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MINISTRY OF WATER RESOURCES

BANGLADESH WATER DEVELOPMENT BOARD

M E S II
MEGHNA ESTUARY STUDY

TECHNICAL NOTE MES-033

DETERMINING SUSPENDED SEDIMENT CONCENTRATION FROM ADCP BACKSCATTER INTENSITY

May 2001

DHV CONSULTANTS BV

in association with

DEVCONSULTANTS LTD
SURFACE WATER MODELLING CENTRE

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

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$$\sigma = N 4\pi\alpha k^4 a^6 \tag{3}$$

in which α is a material parameter given by

$$\alpha = 4\left[\left(1-gh^2\right)/\left(3gh^2\right)+\left(1-g\right)/\left(1+2g\right)\right]^2 \tag{4}$$

(Greenlaw, 1979), where g is the ratio of the density of the scattering material to that of the surrounding medium and h is de ratio of the speed of sound in the particle to the one in the surrounding medium. Consider a mixture of size classes of scattering particles of suspended sediment in a unit volume of water. The partial concentration by weight C_i (mg/l) of one size class i per unit volume will be:

$$C_i = N_i 4/3\pi a_i^3 \rho_i \tag{5}$$

in which ρ_i is the density of the particle. Since the volume backscattering cross section is assumed to be equal to the sum of the individual backscattering cross sections the total scattering cross sections for m size classes is:

$$\sigma_v = 3k^4 \sum_{i=1}^{i=m} C_i a_i^3 \alpha_i / \rho_i \tag{6}$$

Substituting equations (2) and (6) in (1) we get:

$$S_V = 10\log_{10}\left[\left(\frac{3}{4\pi}\right)k^4 \sum_{i=1}^{i=m} C_i \alpha_i^3 / \rho_i\right] \tag{7}$$

This equation is only valid for the Rayleigh scattering range and it assumes that the attenuation of the signal in the water is adjusted for by the built in software from the ADCP.
The amount of energy absorbed by the fluid is depending on the temperature and salinity of the water and the sound frequency of the ADCP (Fischer and Simmons, 1977).

Apart from the empirical model, a theoretical model is available, but this is still in the development stage. This model also uses the principle that the intensity of the backscatter signal is related to the amount of suspended sediment. This relation has to be adjusted for the grainsize distribution, the shape and density of the sediment. The grainsize distribution changes in time and space. The temporal change is caused by the change in hydrological circumstances due to tidal movement. The spatial changes in a vertical direction are caused by the differential settling of the different grain sizes due to varying fall velocities. The lower reaches of the depth vertical therefore have a higher amount of the coarse fraction then the upper reaches. A full physical description of this process in relation to the backscatter intensity is not available at this moment (Visser, 1997).

The results of earlier attempts at estimating the SSC from ADCP have been fairly successful. Weierman (1995) describes the monitoring of plumes of dredged material in Denmark. In coastal water body of 20 m deep with a SSC of 50 mg/l the uncertainty in the estimation was between 3 and 16 %. In the FAP 24, the same procedure as in Weierman (1995) has been using. They concluded that using a 300 kHz only the sand concentration could be defined by ADCP measurements. Total SSC in this research was as high as 1270 mg/l. No reports are known with SSC as high as the maximum SSC found in the Meghna Estuary.

1. INTRODUCTION

The Acoustic Doppler Current Profiler (ADCP) is on board of the MES survey vessel Anwesha in order to define the current velocities in designated areas. In this research, it is attempted to determine the suspended sediment concentration (SSC) from the ADCP signal.

Till now sediment concentration is determined by collecting water samples and quantify the amount of sediment by means of micro-filtering 60 to 80 ml of the fines. This is being done in the SSD sediment laboratory in Chittagong (Technical notes MES-016, estuarine surveys). This routine gives a number of point data on the sampled locations. These point data need to be interpolated over the entire cross section to get a good impression of the SSC. For determination of the sediment transport, the sediment concentration profile is combined with the ADCP current profile. This can be refined on including the settling velocity distribution to get a transport rate by grainsize.

