Turbidity and Suspended Sediment as Measures of Water Quality

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Turbidity is one of 82 chemical and physical parameters listed by Health Canada in their *Summary of Guidelines for Drinking Water Quality* (Health Canada 2004). Elevated turbidity levels are commonly associated with poor resource extraction practices as sediment from roads or disturbed riparian areas collects in runoff. As a measure of water quality, turbidity is frequently (and sometimes inappropriately) used as an analogue for estimating suspended sediment concentrations.

This article examines the connection between turbidity and sediment, and discusses some problems associated with the quantification of these variables. This article provides a general review of the subject. Data included in this article are cited for illustration only, and therefore detailed methodologies of data collection and analysis are not included.

Defining Turbidity

Turbidity is a measure of the cloudiness of a liquid and is usually quantified in nephelometric turbidity units (NTUs). Either organic matter, such as algae, or inorganic particles, like silt, can cause turbidity. Generally, water colour is not a good indicator of turbidity as dissolved compounds such as tannins can cause the water to appear dark without influencing its cloudiness. Turbidity is usually measured by passing a beam of light through a water sample and quantifying the scattering of the photons. Using these methods, turbidity can be measured very accurately in the laboratory (e.g., to within 0.1 NTU) or with less precision under field conditions (Figure 1).

High turbidity levels can degrade the quality of drinking water by reducing the effectiveness of water-disinfection treatments, as the particles that cause turbidity are also vectors for pathogens. These particles can also shield pathogens from chemical treatments such as chlorination and from physical treatments such as ultraviolet irradiation. Health Canada has established guidelines limiting the amount of turbidity in potable water. These guidelines set 1 NTU as the maximum acceptable concentration for water entering a distribution system. Since water containing greater than 5 NTUs appears cloudy to the human eye, this value is commonly used as an aesthetic objective for water at the point of consumption (i.e., at the tap). British Columbia provincial guidelines consider 5 NTUs to be an acceptable level if it can be demonstrated that disinfection treatments are effective (BC Ministry of Environment, Lands and Parks 1997).

High turbidity values can also be associated with conditions that are harmful to fish. For example, particles in the water may irritate fish gills. In response to these stimuli, the gills produce a mucus-like substance that reduces the capacity of the membrane to exchange gases and causes stress to the fish. Furthermore, when these particles are deposited on the streambed, they may cover spawning beds or sources of fish food such as benthic invertebrates. Establishing guidelines for aquatic life is more difficult as their susceptibility varies according to species, life-cycle stage, and the natural background turbidity levels of the water body. The BC Ministry of Environment, Lands and Parks (1997) has established turbidity

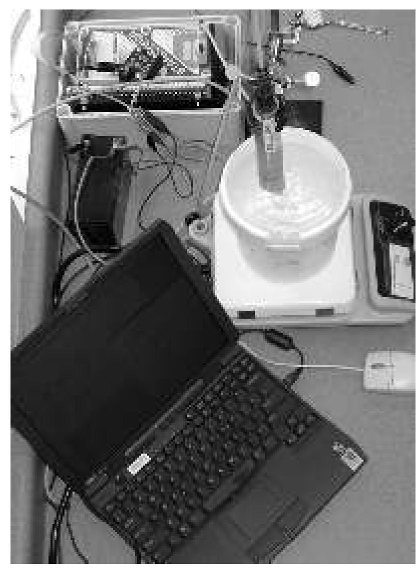

Figure 1. Left: A turbidity sensor installed in a natural stream channel. The OBS-3 probe was originally installed to specifications (D&A Instrument Company 1993), but a peak flow event changed the channel (as shown) and subsequently forced the relocation of this station. Right: An Analite 9500 turbidity probe set up a laboratory. This brand of probe has a smaller "viewing window," which enables it to measure turbidity in a more confined environment.

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guidelines for aquatic life. For example, the guidelines stipulate that under conditions of clear flows (i.e., where the suspended sediment concentration is less than 25 mg/L) induced turbidity should not be greater than 8 NTUs above the background level as measured in hourly samples collected over 24 hours. Other similar objectives have been established for longer periods and for watercourses with higher natural background turbidity levels.

