Field measurement of re-suspension in a tailings pond by acoustic and optical backscatter instruments

Laxmi Kant Kachhwal, Ernest K. Yanful
Geotechnical Research Center, The University of Western Ontario, London, ON, Canada
Colin D. Rennie
Department of Civil Engineering, University of Ottawa, Ottawa, ON, Canada

ABSTRACT
Wind induced re-suspension of bed tailings is an important consideration in the design and implementation of water cover technology for reactive tailings management. Field measured acoustic and optical backscatter data were used to obtain suspended solids concentrations in water. Acoustic backscatter data were correlated with suspended solids concentration obtained from two field calibrated optical backscatter sensors. The optical backscatter results showed the re-suspension up to 25 mg/L. The results also showed that the acoustic backscatter data were relatively less sensitive to small variations in the concentrations than optical backscatter data for the range of re-suspension measured in the tailings pond.

RÉSUMÉ
La remise en suspension des résidus miniers par le vent est in facteur important dans la conception de la technologie de couvert d'eau pour la gestion des résidus réactifs. Des données mesurées au champ de rétrodiffusion acoustique et optique ont été utilisées pour obtenir des concentrations de matières solides en suspension dans l'eau. Des données de rétrodiffusion acoustique ont été corrélées avec la concentration de matières solides en suspension obtenu de deux capteurs de rétrodiffusion optique calibrée au champ. Les résultats optique ont montré la remise en suspension jusqu'à 25 mg/L. Aussi les résultants montrent que les données acoustiques ont été relativement mois sensibles à les petites variations dans les concentrations pour résidus en suspension comparé à données optique pour la gamme mesurées dans le bassin de résidus.

1 INTRODUCTION

Reactive mine tailings deposited under shallow water cover are susceptible to erosion, subsequent re-suspension and transportation by wind induced wave and currents. The degree of re-suspension of bed tailings depends on several parameters including wind speed, fetch length, water cover depth, and of bed tailings characteristics. Accurate knowledge of real time suspended solids concentration in the water is required to study the effect of wind induced waves and currents on re-suspension and hence in the management of tailings pond facilities. In a tailings pond, where there is no inflow or outflow, the suspended solids concentration in water can be assumed mainly due to re-suspension of bed material. In this paper two types of backscatter devices, optical and acoustic, were used to measure suspended solids concentration at the Shebandowan tailings pond.

The optical back scatter sensors (OBS) are widely used instruments to monitor the real time re-suspension events in water (Mian and Yanful, 2003; Kachhwal et al. 2010). The OBS sensor is a compact and easy to handle instrument that can make point measurements of optical backscatter intensity in the water at a certain depth. The OBS sensor works on the principle of emission and recollection of back scattered infrared light. The intensity of back scattered light is proportional to the concentration of the suspended solids (scatters) present in the water. The major limitation in using OBS sensor is that it is subject to fouling by the finer particles deposited on the sensor's window through which it emits and receives the infrared light. These sensors cannot be deployed for longer periods unless they are cleaned frequently depending on the field conditions (Gartner, 2002).

The acoustic Doppler current profiler (ADCP) is mostly used to measure current velocity and direction in the water. This instrument work on the principle of emission and recollection of back scattered acoustic (sound) waves and finding the Doppler's shift in the frequency of the emitted and received waves. This shift in the frequency provides the information of current velocity and direction in the water. The ADCP has the potential to be used for measuring the suspended solids concentration in the water. The strength of backscattered signal can be correlated with the concentration of suspended solids also known as scatters; however, the correlation is not straightforward as it is in the case of optical signals of OBS sensors. Once calibrated, the advantage of using ADCP is that it can make measurements in the entire depth of water column for long term without facing the problem of fouling.

Conversion of backscatter results obtained by both OBS and ADCP depends on the characteristics field sediments. Calibration of OBS sensors is simple and straightforward while calibration of ADCP instruments needs much more information. The major difficulty is complex interaction between sediment properties and sound waves. Deines (1999) presented an approach to convert acoustic backscatter data collected in the form of echo intensity into suspended solids concentration using the echo intensity measured at a reference level. It was based on the proportionality between the ratio of echo intensity measured at a particular level to echo intensity at a reference level and logarithm of concentration ratio at those levels. Gartner (2004) presented a similar approach but assumed a linear relationship between the logarithm of concentration and echo intensity. Poerbandono and Mayerle (2003) did a comparative study of the above two approaches and found that Gartner's (2002) approach gives similar results to those given by Deines (1999) and about 88% of data were within a factor of 2 with an average relative error of 31%.