By SSC determination from the ADCP, it is possible to get an instantaneous sediment concentration profile at a location. This implies that the distribution of the sediment transport in a transect can be estimated with more detail.
The goal of this research is: Establishing a relation between suspended sediment concentration and backscatter intensity from ADCP

In Chapter 2 the main principles of acoustic behaviour of suspended sediment are described. Chapter 3 gives the method of data acquisition, followed by the presentation of results in chapter 4. The discussion is presented in chapter 5. Conclusions are given in chapter 6

2. PRINCIPLES OF ACOUSTIC BEHAVIOR OF SUSPENDED SEDIMENT

An ADCP is an acoustic instrument that sends bursts of high frequency sound waves into the water and registers the amount of energy returned from the water. To accommodate velocity measurements also, the Doppler shift is measured, but no attention will be paid to that here. If a sediment particle is hit by a sound wave, it will reflect the sound. The main idea behind this exercise is that the more sediment is in the water, the higher the amount of energy returned to the instrument.

The theory comes from Weierman (1995). It is an empirical method based on the relation between the backscatter intensity and the SSC. This method is also applied at FAP 24 special report no.12 (1996). The single frequency estimation method is based on quantitative measurements of volume scattering strength S_v, described by the relation between the reflected intensity of sound I_{ref}, measured at a distance of 1 m from a unit volume of scatterers and the corresponding incident intensity I_{inc} as:

$$S_V = 10\log_{10}(I_{ref} / I_{inc}) \tag{1}$$

The unit of S_v is decibels (dB). A measure related to S_v is the volume backscattering cross section:

$$\sigma_V = 4\pi(I_{ref} / I_{inc}) \tag{2}$$

That is, area per unit volume. The parameter σ_v and thereby S_v is dependant on size shape, density and compressibility of the scatterers. For small scatterers the sound frequency is important as well. If k is the acoustic wavenumber ($k=2\pi/\lambda$, in which λ is the acoustic wavelength) and a is the radius of the spherical scattering particle, the term ka expresses the ratio of circumference to wavelength. . For $ka << 1$ the particles are Rayleigh-scatterers (Rayleigh, 1945), and the Rayleigh scattering law determines the individual scattering cross sections σ to exhibit a linear relationship with the product k^4a^6. An upper limit of the Raleigh scattering law is $ka = 0.5$ (Urick, 1983). The scattering cross section for N particles is:

3. METHOD

To make an appropriate regression function the following data are needed:

3.1 ADCP backscatter intensities

This has to be recorded at the same time and depth as the sediment samples are taken. The depth resolution has to be as small as possible to match the spatial support from the water sample. The minimum advisable depth resolution is 0.5 m (ADCP, technical manual). The backscatter intensity values have been adjusted for attenuation due to water and salinity.

The attenuation factor is a function of emitted sound frequency, temperature and salinity (Fisher and Simmons, 1977). Table 1 shows the results of a sensitivity analyses. The temperature and salinity range found at the sample location has little influence on the absorption. Based on the table it has been decided to use an absorption coefficient of 0.063 dB/m. The ADCP will continuously measure backscatter intensity. The output will be averaged every 15 seconds for all four beams.

Sal. = 2 ppt		Temp = 28 C	
Temp (C)	α (dB/m)	sal (ppt)	α (dB/m)
27	0.065	0	0.059
28	0.065	0.5	0.06
29	0.064	1	0.062
30	0.064	2	0.065
		3	0.068
		4	0.071

Table 1 Range of absorption coefficients for 600 kHz ADCP

3.2 Suspended sediment concentrations

Water samples at different depths taken as close in space as possible to the ADCP transducer. The physical distance between the sample site and the transducer was five meter in a downstream direction and one meter perpendicular to the current. The samples have been collected by a one-liter bottle with a cork in the lid. Inside this bottle, a tennis ball was put. At the designated depth, the cork was released and the bottle was filled in 15 seconds. After that, the tennis ball effectively sealed of the opening and the bottle was brought back to the surface. To make the bottle sink a weight of 25 kg was used. The weight and bottle were brought to the surface by manpower, because the winch wasn't working properly. The sediment concentrations were determined by the SSD sediment laboratory in Chittagong by microfiltering 60 to 80 ml of the fines. This has been done for the sand and silt fraction separately.