Turbidity versus Sediment

Turbidity and sediment are not the same. Sediment refers to particulate matter moved by water and is typically measured as a ratio of these two components (e.g., milligrams of particulate matter to litres of water). Sediment is commonly divided into two groups: suspended sediment and bed load, which is also referred to as benthic sediment.

The size of the particulate matter in suspended sediment varies in proportion to the energy of the stream. Particles greater than 50 µm (i.e., sand) will fall out of the water column in seconds once the water is calmed. Silt-sized particles (50–2 µm) can remain in suspension for minutes in still water, while clay-sized particles (< 2 µm) can remain in suspension indefinitely.

Bed load usually refers to coarse sand and gravel-sized particles. This material is moved downstream by rolling or sliding along the bottom. It can also be transported through a form of movement called saltation, where particles skip or bounce by momentarily being pushed into the lower portion of the water column and then fall out again within a few seconds. Transportation of coarse sand and gravel requires higher stream energies and, as such, are usually associated with peak-flow events or high-gradient streams.

Quantifying the amount of sediment in streams involves both field collection and laboratory procedures. Grab samples of suspended sediment can be collected either manually or with an automated system. The samples are then taken to the laboratory where the particles are removed by filtering and, after drying, the mass of the captured particles is determined on an accurate scale. Due to the variability of suspended sediment in natural watercourses, however, the grab sample approach may not provide a representative sample of the average or peak sediment concentration.

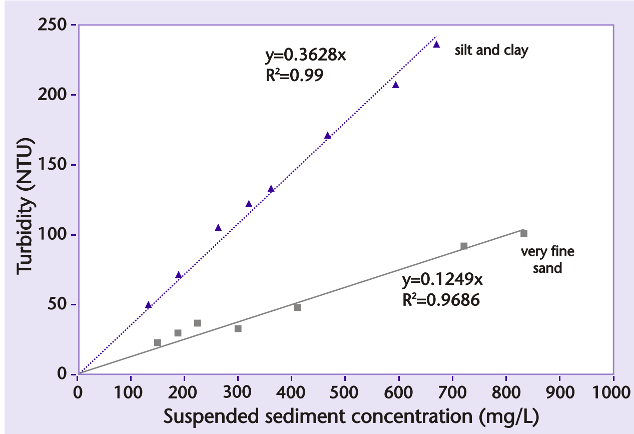

***Figure 2.** The dashed line represents the regression equation for a stream bank sediment sample that was sieved to eliminate particles greater than 53 µm. The solid line was derived for the same sample but for particles between 125 and 53 µm.*

Developing a Relationship between Sediment and Turbidity

To obtain a more complete understanding of the sediment regime of natural watercourses, researchers have tried to establish a relationship between suspended sediment and turbidity (e.g., Jordan 1996; Hudson 2001a, 2001b). The relationship between these two variables is determined by measuring the turbidity of the grab samples at various suspended sediment concentrations and then applying this relationship to a data set of continuous turbidity measurements. For example, at 10:56 the data logger records a turbidity measurement of 100 NTUs and triggers the auto sampler to collect a grab sample. This water sample is then analyzed in the laboratory to determine the amount of suspended sediment it contains (in milligrams per litre), and this value is plotted against the recorded turbidity reading.

Once this procedure has been repeated several times over the entire range of turbidity values recorded by the data logger, the suspended sediment/turbidity relationship can be expressed using a linear function (Figures 2 and 3) and applied to all of the data collected at the specific site. Maintaining the integrity of the suspended sediment/turbidity relationship, however, is difficult as the turbidity of a sample is not only influenced by its suspended sediment concentration but also by the size of the particles (Figure 2).

The suspended sediment/turbidity relationship is not explicitly transferable between watersheds.

