the surface.

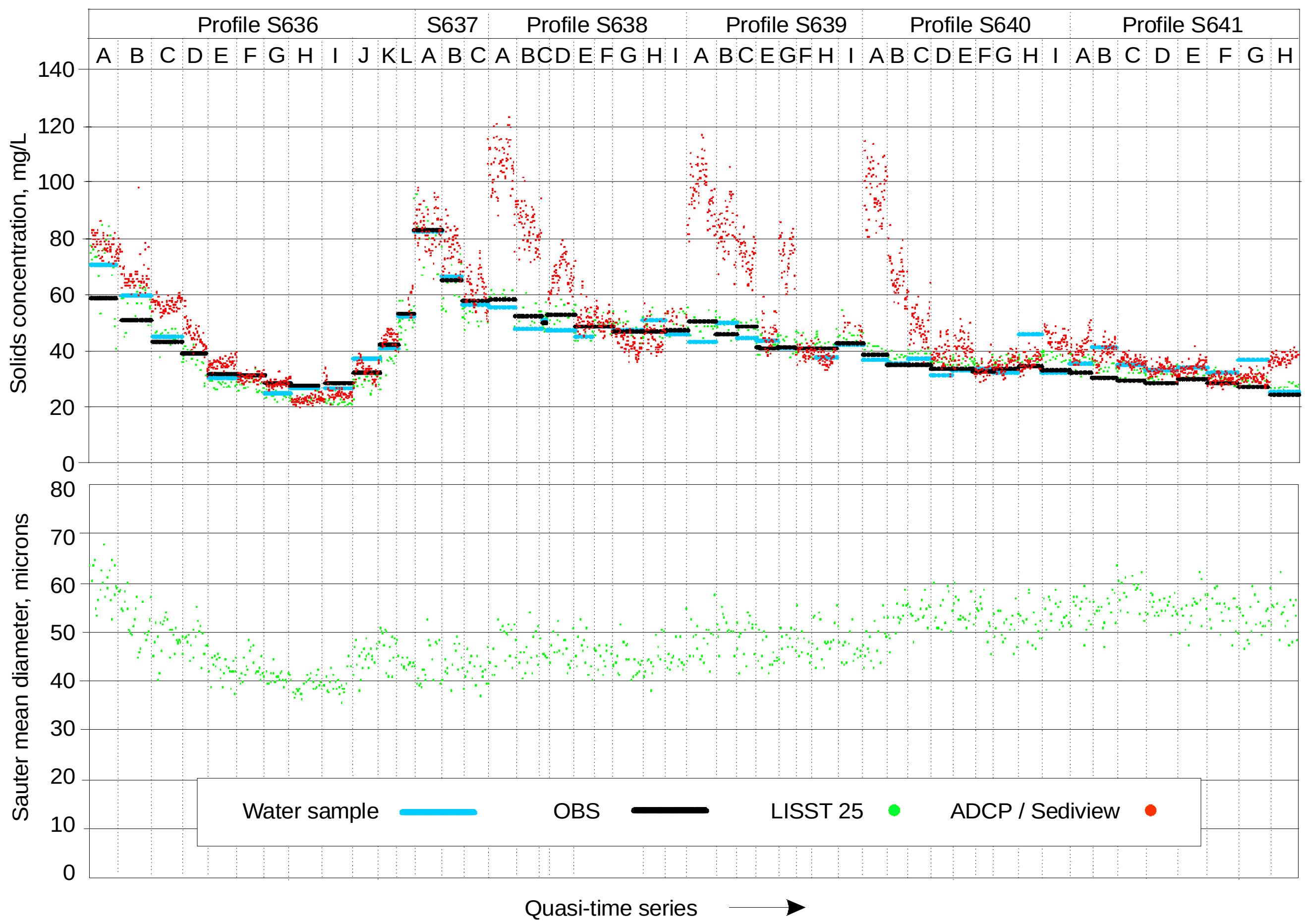

Figure 3.2 - Comparison between data from vessel-mounted equipment, River 2 site, 24 August

Initially (Profile S636), there is a reasonable match between the various data but, as expected from the manner in which the Langley is thought to have moved, the bow mounted ADCP yielded slightly higher concentrations near the bed than the other equipment (Samples S636 A-D). During the latter part of Profile S636 and during profile S637, when the water depth data suggest that the bow of the Langley was very close to the bed-mounted ADCP, Langley's ADCP and all other data are in very close agreement. Thereafter, when the bow of the Langley had moved into relatively shallow water, the ADCP gave much higher concentrations in the lower part of the water column than the other equipment. There is nothing to suggest that this is a result of variable particle size because, up to this time (and at other locations during this experiment), it is clear that the Sediview computations have adequately dealt with a significant change of particle size.

Figure 3.3 shows the data obtained by the bed-mounted ADCP compared with the concentrations measured by the LISST 25, water sampler and OBS. The effects of the moving Langley are again clear to see but, as expected from Figure 3.1, the bed-mounted ADCP yielded lower near-bed concentrations than the Langley's ADCP during the period after the Langley had drifted inshore.

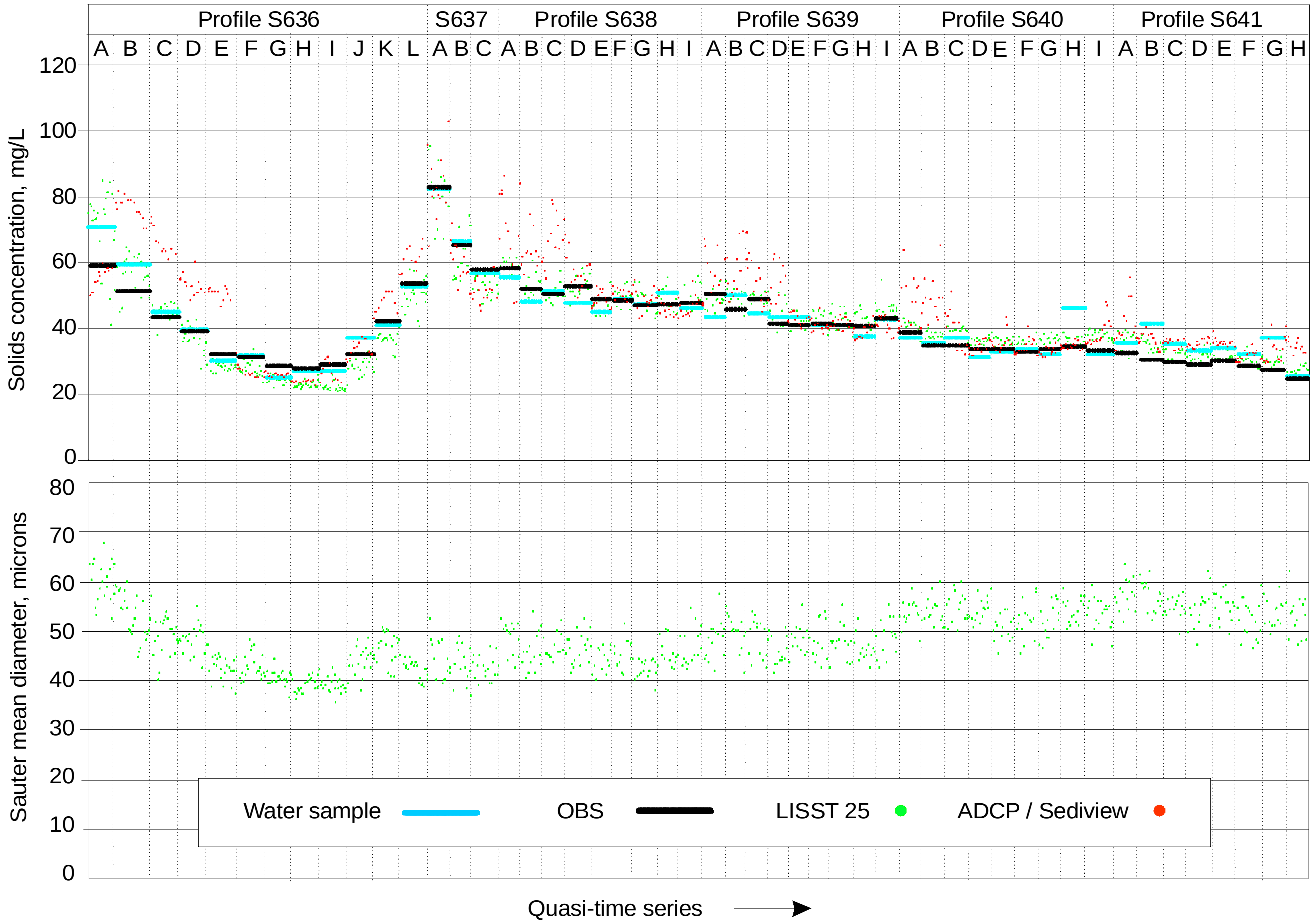

Figure 3.3 - Comparison between data from bed-mounted ADCP and vessel-mounted OBS, LISST and water samples, River 2 site, 24 August

Overall, it is concluded that the four different types of measurement yielded similar results and that the discrepancies between the ADCP data and the other types of measurement are readily attributable to the sloping seabed and the difficulties of spatial synchronisation of the measurements.