Most of the studies available in literature that shows the conversion of acoustic backscatter into suspended solids concentration are for locations where relatively high concentrations (up to 700 mg/L) were observed, which are much higher than values in tailings ponds (less than 50 mg/L) (Poerbandono and Mayerle 2003; Poerbandono and Mayerle, 2004). In this study an attempt was made to correlate the suspended solids concentrations measured by OBS sensors with acoustic backscatter intensities recorded by a 1200 kHz ADCP for tailings material using Gartner's (2005) approach.

2 METHODS AND MATERIALS

2.1 Study Site and Instruments

The optical and acoustic backscatter data presented in this paper were collected simultaneously on September 19, 2008, at the Shebandowan mine site, located 100 km northwest of Thunder Bay, Ontario, Canada. At this site approximately 85,000 m^3 reactive tailings was deposited under the water cover in a tailings pond of area of approximately 115 ha. The whole tailings pond is divided in three cells by the two wave breaks (dykes) to reduce the wind induced activity in the bottom of the pond. The present study data was collected in the middle cell of the pond as shown in Figure 1. The median grain size of bed tailings in the middle cell varies between 0.0065 to 0.009 mm. The water cover depth in this cell varies from 0.6 m to 3 m.

Two OBS sensors (OBS 3+, Campbell Scientific Canada Corp., AB, Canada) linked to a CR10X datalogger were installed at height of 10 cm and 25 cm above the bed at a fixed location in the pond (Figure 1). These sensors gave output in milivolts and to obtain suspended solids concentration, the sensors were calibrated using field tailings. Calibration was undertaken in the laboratory using middle cell tailings (Kachhwal et al. 2010). The calibration curves for the sensors are presented in Figure 2. The equations of straight lines were used to convert the milivolt output of OBS sensors into the suspended solids concentration. In our previous work, these OBS sensors were found to be very effective in recording episodic events of wind induced re-suspension (Kachhwal et al. 2010).

