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Review

Continuous measurement of suspended sediment concentration: Technological advancement and future outlook

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ABSTRACT

Sediment affected water resources require frequent and accurate suspended sediment concentration (SSC) data for proper design, operation and management. The traditional method of collecting water samples is inadequate to provide such large amount of SSC data. Recently, the principles based on optics, acoustics, density, electric properties have shown promising results in the direction of providing continuous SSC data. Namely a few technologies, as some are based on turbidity, laser diffraction, acoustic backscatter, are widely applied in field conditions, whereas others are employed under the development phase. The present article focuses on the recent developments of these technologies along with their basic working principle, advantages, limitations, and field applications. Calibration, as an important aspect for these technologies, is also discussed in detail. The review provides a valuable insight for the researchers and professionals by adding fundamental understanding for selecting the most appropriate measurement technology to monitor SSC efficiently and continuously.

Contents

1. Introduction . . . 210
2. Continuous SSC measurement technologies . . . 211
 2.1. Turbidity-based CMT . . . 211
  2.1.1. Principle . . . 211
  2.1.2. Availability and application . . . 213
  2.1.3. Advantages and disadvantages . . . 213
 2.2. Acoustics-based CMT . . . 214
  2.2.1. Principle . . . 214
  2.2.2. Availability and application . . . 215
  2.2.3. Advantages and disadvantages . . . 217
 2.3. Laser diffraction-based CMT . . . 217
  2.3.1. Principle . . . 217
  2.3.2. Availability and application . . . 218
  2.3.3. Advantages and disadvantages . . . 220
 2.4. Pressure difference-based CMT . . . 220

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2.4.1. Principle . . . 220
2.4.2. Availability and application . . . 221
2.4.3. Advantages and disadvantages . . . 221
2.5. Other CMTs . . . 222
2.5.1. Spectral reflectance-based CMT . . . 222
2.5.2. Digital image capturing-based CMT . . . 222
2.5.3. Electrical properties-based CMT . . . 224
2.5.4. Vibrating tubes-based CMT . . . 224
3. Discussions . . . 224
4. Future outlook . . . 225
5. Conclusions . . . 225
References . . . 226

1. Introduction

The process of sediment transport and depositions has wide spread impact on streams, water bodies, and land forms. In the coastal environments, the movement of suspended sediments impact on water quality, biogeochemistry, and morphology [63,4]. The suspended sediment yield from a stream is required to determine fine sediment delivery to whole downstream lowland river basin [46,51]. In hydropower plants, the mitigation of hydro abrasive erosion and reservoir siltation require frequent and high quality suspended sediment data related to the suspended sediment parameters like suspended sediment concentration (SSC), particle size distribution (PSD), shape of particles, and mineral composition [12,13,22]. Hence, sediment management experts require high temporal frequency suspended sediment data to manage coastal engineering applications, water quality and restoration efforts on the aquatic systems effectively.

The high variation of suspended sediment flow makes the measurement of SSC difficult. Traditional SSC monitoring method involves collection of water samples from the study site and measure suspended sediment properties in laboratory. For mountainous catchments and steep slope regions, the sediment yield often occurs rapidly resulting from intense rainfall events [46]. Further, measurement of SSC variations throughout the duration of a storm event, using traditional SSC monitoring method, requires large number of sample [51]. This makes the traditional method of SSC monitoring expensive, labour intensive, and sometimes hazardous due to inaccessible site conditions [34,29]. Due to these limitations of traditional methods, the number of traditional sediment monitoring stations operated by the United States Geological Survey (USGS) has reduced around 75% in number from 1982 to 2008 [29]. Moreover, the process of aggregate formation and its dynamic behaviour is of fundamental importance in the study of dynamics of cohesive suspensions, frequently occurring in fluvial and coastal environments [20]. The flocculated aggregates are very fragile and can be easily broken down, during traditional sampling process or sample handling. Hence, a non-intrusive in situ particle size measurement, which causes minimum disturbance to the sampling volume, is desirable.

In the past 30 years, Continuous Measurement Technologies (CMT) for SSC based on turbidity, acoustics, laser, and pressure difference have advanced rapidly. For continuous SSC and in some cases PSD measurements, CMTs use suspended sediment properties like light scattering, light transmission, laser diffraction, sound attenuation, sound backscatter, conductivity, and density within a sample volume. As this measurement of suspended sediment properties is indirect, Gray and Gartner [29] referred these technologies as "surrogate" technologies. CMTs have capabilities of more frequent and less expensive data collection compared to traditional method. CMTs can significantly reduce the need for frequent sample collection during traditional methods, though it is required for calibration and verification purposes occasionally, because all CMT instruments require periodic calibration to a mean value of SSC in the cross-section of measurement. Gray and Gartner [30] described two such calibrations: instrument-specific calibration and cross-section calibration. The cross-section calibrations are mandatory to adjust the instrument to site conditions.

Though Wren et al. [66], Gray and Gartner [29] and Gray and Gartner [30] reviewed CMTs, the information provided on recent trends in CMTs is still not sufficient and, hence, needs to be updated. Recently laser diffraction-based CMTs found application in floc size determination [57] and were studied in varying PSD environments [54]. Multi-frequency acoustics received greater attention from the research community in applications and new theories have been proposed [62]. CMTs based on spectral reflectance and image capturing showed greater potential as fast developing techniques for continuous SSC measurement.

This review begins with a detailed description of the principle of measurement, availability, recent field applications, advantages and limitations for every CMT. Further, the article summarises the properties of most commonly applied CMTs and recent developments. Finally, the article overviews the potential future outlooks and developments for CMTs. Readers interested in background and historical development of commonly used CMTs are referred to Gray and Gartner [29], work that traces back to the first attempt to measure SSC in Mississippi River in 1838 and that also presents the development of traditional methods.