International Meeting on Soil Fertility Land Management and Agroclimatology. Turkey, 2008. p: 1007-1014

Continuous Monitoring of Suspended Sediment in Rivers by Use of New Methods

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ABSTRACT

Traditional sampling methods are restrictive for spatial and temporal monitoring of suspended sediment in river. Application of these methods is simple but labour intensive to collect and process. For this reason, the use of new technological methods has recently gained importance. These methods are commonly based on the scattering of sound or light in water. Acoustic methods involve propagating sound at around the Megahertz frequency range through the water column. Short bursts of high frequency sound are transmitted from a transducer and directed towards the measurement water sample. Sediment in suspension will scatter a part of this sound back to the transducer. Another method, laser scattering, directs a laser beam through the sample of water where particles in suspension will scatter, absorb and reflect the beam. The scattered laser beam is received by a ring detector that allows measurement of the scattering angle of the beam. Particle size and volumetric concentration can be calculated from knowledge of this angle. In addition to these methods, optical turbidimeters supply an estimate for suspended sediment concentration through measuring either the backscatter of the light or the attenuation of a light beam passing through a water sample. In this paper, these methods were presented and advantages and limitations of each were given for comparison.

Keywords: Suspended sediment, Acoustic, Optical sensor, Laser diffraction

INTRODUCTION

Correct measurement of amount of sediment load is crucial in the design and management of water resources projects for determining the economical life of the facilities. The sediment load carried by river may lead to reduction in useful storage of a dam and congestion in water inlet. Transportation of sediment load not only causes decrease in economical life of facilities but also harm agricultural areas. The suspended sediment yield is the main parameter for hydrological studies and has spatial and temporal variability depending on many factors such as the hydraulic characteristic of the stream, geomorphologic conditions of the catchments, and the climatic regime of the area and the presence of vegetation. Measurement of sediment concentration in a river for long term requires taking periodic water samples for laboratory analyses and it is necessary for specific studies to monitor sediment concentration along the entire storm hydrograph to predict loads (Nakato, 1990 ; McBean et al. 1988).

Suspended sediment data from rivers can be measured by different techniques. However, despite many attempts, field data is still limited and will continue to be so because of sheer difficulty in making field measurements. In this paper, acoustic, laser scattering and turbidimetric methods as well as the traditional methods were presented, and advantages and limitations were given for comparison.

Suspended Sediment Measurement Methods

Water Sampling Method

The primary traditional measurement method has been to take periodic water samples for laboratory analyses. Two different sampling methods are used in rivers to determine the suspended sediment. Point integrating samplers are designed to be lowered to a specific depth within the water column. By this means, a time averaged sample is taken that represents a specific point in the water column. Taking a series of measurements at different depths allows an analysis of suspended sediments with height above the bed. Depth integrating samplers are lowered and raised through the entire water column and accumulate a sample which integrates all points, thus giving a sample which reflects the entire content of the water column, but does not indicate the distribution of the contents within the column. The velocity at the entrance of the intake tube should be equal to the local stream velocity for an ideal suspended sediment sampler (ASCE, 1975).

Acoustic Method

The acoustic method is based on the evaluation of the backscatter signal from suspended particles in water and described as an acoustic backscatter system (ABS). This method involves the propagation of sound from 0.5 MHz to 5 MHz through the water column. The high frequency sound beams transmitted from transducers are directed towards the measurement volume. Sediment in suspension scatters a portion of this sound back to the transducer. The strength of the backscattered signal allows the calculation of sediment concentration. The backscatter amplitude depends on the concentration, particle size, and acoustic frequency. (Wren et al., 2002; Thorne et al., 1991; Hay and Sheng, 1992)

Since the acoustic backscatter system is an indirect method of measurement, an inversion algorithm is required for determining of sediment concentration with measured backscattered signal strength. The acoustic backscatter equations provide the basis for the development of such an algorithm. (Clay and Medwin, (1997), Thorne and Meral (2007)). This method has been demonstrated and utilised successfully under laboratory and field conditions by several investigators. Results showed that sediment concentration and particle size can be measured relatively non-intrusive, with high spatial and temporal resolution with acoustic backscatter systems. (Thostenson and Hanes (1998). Thorne et al. (1993))

Commercially available three or four frequency acoustic backscatter systems, such as the AQUAscat developed by the Aquatec Group, contain separate transducers to estimate the mean sediment sizes along the water column. Each transducer operates both as a transmitter and as a receiver (Fig. 1).

Fig 1. An acoustic backscatter system (AQUAscat 1000) with transducers

Laser Scattering Method

In recent years, the application of laser scattering techniques has opened new possibilities for the measurement of sediment concentration and size distribution. The LISST-100 (Laser In Situ Scattering Transmissometry) which is developed by Sequoia Scientific Inc. using the laser scattering technique (Fig. 2), directs a laser beam through a sample of water where particles in suspension will scatter, absorb and reflect the beam. The diffracted laser beam is received by a ring detector that allows measurement of the scattering angle of the beam. Particle size and volumetric concentration can be calculated from knowledge of this angle (Agrawal and Pottsmith 1994, Pedocchi and Garcia 2006).