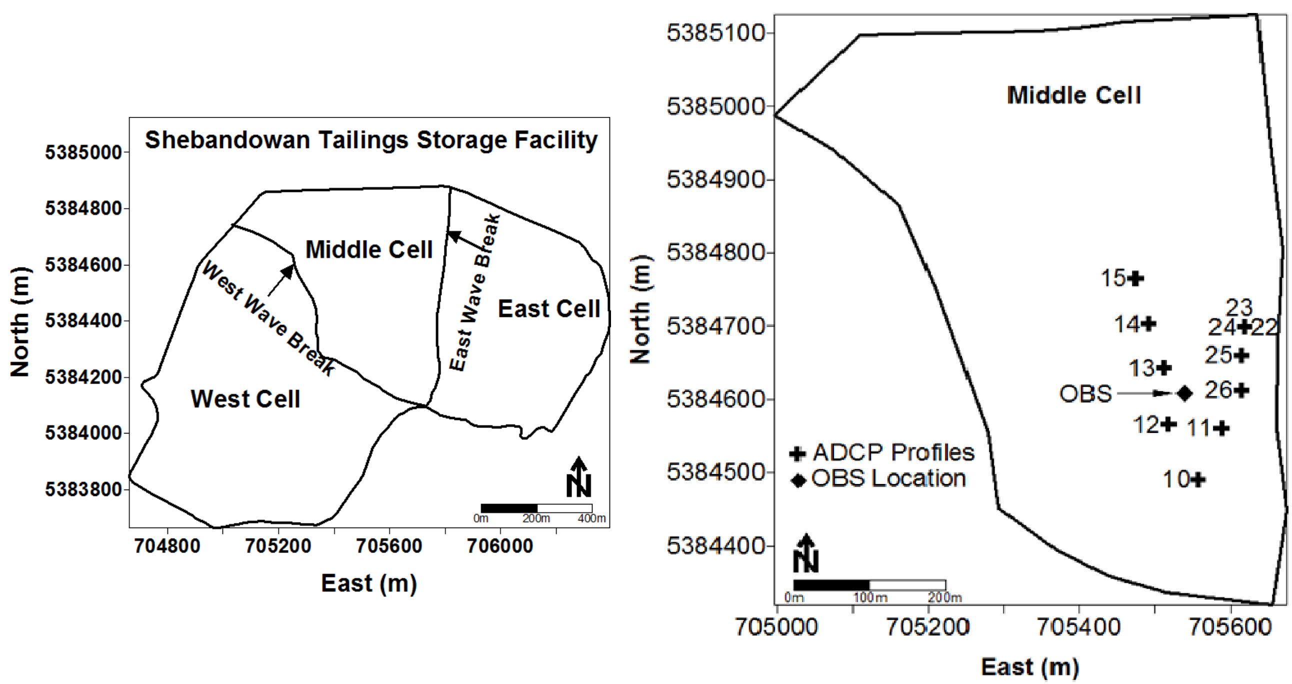

Figure 1. Map of the Shebandowan tailings pond and the middle cell showing the locations of ADCP and OBS data collection points

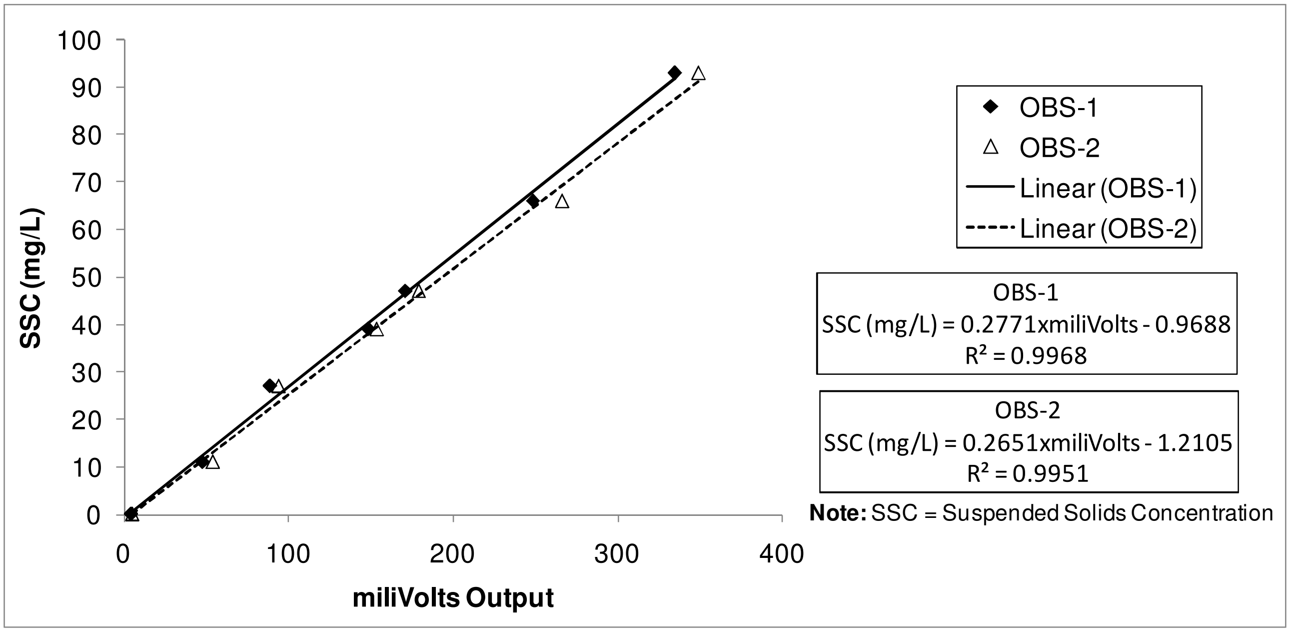

Figure 2. Calibration curves of OBS sensors for the middle cell tailings material (Kachhwal et al. 2010)

A boat mounted 1200 kHz Work Horse Rio Grande ADCP (Teledyne, R D Instruments, CA, USA) was used to record acoustic backscatter and current velocities in the middle cell of the tailings pond. The stationary boat data were collected for about 3 minutes duration at each of the locations in the middle cell as shown in Figure 1. Acoustic backscatter data were collected along three beams in depth cells or bins vertically spaced 5 cm apart, using pulse coherent water mode 11. Average backscatter data of three beams were used in the analysis. In this study acoustic backscatter intensity data of some of the profile locations close to the OBS location were used to calibrate the ADCP for suspended solids concentrations with the help of simultaneous data collected from the calibrated OBS sensors. The locations of both ADCPs and OBS deployment are shown in Figure 1.