The shape and composition of the particles also affect the turbidity of a sample. Figure 3 shows the regression lines of two different stream-bank samples (i.e., fluvial deposits) of very fine sand (i.e., particle sizes between 125 and 53 µm). The line with the greater slope was obtained from samples collected from Chinukundl Creek on the east side of Graham Island while the other sample was collected approximately 30 km to the west in Gregory Creek. The divergent slopes would tend to indicate that different geological origins and (or) processes are

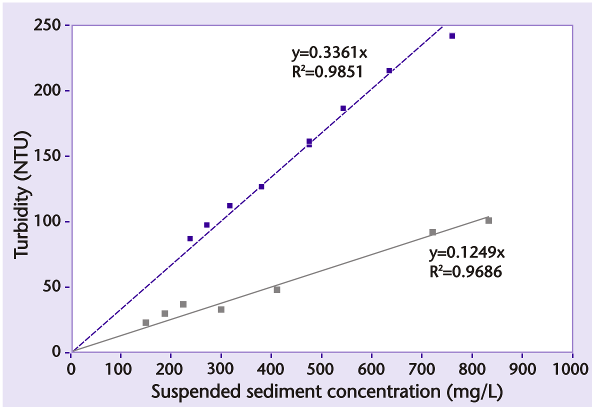

Figure 3. These two suspended sediment/turbidity relationships were developed using the same particle size category (i.e., very fine sand) but were collected from different watersheds. The disparity in turbidity for a given suspended sediment concentration may be attributable to differences in the shape of the particles or the composition of the parent material.

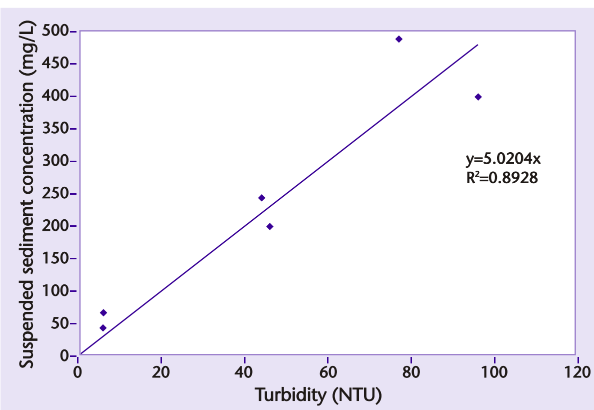

Figure 4. This suspended sediment/turbidity relationship is being developed for a study currently underway in the Queen Charlotte Islands. Note that the R^2 of 0.8928 is less than the value obtained for the similar relationships depicted in Figures 2 and 3, which were developed under idealized laboratory conditions. Before this function can be applied to the turbidity data, many more suspended sediment samples will have to be collected and analyzed.

responsible for sediment generation within the two watersheds. Unfortunately, it also means that the suspended sediment/turbidity relationship is not explicitly transferable between watersheds.

Furthermore, a specific suspended sediment/turbidity relationship may not even be valid over extended temporal intervals as the origins and proportions of sediment can change quickly during runoff. This problem can be further amplified by the hysteresis effect, in which finer particles are more prominent on the rising limb of the hydrograph than they are on the recessional limb (Macdonald et al. 2003).

In reality, the close relationship between suspended sediment and turbidity as developed in the laboratory and depicted in Figures 2 and 3 is never realized with data collected in the field (Figure 4). Sources of error, such as algal growth on the optical components of the turbidity probe, air bubbles in the water column, changes in the composition of the suspended sediment, and variations in ambient light due to changing water levels, tend to corrupt the data. The use of turbidity as an indicator of suspended sediment can produce quality information, but often requires a large investment in instrumentation and much diligence from the investigator.

Summary

Although turbidity is a measure of water quality in itself, the causes of turbidity are more difficult to quantify. Furthermore, turbidity is usually the result of natural erosion processes. Therefore, using this measure as an indicator of the impacts of resource extraction is problematic. Nevertheless, measuring turbidity in conjunction with suspended sediment is likely to give a more comprehensive understanding of the factors affecting water quality than could be derived by the examination of either of these measures in isolation.

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