Measurements were done on 27 and 28 of march 2001. On the 27th sampling was done during a full tidal cycle close to Bhola. On the 28th nine samples were taken from one vertical in a time span of half an hour in the main channel of the Meghna river at a northing of 520000 m.

4. RESULTS

To investigate the relation between the backscatter intensity and the sediment concentration, the following equation was used, based on equation 7:

$$S_v = a + b * 10\log_{10}(SSC) \qquad (8)$$

The backscatter was related to the SSC at the same depth for the sand fraction, the silt fraction and the total sediment concentration. These relations have been evaluated in terms of their correlation.

Figure 1 shows the scatter plot of the silt fraction and the backscatter of all the samples. The straight line is the linear regression line. The correlation coefficient is 0.062. The equation, relating the silt concentration to the backscatter is:

$$S_v = 71.5 + 0.28 * 10\log_{10}(SSCsilt)$$

Figure 2 shows the same type of plot, but for the sand fraction, figure 3 shows the backscatter intensity as a function of the total SSC, below the relations and their correlation coefficients are shown.

Sand concentration $S_v = 73.8 + 0.056 * 10\log_{10}(SSCsand)$, $R^2 = 0.004$

Total sediment concentration: $S_v = 72.2 + 0.11 * 10\log_{10}(SSCtotal)$, $R^2 = 0.012$

Different relations were established for the subset of data from March 28. The data are shown visually in figure 4, 5 and 6. The correlation equations and correlation coefficient are given below:

Silt concentration $S_v = 69.0 + 0.90 * 10\log_{10}(SSCsilt)$, $R^2 = 0.42$

Sand concentration $S_v = 69.8 + 0.69 * 10\log_{10}(SSCsand)$, $R^2 = 0.69$

Total sediment concentration: $S_v = 66.0 + 0.68 * 10\log_{10}(SSCtotal)$, $R^2 = 0.68$

5. DISCUSSION

Considering the sound wave frequency of the ADCP (600 kHz) used by MES, the suspended grainsize was within the Rayleigh scattering range. Therefore, the relation of Weiergang (1995) was used.

There was a fair relation between the data of March 28 with coefficient of correlation of 0.69 and 0.68 for sand and total sediment concentration. The relation for the silt fraction was rather poor. The regression of the whole dataset shows an extremely poor relation as can be seen from the figures. The coefficients of correlation ranged from 0.004 to 0.06. The large difference between these results can be understood from figure 7 and 8. Figure 7 shows the backscatter intensity at different depths for a 15-minute period. The highest intensities are found around 5 m below the surface, in the lower reaches the backscatter intensity drops. This type of intensity profile persisted during the full tidal cycle except a 30-minute period during slack water. From a theoretical point of view the sediment concentrations in the lower reaches should be higher as the grains will fall to the bottom due to gravity, only kept in motion by turbulence. This is in no way reflected in the backscatter intensity plot. Figure 8 shows a similar plot but for march 28. During this whole time period, (34 minutes), the backscatter intensity gradually increased in the downward direction. This is consistent with the theory. The reason for this difference in sediment concentration is the difference in current velocity. This is shown in figure 9 and 10. The velocity on March 27 was generally more than 1 m/s, generating more turbulence. This leads to a higher sediment carrying capacity. In addition, the location was in an area with less more sediment supply, as river influence is less.

The main question remains, why the intensity profiles show highest values in the midrange during the first day. The total sediment concentration of March 27 was on average more the four times higher than the following day (76 and 17 mg/l respectively). It is likely that this higher amount of sediment absorbs more energy than a low sediment concentration. This absorption by sediment is not taken into account in the formula of Fisher and Simmons (1977). Therefore, it works better for lower sediment concentrations, which is clearly shown in figure 4-6. The main disadvantage of the method is that the absorption coefficient is defines the backscatter intensity, which is used for prediction of the sediment concentration. The absorption itself is also influenced by the amount of sediment in the water. This leads to a circular reference in which the prediction of the SSC depends on the SSC. As long as the SSC is low, this is not a problem.