Figure 3.4 overleaf shows the full record of the bed-mounted ADCP during the sampling period. The water samples are shown on the record and the problems of spatial matching are readily apparent especially at the beginning of the record. The record is an interesting example of how single point measurements near the bed could provide a wholly misleading picture of the suspended solids regime in the water column as a whole. This is important in the context of the Corps desire to use Sediview to obtain data throughout most of the water column during long term monitoring. Instruments mounted close to the bed would have provided no indication of the high-level sediment suspension that passed through the site during Profiles 637-9.

It is apparent from this record that the concentrations in the first bin (closest to the bed) are anomalously low. It should be noted that this is not due to a near-field beam spreading computation error. Version 3 of Sediview includes a two-stage correction for beam spreading that accounts for the difference between spreading in the near and far fields. The anomalous data in the first bin are caused by a range computation error in the development version of Sediview 3 which affects only upward-looking ADCPs. This error will be rectified soon.

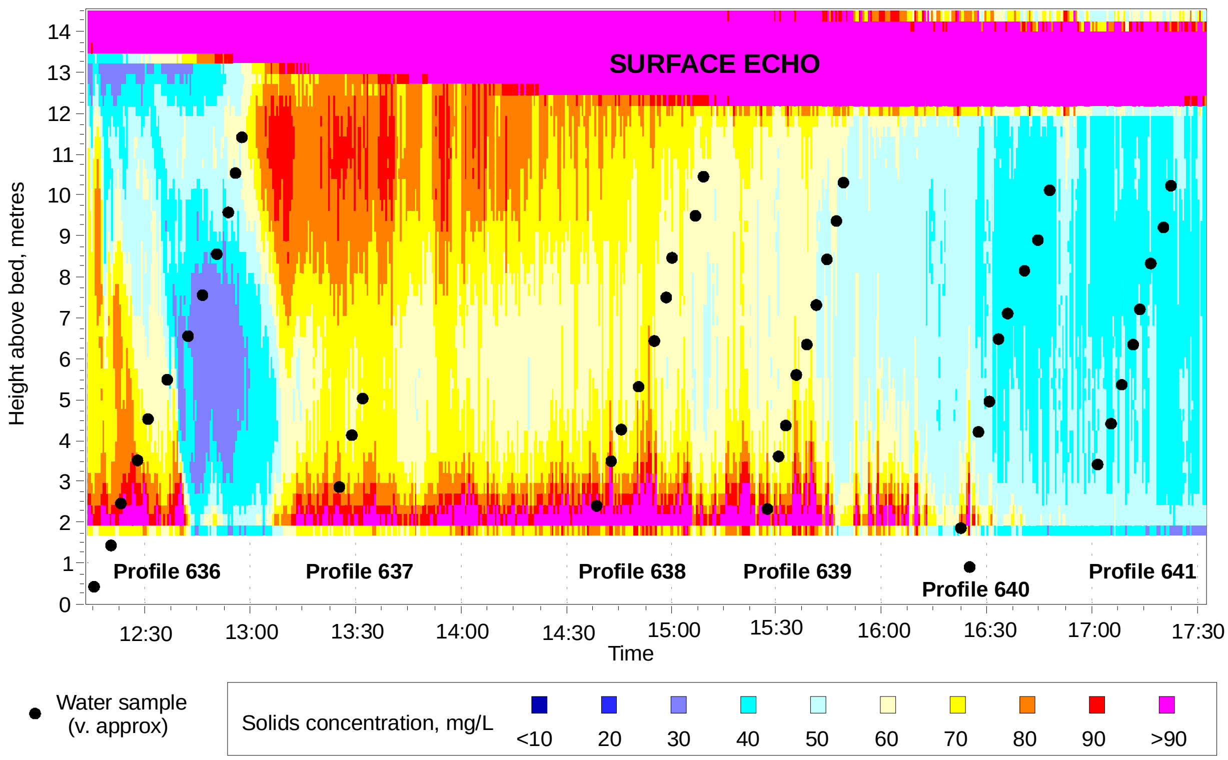

Figure 3.4 Processed record of River 2 bed-mounted ADCP during the sampling period.

3.2 Mound Crest Site

No water sample or OBS data are available for the Mound Crest site due to equipment malfunction and software conflicts. The ADCP / Sediview calibration has therefore relied entirely on the LISST data. The comparison between The Langley's ADCP and the LISST is shown in Figure 3.5. Note that the 'A' samples from each profile have been omitted from Figure 3.5 because they were all obtained well below the lowest valid ADCP measurement bin.

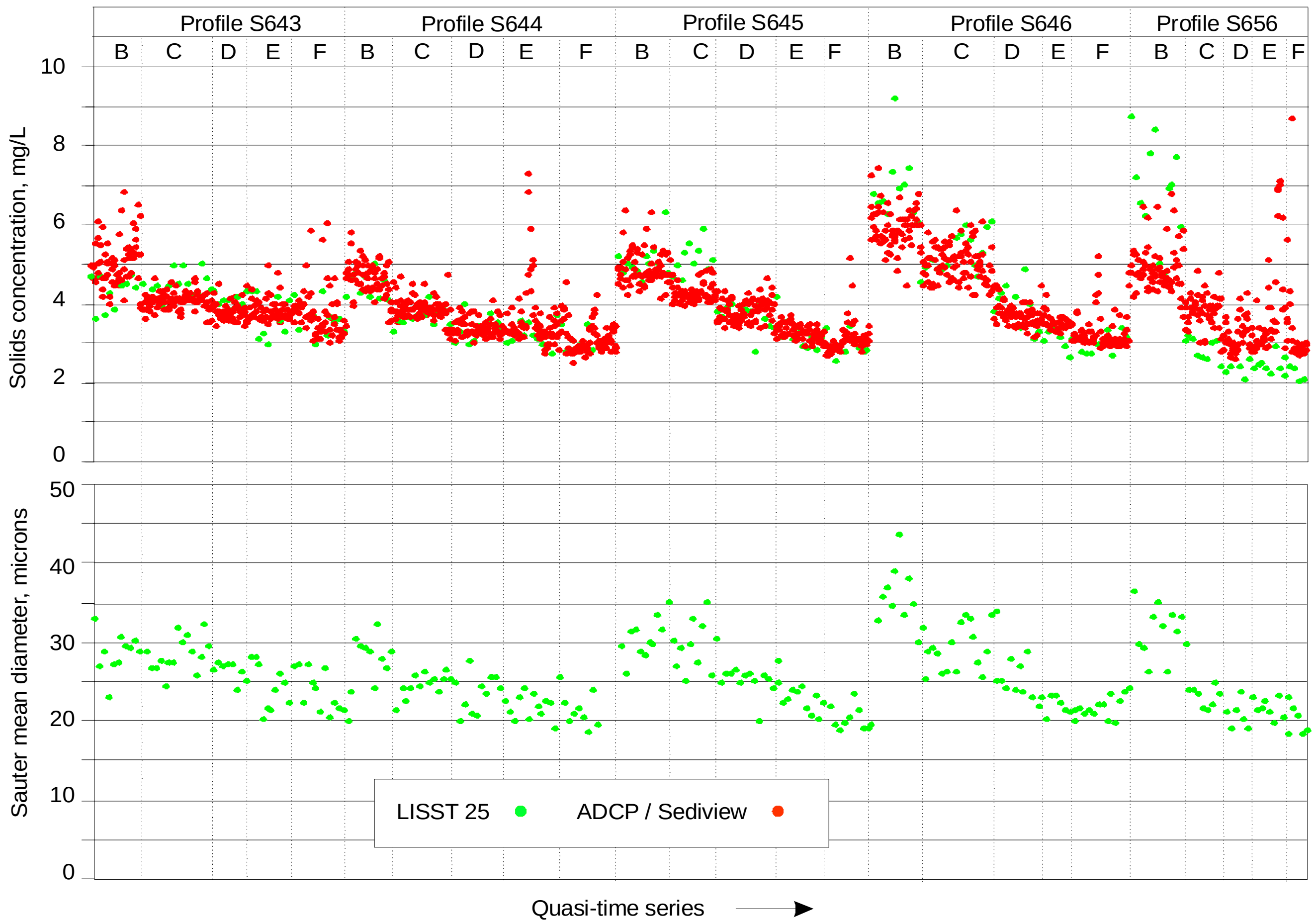

Figure 3.5 - Comparison between data from vessel-mounted ADCP and LISST, Mound Crest site, 25 August

A marked concentration and particle size gradient is apparent from these data but this has no effect on the correlation between the ADCP and LISST data which are in consistently close agreement. Some of the ADCP data in the higher bins are affected by near-surface noise from wave-generated air bubbles.