2.2 Conversion of Acoustic Backscatter into Resuspension

The ADCP recorded acoustic backscatter can be converted into suspended solids concentration using the famous Sonar equation (Dienes, 1999). The acoustic back scatter intensity recorded by ADCP is a function of the loss of sound energy due to absorption by water and suspended sediments, distance between transducer to the measuring layer, and the strength of emitted signal. Gartner (2002) developed an approach by converting the Sonar equation to a very simplified relationship between echo intensity and suspended solids concentration as given below:

$$10 * Log_{10}(SSC) = A * EI + B \quad [1]$$

$$EI = I * K_c + TL \quad [2]$$

$$TL = 20 * Log_{10}(R) + 2 * \alpha * R \quad [3]$$

Where, SSC is the suspended solids concentration (mg/L) in water; EI is the echo intensity in dB; I is the echo intensity in counts; K_c is the constant used to convert echo intensity from counts to dB ranging from 0.35 to 0.55 with a default value of 0.43; R is slate range or distance from ADCP transducer to the layer being measured; α is total absorption coefficient that included absorption of sound pulse by both water and sediments in re-suspension; Slope A and intercept B will be determined by the regression analysis of possible calibration. The relationship above can be used to measure the re-suspension, once constant A and B are known for the specific ADCP instrument corresponding to the sediment and water conditions of the site under study. Hoitink and Hoekstra (2005) found sound attenuation for suspended solids concentration up to 30 mg/L to be negligible.

3 RESULTS AND DISCUSSIONS

OBS sensors have been successfully used to record episodic re-suspension events in tailings pond in our previous research and results were fairly correlated with on site measured wind conditions (Mian and Yanful

2005; Kachhwal et al. 2010). Simultaneous data obtained from two OBS sensors and on site recorded wind data are shown in Figure 3. Wind conditions on September 19, 2008 were apparently favourable for sending bed tailings into suspension as evident by OBS results. Although wind direction was not along the longest axis of the pond or in the direction of the longest fetch of the water cover, strong winds of up to 9 m/s would have caused some erosion and subsequent re-suspension, as recorded by two OBS sensors. The maximum amount of re-suspension was 18 mg/L for OBS-1 and 25 mg/L for OBS-2. The difference in re-suspended concentration is due to the height of the sensors from the bed. The sensor closer to the bed shows a higher value of re-suspension than the other one. ADCP data collected at different locations, as shown in Figure 1, were processed using the software WinRiver-II (developed by Teledyne, R D Instruments, CA, USA) to obtain time averaged acoustic backscatter data in dB. Figure 4 shows a typical profile of time averaged backscatter data recorded by ADCP at location 11. These backscatter results from all locations were compared with suspended solids concentration measured by OBS sensors using Equation 1. Although ADCP profile locations and OBS location were not exactly the same, they were close enough and the difference in concentrations between these locations at a time was expected to be very minimal. OBS results were available for the two heights 10 cm and 25 cm above the bed. As presented in Table 1, ADCP backscatter data were obtained for the same heights above the bed and also the depth average data.