A large part of the sediment consists of silt (36 and 45 percent on march 27 and 28 respectively). In addition, in FAP 24 the correlation with the silt fraction was rather poor. It was concluded that; as the intensity of the backscatter scales to the cubicle of the grainsize, see equation 7, the influence of the silt fraction is very small.

Another source of errors is the spatial separation of the location of the ADCP beamer and the place where the water samples are taken. It has been seen that boils with larger amounts of sediment are much localized. This means that the SSC can vary a lot in time, which makes it more difficult to consistent results.

6. CONCLUSIONS

Estimation of suspended sediment concentration works reasonably well at very low concentrations. The following relation are found:

Silt concentration	$S_v = 69.0 + 0.90 * 10\log_{10}(SSCsilt)$,	$R^2 = 0.42$
Sand concentration	$S_v = 69.8 + 0.69 * 10\log_{10}(SSCsand)$,	$R^2 = 0.69$
Total sediment concentration:	$S_v = 66.0 + 0.68 * 10\log_{10}(SSCtotal)$,	$R^2 = 0.68$

They work for a total sediment load of 17 mg/l on average.

At higher sediment concentration the method shows extremely poor results.

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- FAP 24, River survey project, Special report no.12, Optimization of sediment measurements, 1996, Government of the peoples republic of Bangladesh, Water resources planning organization, Dhaka, Bangladesh.
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- Visser, R., 1997, Ralation between reflection of sound in water and concentration of suspended sediment (in Dutch), faculty of Geographical Sciences, University of Utrecht, and S.D. Kamminga engineering, The Netherlands.
- Weiergang, J., 1995, Estimation of suspended sediment concentration based on single frequency acoustic dopples profiling, Danish Hydraulic Institute, Horsholm, Denmark

Figure 1. Relation between silt concentration and backscatter intensity

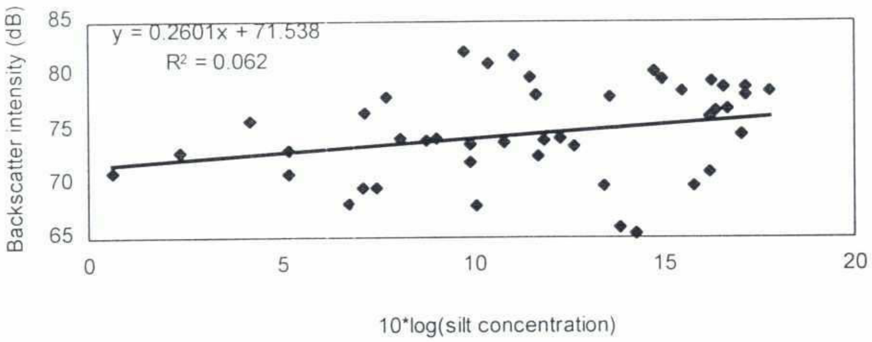

Figure 2. Relation between sand concentration and backscatter intensity

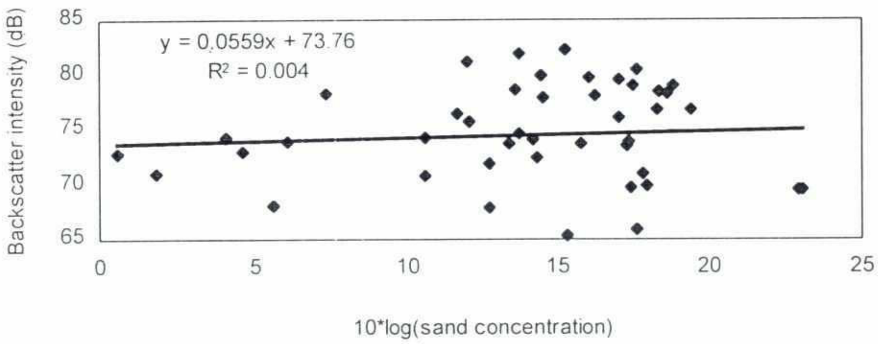

Figure 3. Relation between total sediment concentration and backscatter intensity