Figure 3.6 shows the comparison between the bed-mounted ADCP data and the LISST. Overall there is a close agreement between the two methods although Sediview appears to be overestimating the near bed concentrations in Profiles 643 and 644 (B-samples). However, it is clear from the later profiles that this is not a particle size problem. More likely it is due to spatial mismatching.

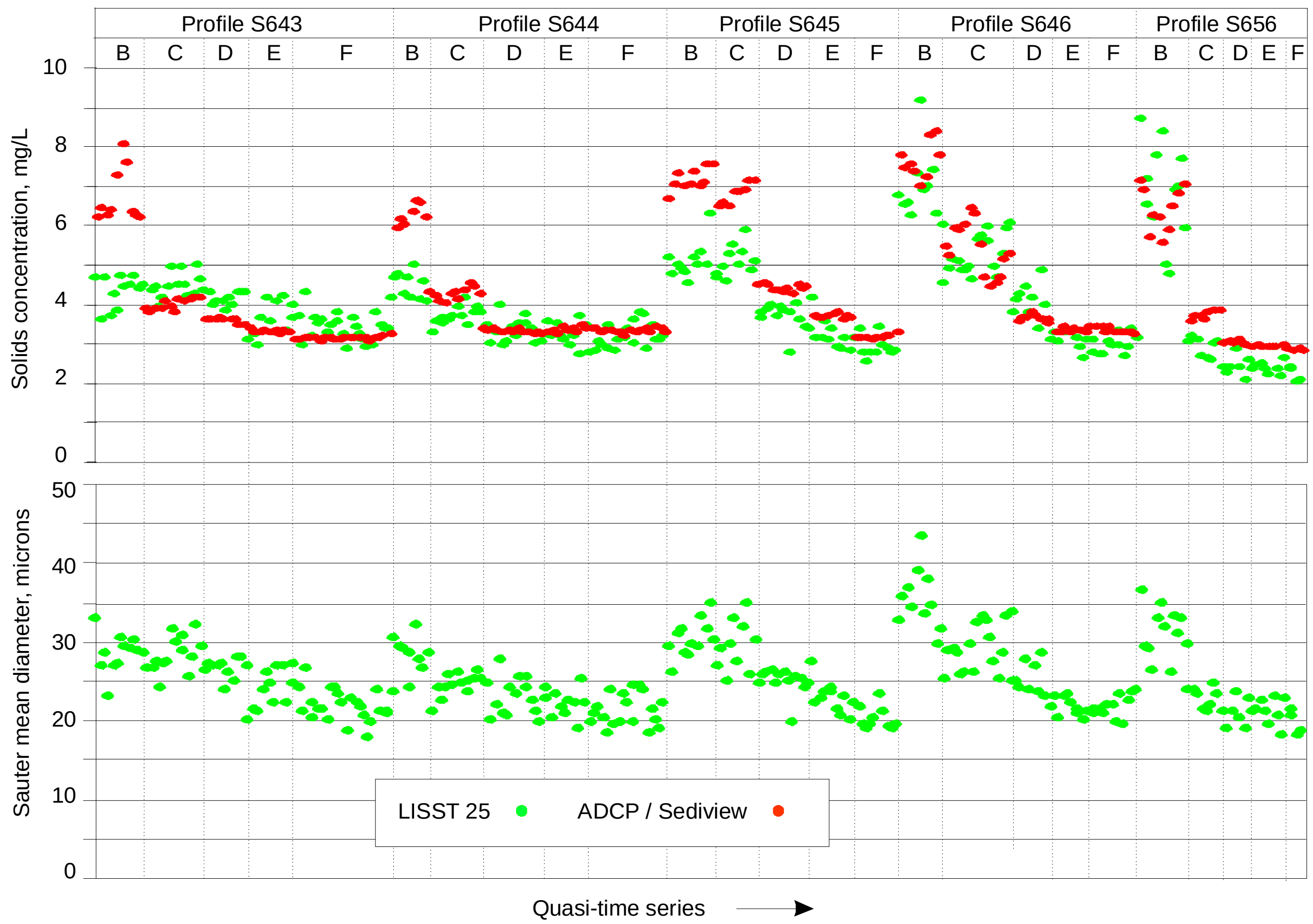

Figure 3.6 - Comparison between data from bed-mounted ADCP and LISST, Mound Crest site, 25 August

Figure 3.7 overleaf shows the processed bed-mounted ADCP data for the full duration of the measurement period. The near-surface data corruption due to entrained air bubbles is readily apparent but has not significantly affected the data at the depths at which the water samples were obtained.

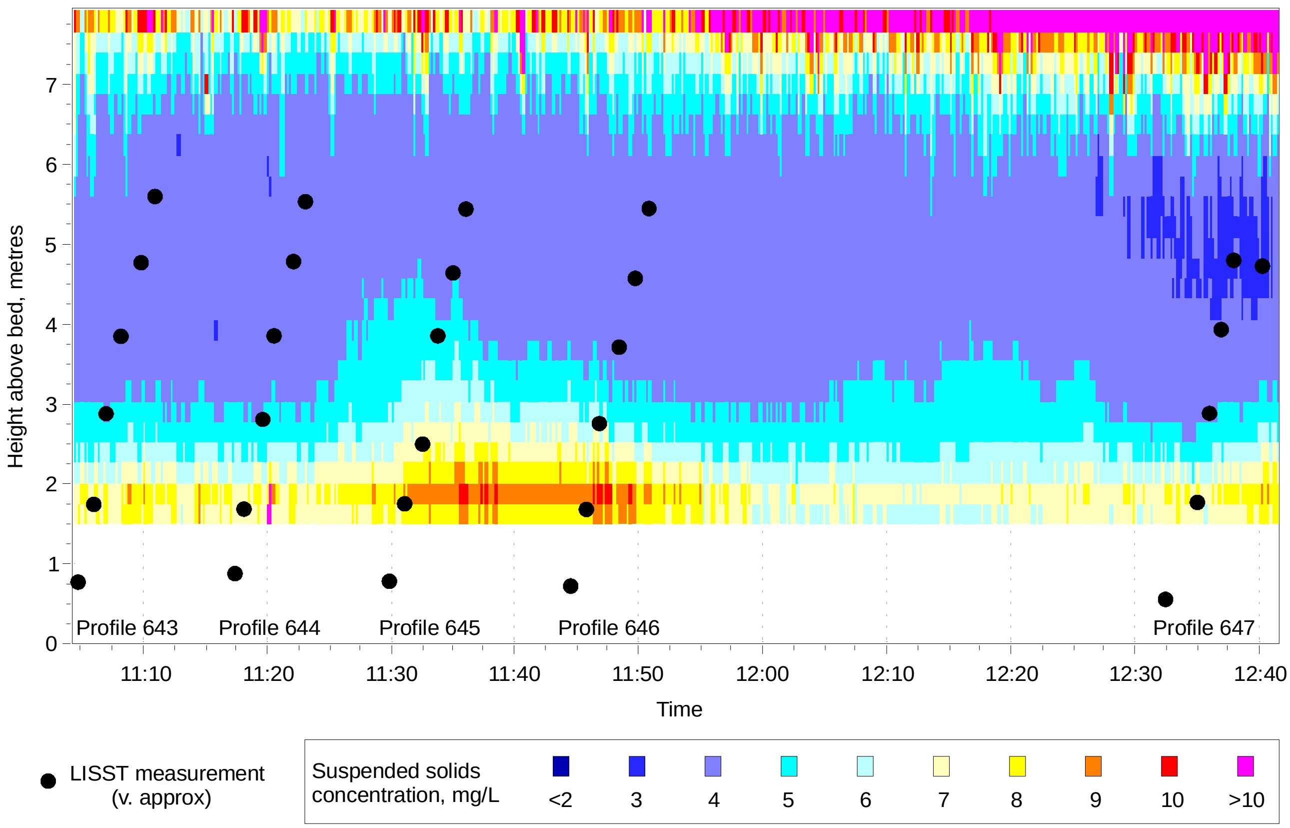

Figure 3.7 Processed record of Mound Crest bed-mounted ADCP during the sampling period.