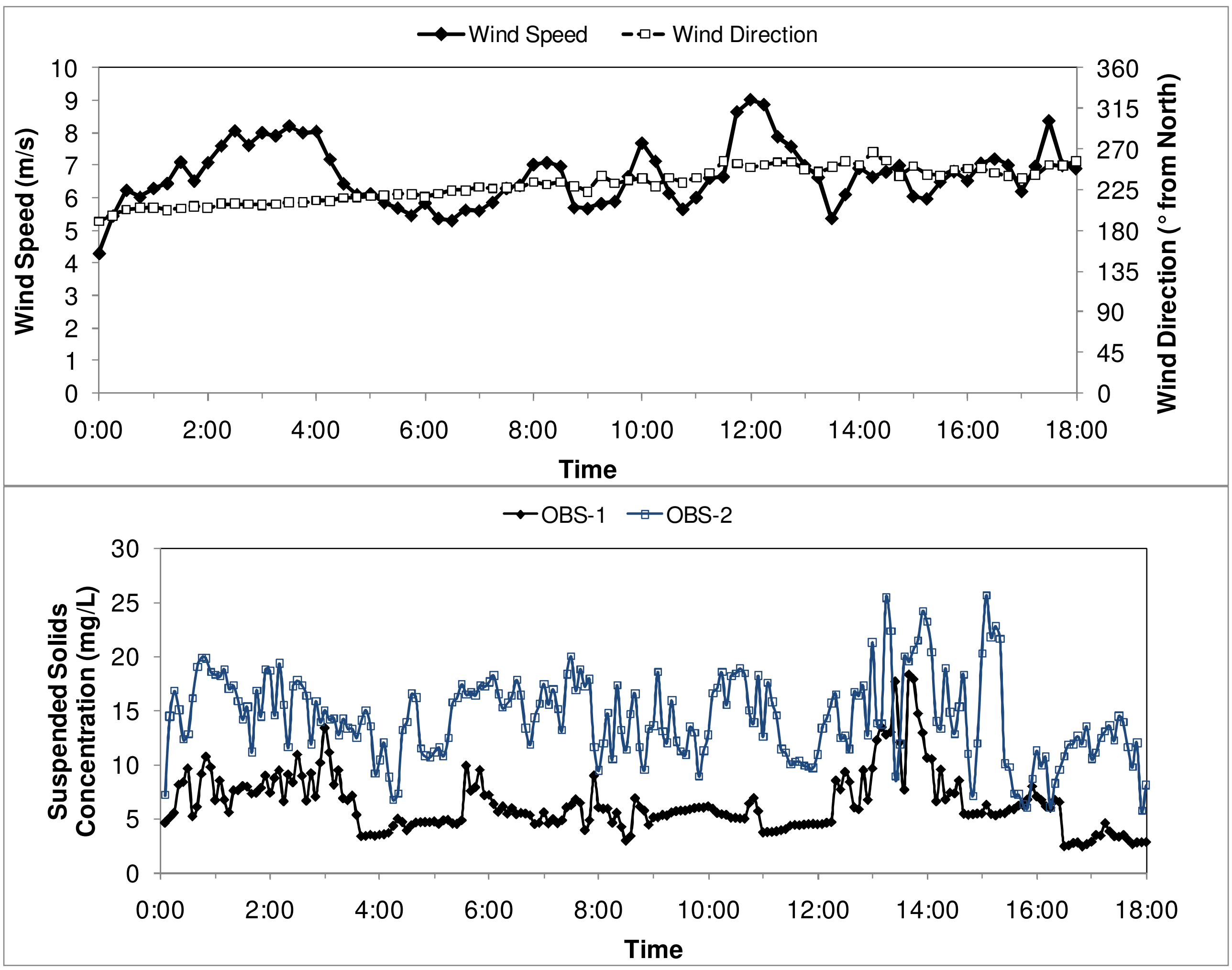

Figure 3. Re-suspended solids concentration recorded by OBS sensors and corresponding wind data on September 19, 2008

Table 1. OBS measured suspended solids concentrations and ADCP recorded acoustic backscatter results

Profile ID	OBS Results (mg/L)		ADCP Backscatter Results (dB)		
	At 10 cm above the bed	At 25 cm above the bed	At 10 cm above the bed	At 25 cm above the bed	Depth Averaged (close to bed)
10	21.8	5.4	81.6	78.35	77.95
11	18	5.3	72.5	71	71.47
12	10.1	5.5	73	70.62	70.86
14	7.3	6.2	70.75	69.1	69.44
15	6.0	6.8	72.92	70.27	69.96
22	22.0	2.5	96.75	89.05	90.95
23	19.7	2.7	96.2	73.47	79.59
24	16.3	2.7	87.18	73.72	78.23
25	12.2	3.3	75.32	70.32	70.29
26	13.9	2.4	72.52	70.95	71.49

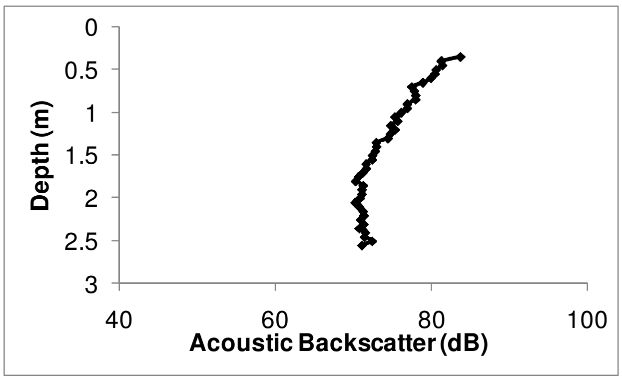

Figure 4. Acoustic backscatter intensity (in dB) profile recorded at location 11 by a 1200 kHz ADCP

Depth averaging was performed close to the bed only or for depth cells located between 5 cm to 25 cm above the bed excluding the last depth cell. Normally, the last depth cell results are influenced by the reflection from bed material and gives relatively high acoustic backscatter intensity which is not representative of suspended solids concentration in water (Poerbandono and Mayerle 2004).