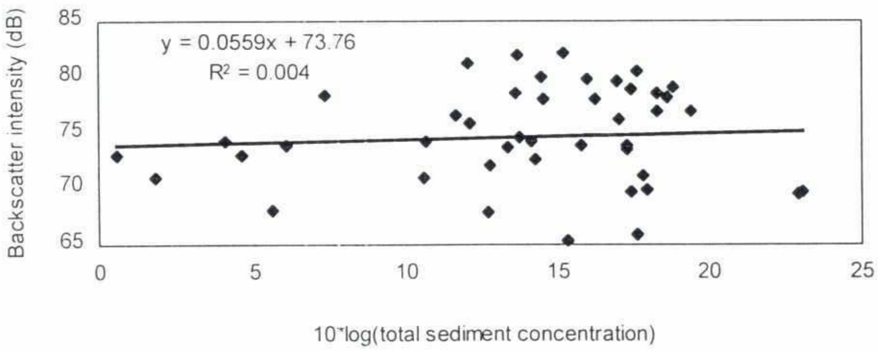

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Figure 4. Relation betw een backscatter intensity and silt concentration

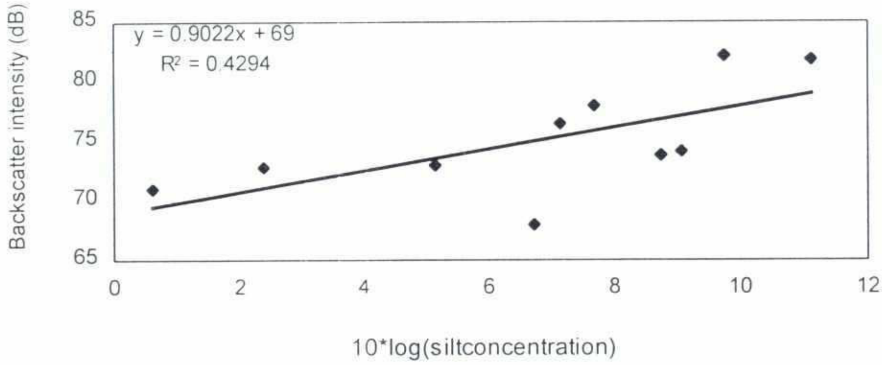

Figure 5. Relation betw een backscatter intensity and sand concentration

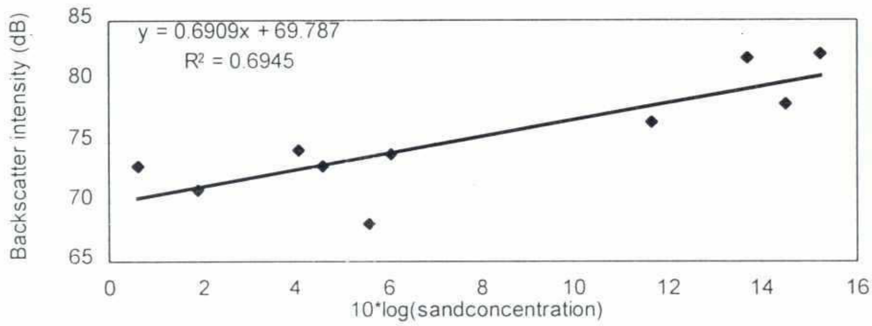

Figure 6. Relation betw een backscatter intensity and total sediment concentration

