Methods of measuring suspended sediment

Introduction

Understanding the concentration of suspended sediment in natural waters is important for a wide variety of reasons. The amount of particles in suspension varies both naturally and as a result of human activities such as dredging, mining and forestry. Sediment can impact biological organisms such as corals and can be a method of transport for pollutants. For coastal engineering, understanding the fundamental processes of sediment dynamics is important when considering the impact of scour on offshore structures, or development on natural deposition processes (e.g. beaches). In hydropower stations, sediment can damage turbines, and the changes in hydrodynamics can impact the sediment load downstream. For many disciplines, understanding sediment is critical.

Turbidity is often seen as a proxy for SSC (suspended sediment concentration) – it is easy to measure and uses well known techniques. Turbidity is a measure of the clarity of the water but cannot directly be converted to SSC without in situ samples, as turbidity varies with the size, type and colour of suspended material as well as the concentration.

This article considers a range of technologies available for measuring turbidity and suspended sediment concentration, from the simple Secchi disk, to more complex acoustic suspended sediment profilers.

Visual

A Secchi disk is a simple tool used to give an indication of turbidity. It is a painted disc, typically 30cm in diameter, either white in colour, or with zones of black and white (Figure 1). The user deploys the disc on a piece of rope and measures the depth at which the disk cannot be seen. This depth is known as the Secchi depth and is related to turbidity. A smaller Secchi depth means there is more material in the water attenuating light, which indicates a higher turbidity. A simple formula can be used to relate light attenuation to the Secchi depth.

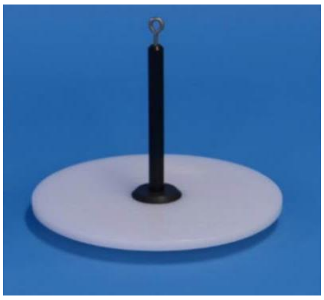

Figure 1: Secchi disk (image courtesy of KC Denmark)

This method is simple, easy to do and does not need expensive equipment. As such, it is ideal for citizen science projects such as the Secchi Dip-In (www.secchidipin.org). However, there are many limitations. The depth itself cannot be directly equated to a turbidity, and will vary with the amount, type and colour of the material in suspension. The depth will also vary with the user, as it relies on vision and manual selection of a stopping point. Surface conditions, such as waves and sunlight, and hydrodynamic conditions, such as strong currents, also have an impact.

Optical backscatter

Optical backscatter is probably the most well-known and commonly used method of measuring turbidity in situ. Optical sensors emit light at a set frequency and then measure the amount scattered back to the sensor. A higher return signal indicates more material in suspension and a higher turbidity. Turbidity itself is measured in dimensionless units, commonly NTU or FTU. The angle at which the backscatter is recorded from varies from instrument to instrument.

Nephelometers typically measure light scattered at 90°, in accordance with standards such as ISO 7027-1:2016 (ISO, 2017). The units of turbidity are usually NTU for these instruments. Other turbidity instruments measure scattered light from a wider range of angles. If Formazin is used for calibration, the units will be in FTU.

The frequency of light used is typically in the region of 880nm. Attenuation and absorption of light at this frequency results in a small volume of water being observed, typically 5 cm from the optical window. This effectively gives a single point measurement.

Optical instruments measure turbidity as a proxy of SSC. As defined in the introduction, turbidity is a measure of the clarity of the water, and varies with the amount, type and colour of suspended material. As such, turbidity cannot be converted to SSC without in situ samples. For example, the same concentration of mud and kaolin will give significantly different turbidity values.

Optical backscatter instruments are popular, as they offer a simple and user-friendly method of measuring turbidity. Turbidity sensors are small and compact, and when combined with data loggers can be deployed in situ for long periods of time, as well as used in high frequency profiling (Figure 2).

Figure 2: AQUA*logger* 310TY – self-contained turbidity logger

Figure 3: Biofouling on an AQUA*logger* 210TY – optical window cleaned by mechanical wiper (image courtesy of Fugro EMU)

Turbidity is a widely accepted proxy for SSC and is itself a regulated parameter for dredging operations, environmental licensing and water/wastewater operations. Turbidity instruments give a single point measurement, but the fact that instruments output turbidity without further processing means that real time data is possible. Optical instruments, although more expensive than Secchi disks, are cost effective and can be calibrated to give defined levels of accuracy and linearity. Depending on the sensor, instruments can also record a wide range of turbidity levels in one instrument, a feature important in the natural environment, where turbidity levels may vary significantly with natural (e.g. rainfall) or anthropogenic (e.g. deforestation or mining) events.

The main limitations of turbidity instruments are the sampling required to convert to SSC and the lack of profiling ability. Depending on the environment, the optical sensors also show sensitivity to biofouling, although many options for prevention exist, including mechanical wipers, copper, UV irradiation and the application of anti-fouling chemicals (Figure 3).