3.3 BALD HEAD SITE

The data obtained at the Bald Head site are shown in Figure 3.8. OBS data were not obtained due to a software conflict. The sea conditions at the site were very poor and the shipboard ADCP data are corrupted by air bubbles in the near-surface bins where random anomalously high concentrations can be seen (‘C’ and ‘D’ samples). The ADCP calibration was derived using settings similar to those used elsewhere but has little merit due to the data corruption and because of the very limited range of concentration. However, it is interesting to note that the LISST tended to yield consistently slightly lower concentrations than both the ADCP and the water samples. We surmise that this may be due to the application of the correlation factor of 7.8 derived by Sequoia. This was based mainly on data obtained from the river sites where the sediment is though to have been flocculated. This is less likely to have been the case at the sea sites.

Figure 3.8 - Comparison between data from vessel-mounted equipment, Bald Head site, 26 August

The data from the bed-mounted instrument (Figure 3.9 overleaf) are less affected by noise except in the uppermost bin (the D samples) where sidelobes from the ADCP beams were interfering with wave troughs and where there was some aeration due to the waves. As was the case with the vessel-mounted ADCP, the bed-mounted instrument yielded concentrations that were generally higher than the LISST.

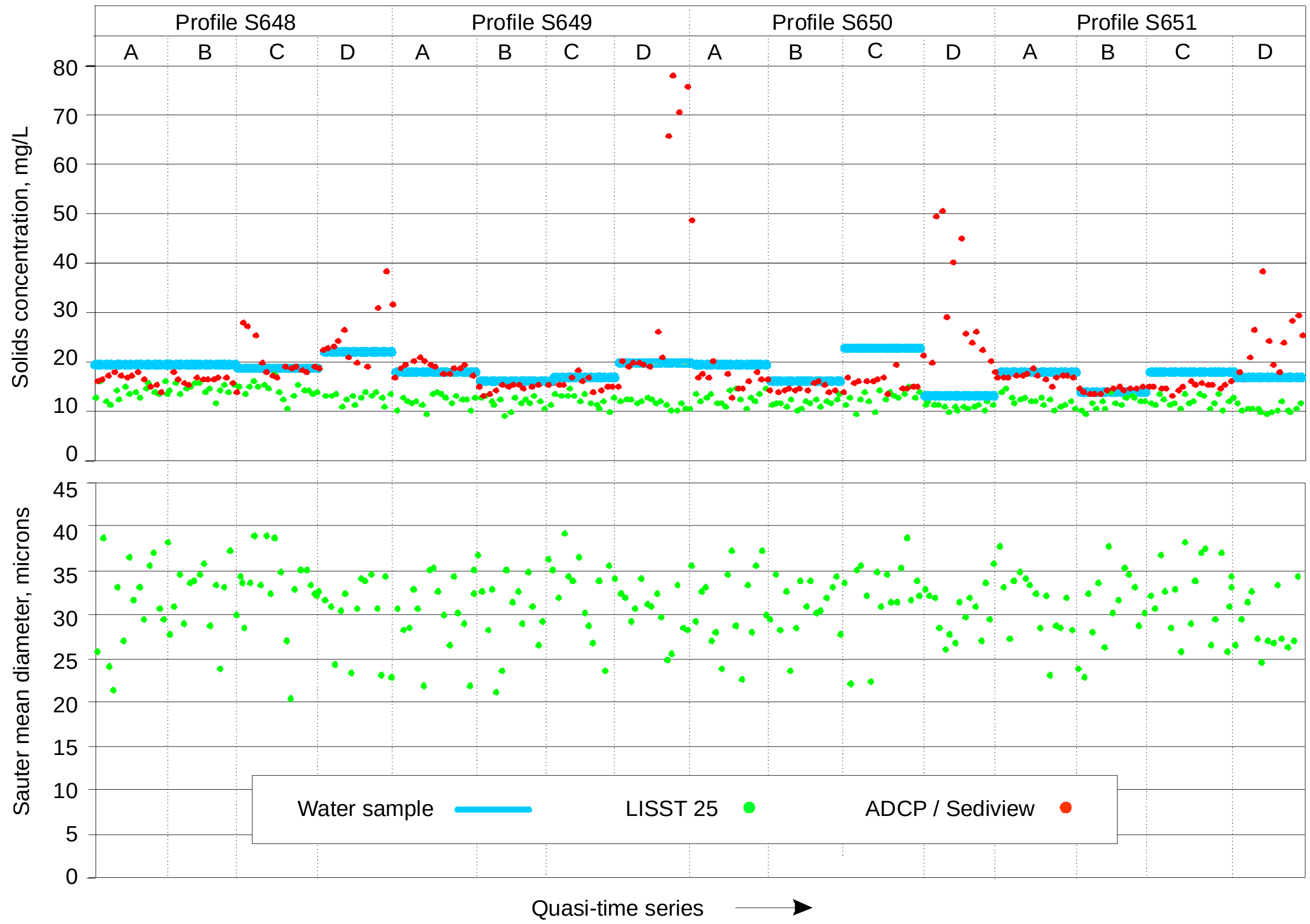

Figure 3.9 - Comparison between data from bed-mounted ADCP and vessel-mounted LISST and water samples, Bald Head site, 26 August

Figure 3.10 (overleaf) shows the processed bed-mounted ADCP data for the full duration of the measurement period. The near-surface data corruption due to entrained air bubbles appears to be much worse than that at the Mound Crest site but sea conditions were similar. It is possible that some of the apparent aeration is, in fact, caused by the Langley drifting directly over the bed-mounted instrument and interfering with the ADCP beams.

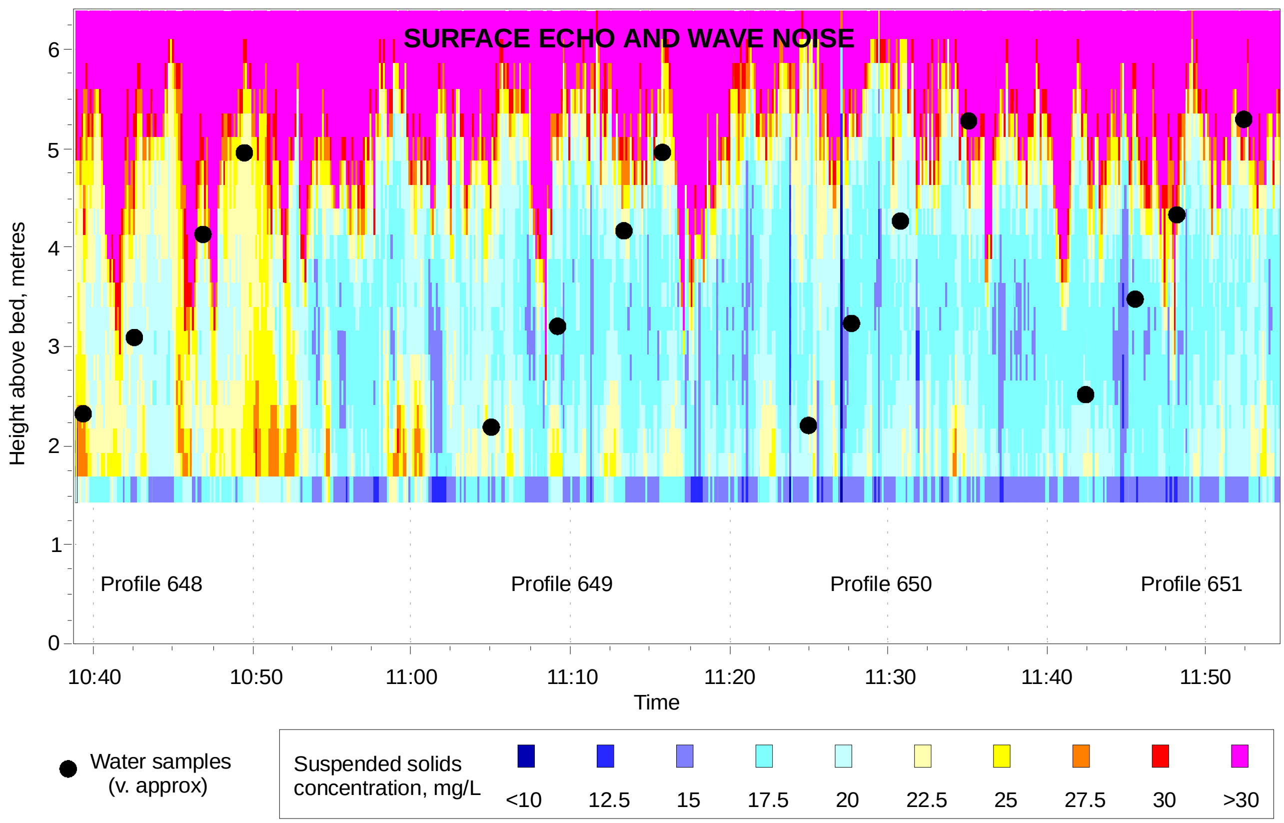

Figure 3.10 - Processed record of Bald Head bed-mounted ADCP during the sampling period.