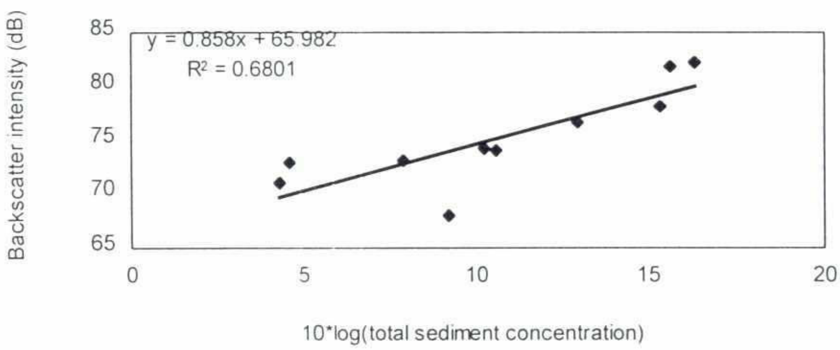

Figure 7: Backscatter intensity plot for high SSC, March 27

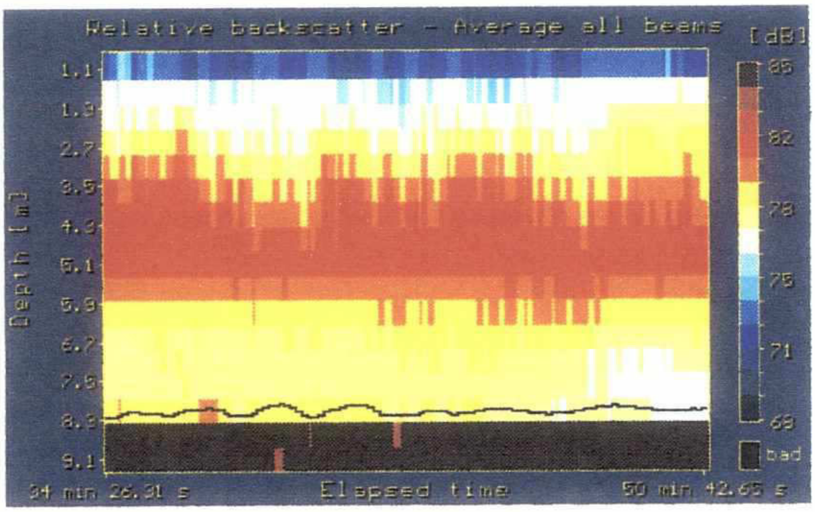

Figure 8: Backscatter intensity plot for low SSC, March 28

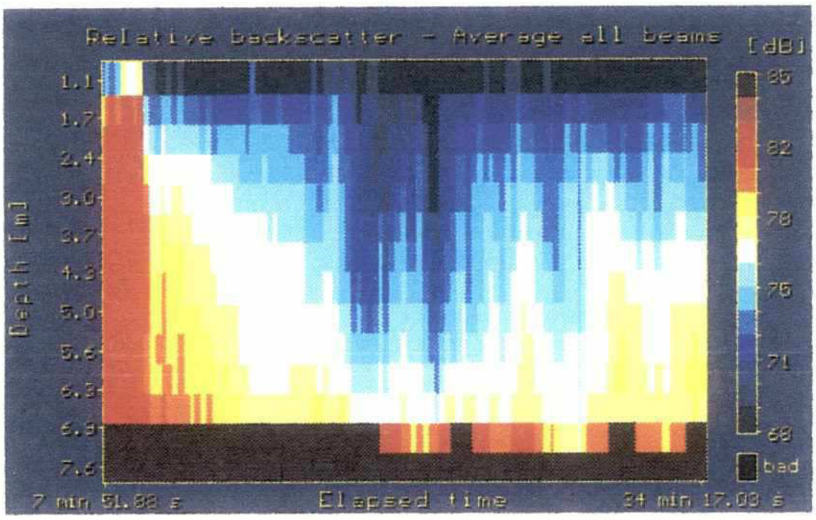

Figure 9. Current speed 27-03, Bhola channel

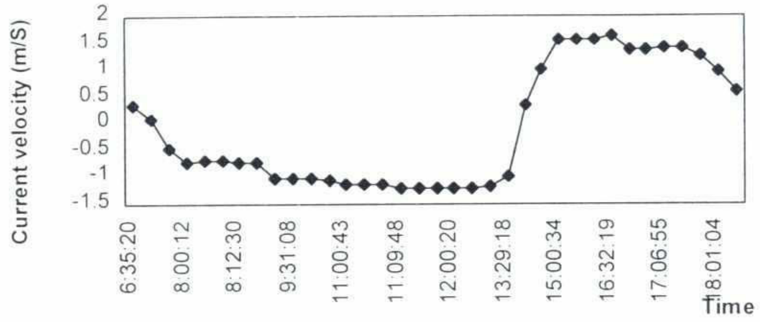

Figure 10. Current speed 28-03, main channel

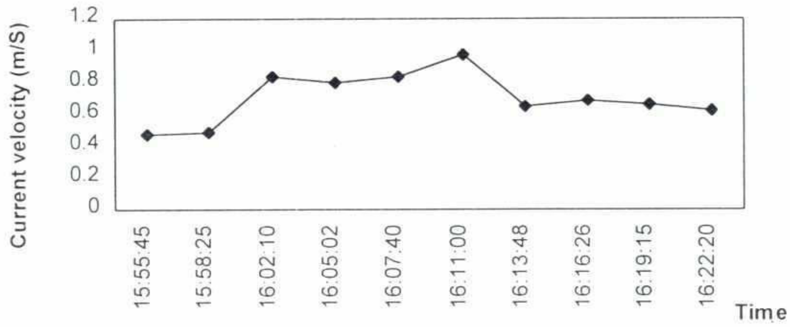

Table 1. ADCP backscatter data and sediment concentrations

			Sed. Conc. <0.063	Sed. Conc. >0.063	Total Sed. Conc.
sample-id	depth	I(dB)	mg/l	mg/l	mg/l
AD1	5.10	76.18	41.73	50.58	92.31
AD2	7.10	74.61	50.58	23.65	74.23
AD3	3.10	69.83	38.24	62.16	100.39
AD4	8.10	69.69	22.12	55.38	77.50
AD5	6.10	65.96	24.23	57.69	81.92
AD6	4.10	65.30	26.92	34.04	60.96
AD7	3.10	64.83	24.81	54.62	79.42
AD8	6.10	67.95	10.20	18.63	28.82
AD9	9.10	74.13	16.92	26.15	43.08
AD10	9.10	78.01	22.88	41.92	64.81
AD11	4.10	69.63	5.10	204.12	209.22
AD12	5.10	69.56	5.58	196.54	202.12
AD13	8.60	78.91	45.38	55.77	101.15
AD14	9.10	79.53	42.40	50.00	92.40