Acoustic backscatter

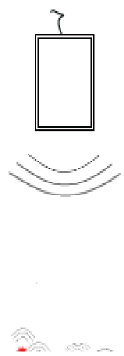

Figure 4: Acoustic backscatter principle

Acoustic backscatter instruments are less well known but provide an alternative method of observing SSC that fills the gaps highlighted by the limitations of optical instruments. Acoustic instruments transmit pulses of sound at set frequencies into the water and recorded the sound signal scattered back. The frequency of sound transmitted is typically between 300 kHz and 5 MHz, and so is attenuated and absorbed to a lesser degree than light. As a result, acoustic instruments can provide profiles of backscatter, rather than single point measurements.

In order to calculate SSC from acoustic backscatter, multiple frequencies of sound are transmitted into the same body of water. The size dependent response from the same sediment particles scattering different frequencies of sound enables the mean particle size and SSC to be calculated for bins along the profile range (Figure 4). This is the principle of operation adopted by the AQUA*scat* acoustic suspended sediment profiler (Figure 5) (more details on the acoustic backscatter method can be found in the article '*Using acoustics to observe suspended sediment concentration*'). As a result, in situ samples are not required to output SSC, although they can be useful for ground-truthing data.

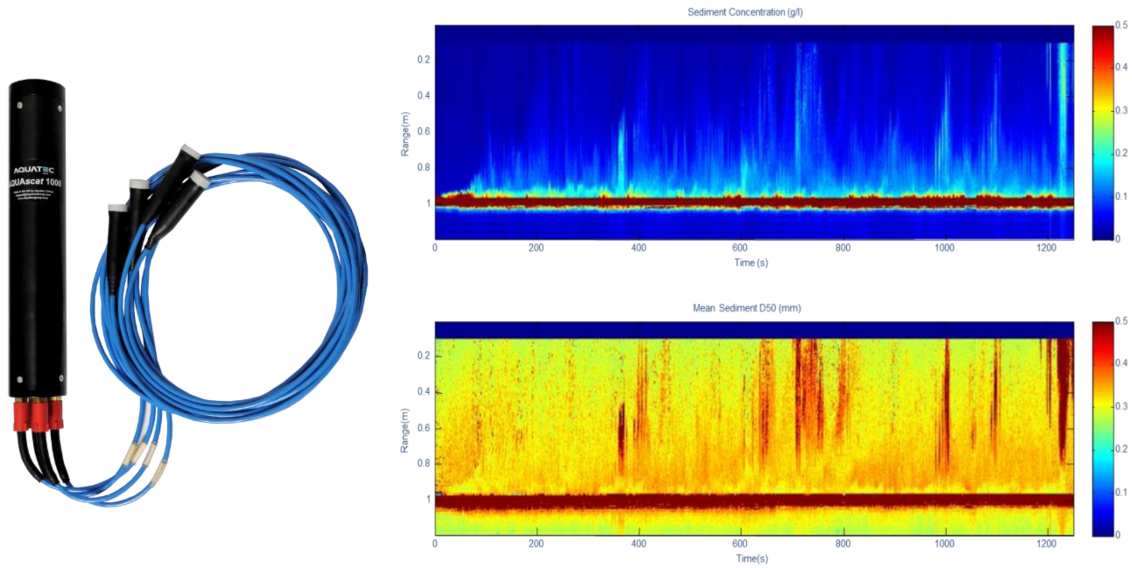

Figure 5: AQUA*scat* instrument and example data

Dedicated sediment profiling instruments such as the AQUA*scat* are designed to record backscatter as their primary function. It is becoming more commonplace to use the backscatter readings from other acoustic instruments such as ADCPs for sediment analysis, although these are often at one frequency and give qualitative information in most circumstances.

In addition to the benefits of profiles rather than single point measurements and a direct calculation of SSC often without samples, acoustic instruments are less susceptible to biofouling. The limitations of these instruments lie in the post-processing required to calculate SSC, which prevents real time data transfer.

Physical sampling

The methods described so far are all in situ observations of SSC and have one common limitation – none of the methods above will tell you what type of material is in suspension. This is where physical sampling can add value. Equipment such as sediment traps and water samplers (Figure 6) capture the sediment from the environment and allow a detailed analysis to take place in the laboratory. It is here that the type and nature of the suspended material can be understood. Physical sampling is often used in conjunction with the other methods, for calibration, validation and enhancement of understanding.

Figure 6: sediment traps and water samplers (images courtesy of KC Denmark)

However, physical sampling is both spatially and temporally limited, and can be highly expensive in both time to take the samples and cost of analysis.

Conclusion

This article has described a full spectrum of technologies and methodologies to observe suspended sediment concentration. Each of the options has strengths and weaknesses, and will be appropriate for different projects. The Secchi disc is simple to use and cost effective, but does not give direct or accurate readings. Optical backscatter instruments use a well-established method, and have flexibility in deployment including real time output, but measure a proxy of SSC and are susceptible to biofouling. Acoustic instruments are less well known, but can give profiles of SSC without samples. Finally, physical sampling can give information on the type of sediment as well as the concentration, but is expensive and limited temporally/spatially. In selecting the most appropriate method for measuring SSC, the goals of the project and the natural processes to be studied should be considered and perhaps more than one technology deployed.

References

ISO. 2017. www.iso.org/standard/62801.html. *Accessed 2nd November 2017.*