Figures 5 and 6 show the plots of the logarithm of suspended solids concentration multiplied by 10 (10*Log (SSC)) and acoustic backscatter results recorded at 10 cm and 25 cm heights above the bed. The results at the 10 cm height above the bed show a slight linear correlation (R^2 = 0.444) between the data but at 25 cm height above the bed, there was correlation. Acoustic backscatter data collected in the present study was found to be relatively less sensitive to the vertical variation in suspended solids concentration than the optical backscatter data within the range of concentration measured in the tailings pond. A small but relatively improved correlation was found between the depths averaged acoustic backscatter data and average suspended solids concentration as shown in Figure 7.

From the linear regression analysis, the constants A and B can be obtained as 0.1169 and 0.8482 respectively and used further to convert the acoustic backscatter into suspended solids concentrations. Gartner (2004) found these regression parameters quite variable from one location to other.

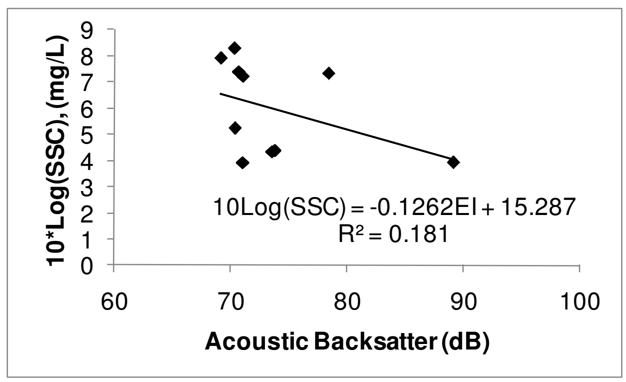

Figure 5. Possible correlation between suspended solids concentration measured by OBS and ADCP backscatter at 25 cm height above the bed

4 CONCLUSIONS

An attempt has been made to correlate ADCP recorded acoustic backscatter data and suspended solids concentration measured by field calibrated optical back scatter (OBS) sensors. The results showed that calculated acoustic backscatter data were less sensitive to variation in suspended solids concentration than the optical backscatter data within the range of concentrations measured in the tailings pond. From these results, it can be concluded that although acoustic backscatter instruments have the potential to measure suspended solids concentration in the entire depth profile, instead of the single point measurements at a specific depth with optical backscatter devices, the latter.

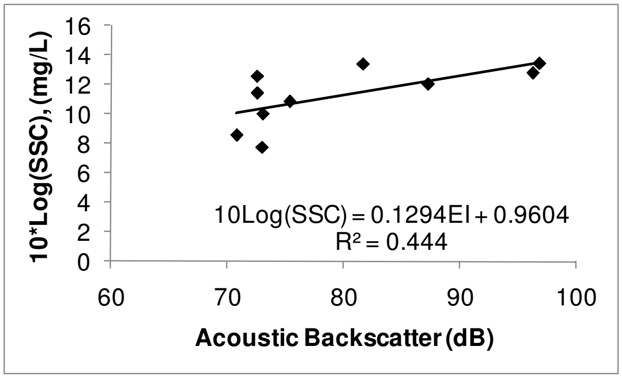

Figure 6. Possible correlation between suspended solids concentration measured by OBS and ADCP backscatter at 10 cm height above the bed

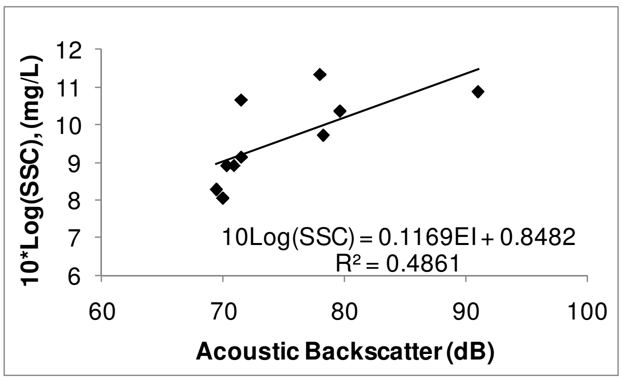

Figure 7. Possible correlation between average suspended solids concentration measured by OBS and depth averaged ADCP backscatter

the optical device was found to be more sensitive and accurate in measuring small variations in suspended solids concentrations, which are mostly observed in tailings pond studies

5. REFERENCES

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