AD15	8.10	78.29	14.62	5.38	20.00
AD16	6.10	70.86	3.27	11.54	14.81
AD17	4.10	74.19	6.47	11.57	18.04
AD18	6.10	73.70	9.80	21.80	31.60
AD19	3.10	79.76	31.35	39.81	71.15
AD20	8.10	78.55	60.00	23.00	83.00
AD21	5.10	80.49	30.00	58.08	88.08
AD22	7.10	78.54	35.47	67.92	103.40
AD23	4.10	81.21	10.96	15.96	26.92
AD24	6.10	79.95	14.04	27.88	41.92
AD25	3.10	79.01	52.31	75.96	128.27
AD26	2.60	78.20	52.35	72.94	125.29
AD27	5.10	76.82	43.27	86.73	130.00
AD28	5.10	76.88	46.92	67.50	114.42
AD29	3.10	73.48	18.40	53.80	72.20
AD30	4.10	72.51	14.81	26.92	41.73
AD31	6.10	71.08	41.73	60.77	102.50
AD32	5.10	73.90	15.38	54.04	69.42
AD33	4.10	73.75	12.12	37.88	50.00
AD34	3.10	75.75	2.60	16.20	18.80
AD35	5.10	71.94	9.81	18.85	28.65
AD36	6.60	82.20	9.42	33.27	42.69
AD37	6.10	81.90	12.88	23.46	36.35
AD38	5.60	78.00	5.88	28.24	34.12
AD39	5.10	76.50	5.19	14.62	19.81
AD40	4.60	73.90	7.50	4.04	11.54
AD41	4.10	73.00	3.27	2.88	6.15
AD42	3.60	74.20	8.04	2.55	10.59
AD43	3.10	72.90	1.73	1.15	2.88
AD44	2.60	71.00	1.15	1.54	2.69
AD45	2.10	68.08	4.71	3.61	8.32