3.4 RIVER MOUTH SITE- 26 AUGUST

Although there was no bed-mounted ADCP at the mouth of the river, it was decided to take measurements at this relatively sheltered location in order to investigate possible calibration variations at different locations. Three profiles were measured. Due to a software conflict, OBS data were not obtained during the first part of this series of measurements. All available data are compared in Figure 3.11.

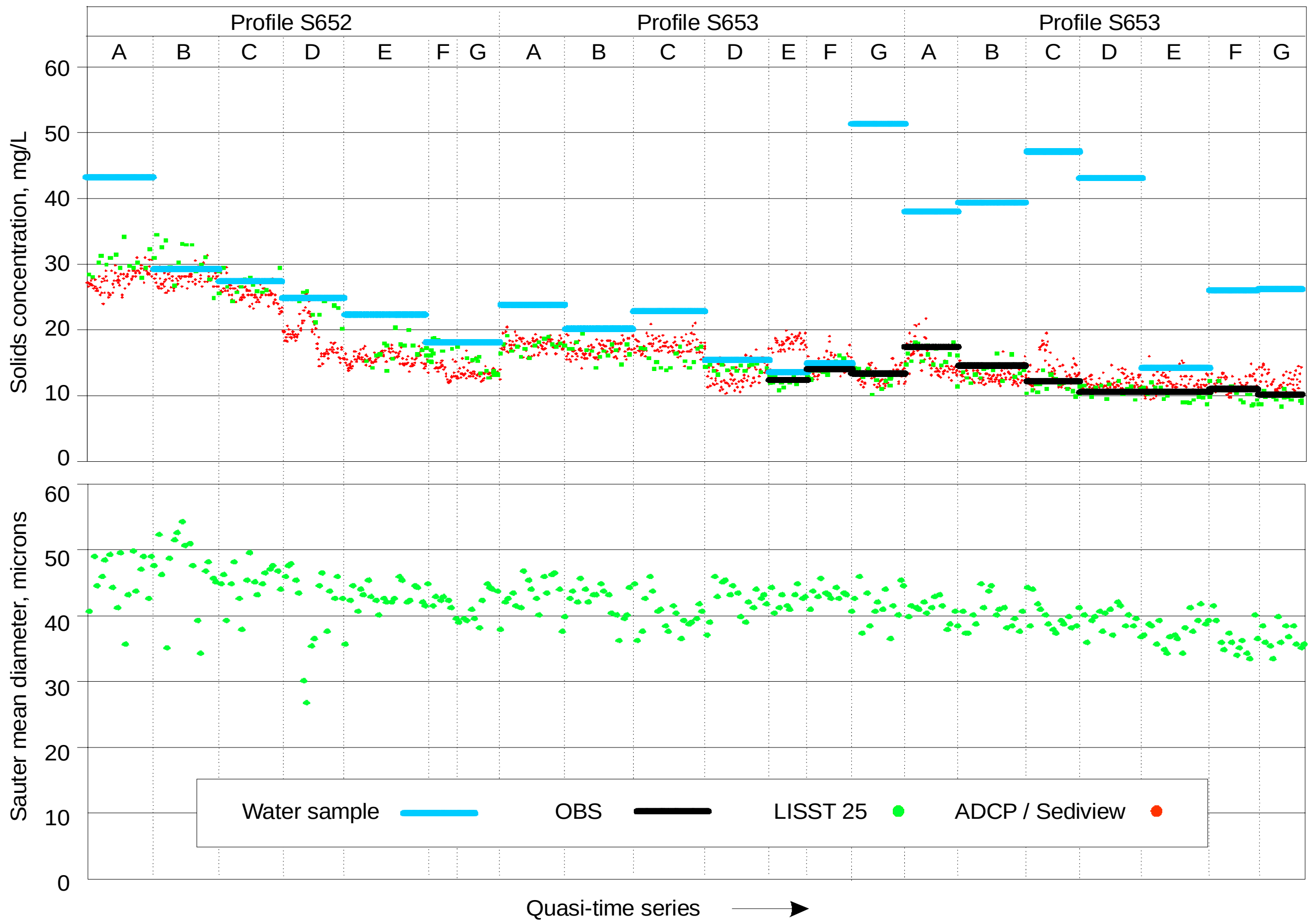

Figure 3.11 - Comparison between data from vessel-mounted equipment, River Mouth, 26 August

Some of the vessel-mounted ADCP data ensembles have been removed from the record because of air bubble contamination. This particularly affected the top one or two bins and was caused by the rolling motion of the R/V Langley.

There is a very close agreement between the LISST 25, Sediview and the OBS. However, there are significant discrepancies with several of the water samples which yielded anomalously high concentrations.

The particle size data suggest both time- and depth-related changes. During the 90-minutes of measurement there appears to have been a general decrease of particle size and the data indicate that the near-bed sediment was slightly coarser than that near the surface.

3.5 River 2 site - 26 August

The River 2 site was visited again on 26 August but no data are available for the bed-mounted ADCP. Figure 3.12 shows the comparison between the measurements made using the vessel-mounted equipment. The initial discrepancy (Profile S655, Samples A-D) between the ADCP data and the OBS, water sample and LISST data is likely to be due to the slope of the bed but, as no bed-mounted ADCP data are available, it is not possible to determine how much the Langley may have moved during this set of measurements. However, it is noticeable that the particle size did not vary significantly during profile S655.