Gartner et al., 2001 have reported that laboratory and field measurements indicate the potential of the LISST as a powerful research tool for sediment measurement studies and the instrument is capable of determining size distribution and volume concentration within acceptable limits. Traykovski et al. (1999) performed several experiments with natural sediments in the laboratory to compare LISST results to traditional sieving, filtering and weighing techniques. They found the LISST was able to adequately determine the particle volumetric size distribution of two different natural sediments. van Wijgaarden and Roberti (2002) have used LISST for the measurement of the particle size and settling velocity of suspended sediment in calm fresh water and Thonon et al. (2005) have used LISST on river floodplains. Both of these authors report a greatly expanded capacity for the collection of the spatial and temporal variability of suspended sediment in these conditions.

Fig. 2 . The LISST-100 devices for sediment measurement with laser scattering technique

A disadvantage of the LISST instrument is its large size, which causes a significant flow obstruction. Another disadvantage is the design of the LISST laser mount, which is sensitive to impacts that can easily throw it out of alignment. The high energy regime of the surf zone could easily provide impacts of such magnitude (Battisto, 2000).

Turbidimetric Method, TM

Turbidity measurements are being used to generate continuous records of suspended sediment concentration in rivers. Turbidity is described as, 'an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample‘. Turbidity, an index of light scattering by suspended particles, has been widely used as a simple, cheap, instrumental surrogate for suspended sediment that also relates more directly than mass concentration to optical effects of suspended matter (Ziegler, 2002). The Seapoint Turbidity Meter, manufactured by Seapoint Sensors Inc, is a sensor that measures turbidity by detecting scattered light from suspended particles in water (Fig 3). Its small size, very low power requirement, high sensitivity and wide dynamic range allow this sensor to be used in most applications where turbidity or suspended particle concentrations are to be measured.(Seapoint Sensors Inc., 2008)

Fig 3. The Seapoint Turbidity Meter sensor

The use of turbidity values for sediment monitoring generally requires the user to get a statistical relationship between the turbidity and suspended sediment concentration (SSC). This relation is often expressed in a linear regression or a non-linear equation or as a polynomial function (Sun et al., 2001).

Minella et al. 2007 investigated the relationship between suspended sediment concentration and turbidity values with two calibration methods. The first calibration relationship was derived with the turbidity readings during flood events in a river. With the second method, the calibration was based on the readings obtained from the turbidity meter with the probe immersed in samples of known concentration prepared using soils collected from the catchment. They reported that the first calibration method corresponded closely with the conventionally measured sediment concentrations.

Pavanelli and Bigi (2005) reported that the relation of SSC with nephelometric turbidity units (NTU) for high sediment concentrations range is not completely investigated yet. They prepared water samples with 12 different sediment concentrations (1.5 - 30.0 gL^{-1}) for calibration of a turbidimeter and obtained very good correlation between sediment concentration and NTU values.

Besides sediment concentration, the sediment size, colour, and mineral composition have an effect on turbidity value. These effects probably should be calibrated with suspended-sediment samples collected over the range of turbidity conditions at the same time that continuous turbidity measurements are made (Ziegler, 2002). Gravimetric analysis with water sampling is the most reliable tool to estimate SSC and is essential to properly calibrate measurements of the various surrogates in spite of its limitations.(Gray et al., 2002).

DISCUSSION and CONCLUSION

The requirement for monitoring of suspended sediment concentration with temporal and spatial resolution has led to the development of sediment measurement. At the present time many methods exist for the measurement of suspended sediment in water. Four methods are reviewed above; in addition, a summary of the advantages and disadvantages of these methods is given in Table 1.

Table 1. The comparison of different suspended sediment measurement methods

Methods	Advantages	Disadvantages
Water Sampling	1. Simple and cheap method 2. No calibration needed 3. Not sensitive to grain size	1. Labour and time intensive to collect and process 2. Can not sample an "instantaneous" concentration or a time series 3. Difficulties of balance between the velocity entrance of the intake bottle and stream velocity
ABS	1. Can sample a full concentration profile with a single instrument 2. Most non-obtrusive of all sensors 3. More sensitive to larger grain size than fine grain size 4. Multiple frequencies can estimate mean sand size	1. Signal highly susceptible to absorption and scattering by air bubbles 2. Flow depth limitation for shallow rivers 3. Software difficult to learn and data processing labour intensive 4. Expensive when compared to TM
LISST	1. Ability to measure time series of size distribution 2. Can make measurement without calibration 3. Easy to operate commercial software package	1. Large and would cause flow obstruction if deployed underwater 2. Laser mount sensitive to bumps 3. Expensive when compared to TM 4. More difficult to set up and operate than TM
TM	1. Relatively inexpensive 2. Easy to install and operate 3. Relatively insensitive to bubble entrainment because of short signal path length	1.colour, and mineral composition effect on turbidity value 2. Sensitive to grain size 3. Requires calibration for each condition

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