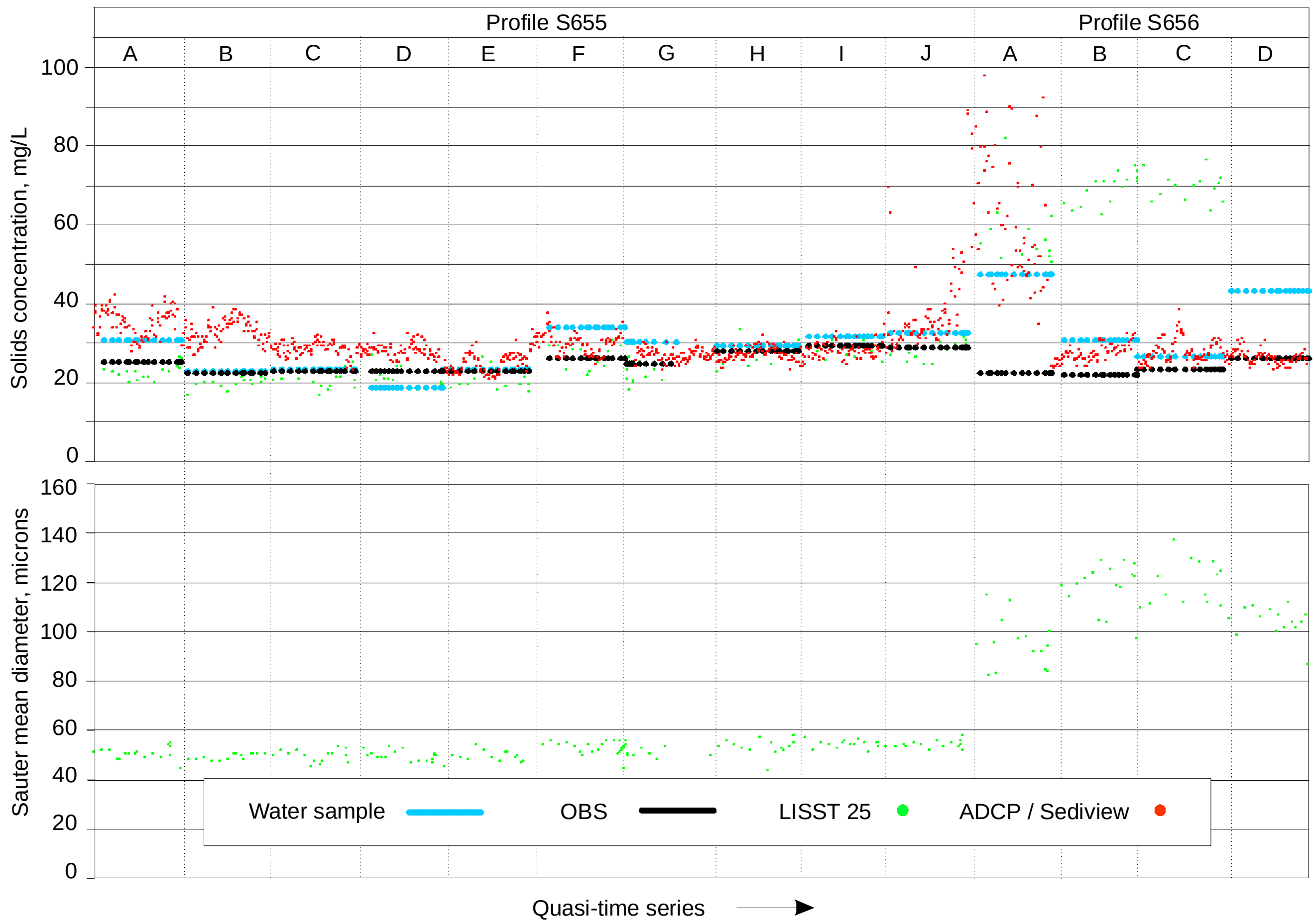

Figure 3.12 - Comparison between data from vessel-mounted equipment, River 2 site, 26 August

As sample S655J was being taken, the ADCP recorded rapidly increasing concentrations. Sample S656A shows erratic results with both the LISST and ADCP giving high and extremely variable concentrations, and the water sample yielding a concentration of almost double the OBS. Samples B, C add D show more consistent results except for the LISST which continues to yield erratic data (including particle size). There is no obvious explanation for this but it is worth noting that one of the four ADCP beams was particularly affected, the other three returning data more in line with the OBS and water sampler. It seem at least possible that the data during profile S656 were affected by debris (eg. weed) or, possibly, a small shoal of fish.

4. Discussion

4.1 Intercomparison of Measurement Methods

Summary data comparisons are shown in Figure 4.1. The OBS, water sample and ADCP data are compared (Y-axis) with the LISST 25 measurements (X-axis). The OBS, LISST 25 and ADCP data have been averaged over the duration of each water sample (approximately 60 seconds). All data are presented except for the anomalous measurements obtained from Profile S656 at the River 2 site on 26 August.

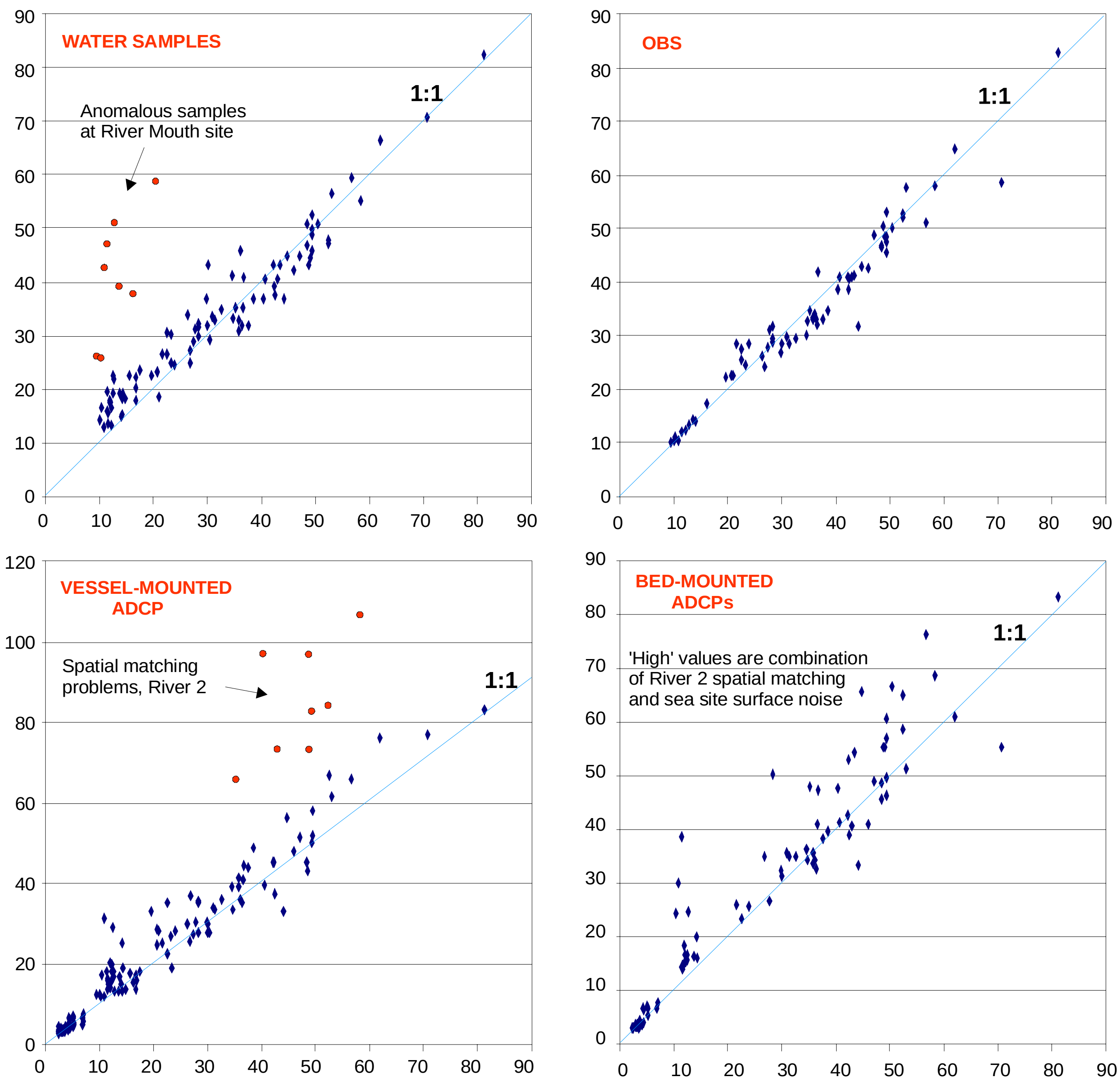

Figure 4.1 Comparisons of water sample, OBS and ADCP concentration measurements (Y-axis) with LISST 25 data (X-axis) - all units are mg/L

As might be expected simply from consideration of spatial synchronisation, the ADCP data show the greatest scatter when compared with the LISST data and the bed-mounted ADCPs show more scatter than the vessel-mounted ADCP. Both sets of ADCP are biased slightly high. This is due mainly to the near-bed data at the River 2 site (24 August) and to near-surface air bubble contamination the Bald Head and Mound Crest sites. If all of these data were filtered out, there would be a very acceptable degree of correlation between the two methods of measurement.

For the most part, the water samples are also in close agreement with the other measurements. However, there are a number of samples that are in marked disagreement. Almost all of these indicate anomalously high concentrations. It seems likely that these were contaminated in some way or included a few discrete coarse particles that might not have been measured using the other techniques (or 'averaged out' due to a high measuring frequency).

The OBS data show the closest agreement with the LISST data. This is also to be expected as a properly-functioning OBS is not subject to the same random experimental errors that water samples often exhibit and because the OBS and LISST sensors were mounted very close together.

Discounting obviously anomalous, spurious and/or (air bubble) contaminated data, it is clear that the LISST 25, ADCP / Sediview and OBS measurements are generally in very close agreement and that they yielded essentially the same data.

4.2 Effects of Particle Size - Implications for Calibration of bed-Mounted ADCPs

A particular advantage of the LISST is that it measures both particle size and concentration and, in contrast with turbidity meters, is claimed not to bias concentration estimates in response to varying particle size. The potential effect of varying particle size on the Sediview calibration is frequently cited as a major limitation of the technique. It is therefore relevant to discuss here in more detail, the effects of particle size on the concentration measurements made during this experiment. This is particularly important in the context of developing reliable Sediview calibrations that can be used for the bed-mounted instruments over long periods of time.

Sediview takes particle size into consideration in two ways:

1) by site-specific calibration at the time of data collection;
2) by assuming that, in the short term, there is a reasonably linear relationship between particle size and solids concentration.

The former will clearly not be possible during long-term deployments but data from other bed-mounted instrumentation (eg. OBS and LISST) will provide some degree of verification in the near-bed zone where particle size variations are likely to be greatest.

It should be noted that while the current version of Sediview assumes a linear relationship between concentration and particle size, it does not assume a slope of 1:1 nor does the computation of concentration assume a 1:1 slope (1:10 in dB) in the relationship between backscatter intensity and log [M]. In fact, we have never observed a slope of 1:1 during the 8 years that we have been working with this technique. The slope of the backscatter relationship generally lies in the range 1.5-2.5 and has been observed to be as high as 3.5. This is simply a reflection of the fact that natural suspensions are not 'perfect'. It should also be noted that natural sediment populations never comprise single size particles. They comprise a wide range of particle sizes which tends to 'mute' the theoretical effects on backscatter of a shift of the average size. Because of the manner in which Sediview deals with the backscattering and because in its normal application, calibration data are obtained at frequent intervals during a survey, we normally achieve a degree of correlation between Sediview estimates and measurements by other methods which make them virtually indistinguishable.

Our concern about this particular application of Sediview is that ‘step changes’ in the nature of the sediment in suspension may occur which will not be easily detectable in the long-term monitoring data from bed-mounted ADCPs and could therefore give rise to errors. These step changes are most likely to arise mainly through storm action when very coarse sediment might suddenly be put into suspension but may also occur over the tidal cycle, particularly in the river.

The particle size varied significantly during the experiment. Excluding the obviously spurious data obtained at the end of the River 2 deployment on 26 August, the one-minute time-averaged data show a size (SMD) range of between 20 and 60 microns. If Sediview was adversely affected by particle size, it would be expected that, at a given ambient solids concentration, the concentration estimates would increase as the particle size increases.

The River 2 site (24 August) showed the greatest variation of particle size. Although the results are slightly obscured by the difficulties of spatial correlation, particularly in the near-bed area, there are very strong indications that the concentration estimates have not been affected by varying particle size. The most rapid variation of particle size occurred while the first 10 samples were obtained during which time the particle size fell from about 60 microns to 40 microns and then rose again to about 45 microns. Throughout this period, the Sediview concentration estimates, spanning a range of 22-83 mg/L, were a near perfect match with the other measurements. After this period, there was a progressive increase of particle size at all depths. It is evident from the trend of the data that the Sediview estimates were not influenced by this change.

At the River 2 site on 26 August, there was again a progressive increase of particle size (up to the point at which the data became anomalous) yet the Sediview estimates show no response to this change. At the site near the mouth of the river, there was a rather consistent decrease of particle size over time which, again, is not reflected by any discrepancies between the Sediview estimates and the other measurements.

Similarly, at the Mound Crest site, the marked particle size variation with depth appears not to have biased the Sediview concentration estimates.

Despite this, we remain cautious about the effects of particle size. Figure 4.2 shows the comparison between LISST concentration estimates and particle size for all sites.

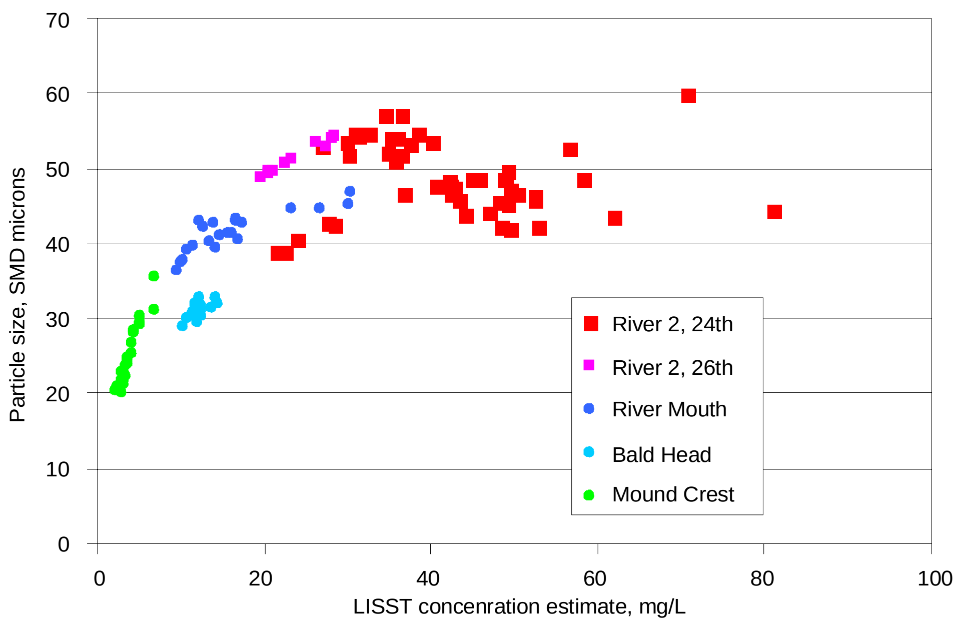

Figure 4.2 - Particle size variation with concentration, all sites

With the exception of the River 2 site, all sites show a distinct relationship between concentration and particle size. The River 2 site shows little or no relationship. However, this is likely to be due to the fact that the sediment regime in the river is more complex than those at the other sites. We would expect that a more detailed examination of a data set obtained over a full tidal cycle would reveal a systematic time-related variation of particle size and that, at any one moment in time, would show a clear relationship between particle size and concentration.

The important point about Figure 4.2 is that it clearly shows that the sediment populations at the different sites are distinctive and that the variations from one site to another (time-related variations) should not be ignored. By way of illustration, Figure 4.3 shows the ratios between the Sediview and the LISST estimates and between the OBS and LISST estimates plotted against particle size. All available data are shown excluding the suspect data from Profile S656.

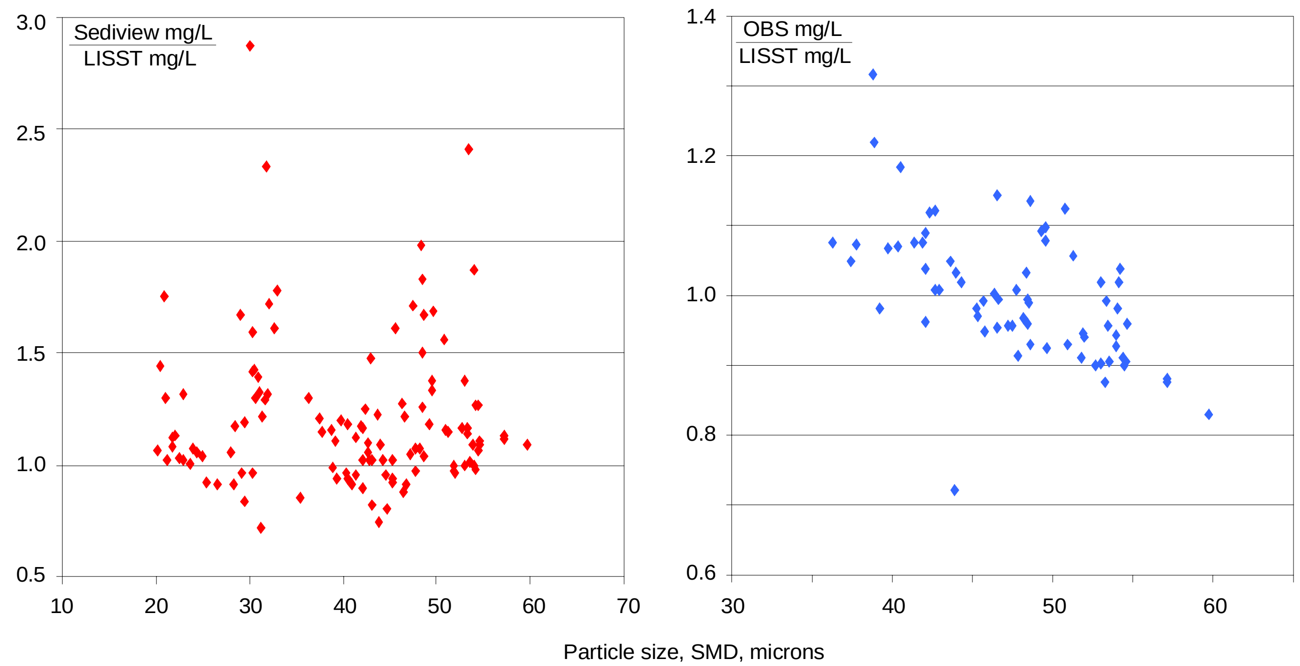

Figure 4.3 Effects of particle size on Sediview and OBS concentration estimates.

Although the Sediview data show no particle size related trends, there is a marked trend in the OBS data. However, it should be noted here that the Sediview calibration was adjusted slightly for each location whereas the OBS calibration is based only on comparison of OBS output and the River 2 water samples. It is thus clearly indicated that site-specific calibrations are required for both Sediview and for the OBS. It may also be the case that the LISST 25 should be calibrated for each location.

Several conclusions can be drawn from this review:

1) the apparently very high degree of correlation between the measurements masks a dependence on particle size that is apparent in the Sediview data (different calibration needed for each site) and the OBS data (obvious particle size related error trends);
2) the Sediview calibration and computation method (and the assumptions on which it is based) was adequate to deal with the particle size variations encountered during the experiment;
3) it is likely that the success of the Sediview calibration is due in part to the fact that each ADCP was calibrated separately, thus taking account of site-specific sediment characteristics;
4) there is clear evidence that OBS sensors should also be calibrated on a site-specific basis; this will be particularly important if OBS are to be used to verify long-term Sediview data;

5) it may also be necessary to develop site-specific calibrations for the LISST;
6) much more calibration work is required to investigate temporal changes of calibration, particularly in the River where significant variations of sediment character can reasonably be expected;
7) this initial work provides some encouragement that long term calibrations could be developed for use with the bed-mounted ADCPs.

4.3 ADDITIONAL WORK REQUIRED TO DEVELOP LONG-TERM CALIBRATIONS

The data obtained during the experiment showed clear trends of sediment particle size variation.

1) at the River 2 site, on both 24 and 26 August, there was a trend of increasing particle size during the ebb tide.
2) at the river mouth site, the sediment appeared to become slightly finer during the early stages of the ebb tide;
3) the particle size at the Bald Head site was finer than that in the river but, during the short measurement period, appeared to be reasonably constant with both time and depth;
4) the particle size at the Mound Crest site was lower than all the other sites but showed marked variation with position in the water column.

This suggests that the terrestrial sediment input from the river is coarser than the marine sediment, that the river sediment is subject to size variation related to the state of the tide and that the sediment in the sea becomes finer offshore. It is very likely that the size of the sediment in suspension at the sea sites will vary significantly depending on sea conditions. While Sediview was clearly not affected by the variations of particle size encountered during the measurements, it would be imprudent to assume that this applies over full tidal cycles (and different types of tide), for all river discharges and to all weather conditions at sea. More work is therefore required to investigate possible calibration variations and to develop confidence in future data processing. It is also necessary:

1) to obtain basic calibration data for the Outer Mound and Oak ADCPs that were not investigated during this experiment;
2) to develop site-specific calibrations for the OBS sensors.

It is also suggested that, subject to discussion of this review with Sequoia, some additional calibration work might be necessary for the LISST. Our recommendations are set out below.

4.3.1 River Site(s)

The objective in the river is to establish any calibration shifts that may occur during the full tidal cycle, during spring and neap tides and in response to varying river discharge. A detailed investigation of all combinations requires a considerable amount of work but a database could be built up over time by ensuring that some calibration data are obtained whenever a boat is mobilised to service the ADCPs and other equipment.

As an initial minimum requirement, we recommend that at least 2 dedicated calibration surveys are undertaken, each of which must span a full tidal cycle. The surveys should be undertaken during neap and spring tides (easy to programme) or during low and high river discharges (not so easy to programme). Two locations should be investigated, the River 2 site and a site near the mouth of the river. Assuming the use of single survey boat, samples could be obtained alternating between the two sites at time intervals of say, 45 minutes. During each visit to a site, at least eight samples should be obtained through the full depth of the water column.

4.3.2 Sea Sites

The calibration surveys at the sea sites should be designed mainly to identify possible changes of calibration in response to sea conditions and major changes of river discharge. However, the conditions in which this experiment was conducted were marginal and it is unlikely that sensible data could be obtained in worse conditions. A larger or more stable vessel (such as a catamaran) may yield slightly better data but much of the air bubble contamination was caused by wave action. It may be that we must accept that data obtained from bed-mounted ADCPs during storms should be regarded as semi-quantitative. However, some effort should be made to obtain calibration data in calm conditions and to investigate the effects of variable river discharge.

As an initial minimum requirement, we recommend that a dedicated survey be undertaken during calm sea conditions to collect calibration data spanning a complete tidal cycle at all sea sites, preferably during a spring tide and/or high river discharge. Calm sea conditions will provide a contrast to the work done during this experiment and working over a full tidal cycle will permit the study of the mixing of terrestrial and marine sediments. It may be possible to complete this work in two days if two ADCPs are investigated each day.

Investigation of varying river discharge might best be accomplished on an opportunistic basis when equipment is being serviced.

4.3.3 General Recommendations

If possible, the separation between the vessel-mounted ADCP and the water sampler should be reduced. Water samples must be supported by LISST and OBS measurements. The LISST provides the only positive indication of particle size variation and is therefore of great importance in gaining a complete understanding of how the sediment changes over time and depth.

Shipboard ADCPs and other instruments should be interfaced with a DGPS system (with antenna mounted directly over the instrument) in order to determine the position of all calibration data relative to the location of the bed-mounted ADCPs.

5 Conclusions

The following conclusions can be drawn from the intercomparison of the measurements made using the LISST 25, water samples, OBS and ADCP / Sediview:

1) The experiment has shown a very high degree of correlation between all four methods of suspended solids measurement. Discrepancies were generally isolated and can either be explained as rogue data (eg. the anomalous water samples at the end of the measurement period at the river mouth) or due to spatial mismatching (eg. in the near-bed zone at the River 2 location).

2) Although there was significant variation of particle size distribution from one site to another and, at some individual sites, with depth and time, the accuracy of the Sediview concentration estimates show no sign of being affected. However, this indicates only that the calibrations that were used were able to accommodate the range of particle sizes observed during this limited experiment.

3) The use of three or more methods of measurement is desirable because it permits the identification of anomalous or rogue data. For example, calibration of the ADCP at the River Mouth site based only on the water samples would have resulted in the use of several obviously spurious high-concentration data points.

4) Use of the LISST during calibration surveys to measure particle size greatly enhances the understanding of the sediment regime and its variation and permits more confident development of Sediview calibrations.

With respect to the development of Sediview calibrations for long-term monitoring using bed-mounted ADCPs, we draw the following conclusions:

1) The data are very encouraging and suggest that it may be possible to develop calibrations despite the difficulty of temporal and spatial synchronisation of ADCP and calibration data.

2) Although the Sediview calibrations differed for each instrument (because of differing performance characteristics) the ‘environmental’ components of the calibrations (ie, those that concern the sediment in suspension) were broadly similar. At each site, a single calibration was applied to the full data set and appears to have been good for the full duration of each measurement period.

3) The success of the Sediview calibrations, in the light of the varying particle size and sea conditions that ranged from good to very poor, suggests that it will be possible to develop calibrations that can be applied with reasonable confidence to long term monitoring data from bed-mounted instruments. However, more work is required to fully develop these calibrations and to establish their limitations.

4) The additional calibration work needs to investigate possible step-changes of sediment characteristics in response to different tidal and sea conditions. It is recommended that the additional work comprises a limited number of dedicated calibration surveys followed by opportunistic data collection (whenever the ADCPs and other instrumentation are serviced) in order to gradually compile a large calibration database.

When the ADCPs have been fully calibrated, care will be required when interpreting long term records, especially in the near-surface zone where poor sea conditions severely corrupt concentration data. These effects are expected to be easy to identify, especially in view of the fact that the ADCPs are set up to monitor wave conditions. Data processing and interpretation should include analysis of the concentration data obtained by the instruments mounted on the bed frames (eg. LISST and OBS) in order to provide verification of the ADCP concentration data. If used in this manner, OBS (and possibly LISST) calibrations should be investigated in more detail.