ISSUES RELATED TO USE OF TURBIDITY MEASUREMENTS AS A SURROGATE FOR SUSPENDED SEDIMENT

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ABSTRACT

This abstract summarizes issues related to the use of turbidity measurements as a surrogate for suspended sediment. Issues discussed are: (1) methods used for measurement, (2) wavelength of light, (3) detector orientation, (4) standards for calibration, (5) grain-size and color effects, and (6) data reporting.

Turbidity Definition and Methods: Turbidity can be defined as a decrease in the transparency of a solution due to the presence of suspended and some dissolved substances, which causes incident light to be scattered, reflected, and attenuated rather than transmitted in straight lines; the higher the intensity of the scattered or attenuated light, the higher the value of turbidity. Turbidity can be expressed in nephelometric turbidity units (NTU). Depending on the method used, the turbidity units as NTU can be defined as the intensity of light at a specified wavelength scattered or attenuated by suspended particles or absorbed at a method-specified angle, usually 90 degrees, from the path of the incident light compared to a synthetic chemically prepared standard.

Currently approved methods for use by USGS include USEPA Method 180.1, (U.S. Environmental Protection Agency, 1979), ISO 7027 (International Organization for Standardization, 1999), GLI Method 2 (Great Lakes Instruments, Inc., 1992), ASTM Method (American Society for Testing of Materials, 2000), and Standard Methods (SM) (Clesceri and others, 1998). ASTM and SM methods are similar to USEPA Method 180.1 and are not discussed here. Because results from these methods typically are all reported in NTU, it is important that the method of measurement and type of instrument be identified when storing or reporting the data.

Discussion: As shown in table 1, turbidity methods, standards, reporting of units, and instruments are not identical. For each applicable method, the range in turbidity measurements does not cover all values for natural water. Because turbidity is an apparent optical property of water, it is likely that dilution of samples would not result in a physically reproducible measurement (Davies-Colleys and Smith, 2001). Light wavelengths are different, and color can affect the measurements. Different instruments may use forward or backscatter detection devices and multiple incident light sources and detection devices at different orientations that can compensate for the effects of color and grain size (Sadar, 1998). The detector-orientation measurement angles can be wide (USEPA Method 180.1) or narrow (ISO 7027). Therefore, measurements of the same water by different methods and different instruments are not likely to yield similar values.

Table 1.—Comparison of selected turbidity methods.
[NTU, nephelometric turbidity units; FTU, formazin $(C_2H_4N_2)_n$ turbidity units; FAU, formazin attenuation units; nm, nanometers; cm, centimeters]

Characteristic	**USEPA Method 180.1 (nonratio mode)**	**ISO Method 7027 (diffuse radiation)**	**ISO Method 7027 (attenuated radiation)**	**GLI Method 2**
Use of data	Drinking water	Drinking water	Wastewater	Drinking water
Range of method	0-40 NTU (dilution permitted)	0-40 FTU (diluted permitted)	40-4,000 FAU	0-40 NTU (dilution permitted)
Light source	Tungsten Lamp	Photodiode	Photodiode	Photodiode
Wavelength	400-600 nm,	860 nm	860 nm	860 nm
Spectral bandwidth	Not specified	60 nm	60 nm	60nm
Detector orientation measurement angle	90+/-30 degrees	90 +/-2.5 degrees	90 +/- 2.5 degrees	Two sources, two detectors at 90 +/- 2.5 degrees
Aperture angle	Not specified	20-30 degrees	20-30 degrees	unknown
Path length	Less than 10 cm	Less than 10 cm	Less than 10 cm	Less than 10 cm
Primary standard	Formazin polymer	Formazin polymer	Formazin polymer	Formazin polymer
Secondary standards	Polymer microspheres	Polymer microspheres	Polymer microspheres, cubes, or filaments	Polymer microspheres

Primary formazin standards can be unstable and have a wide variability in particle size and accompanying light-scattering characteristics (Papacosta, 2002). Secondary standards using other polymers may have a more defined (0.02 to 0.2 micron) size range, but can have different instrument and manufacturer response readings relative to formazin (Papacosta, 2002). The nephelometric design, with a detector at 90 degrees, is optimized for particle sizes of 1.0 micron or less (Papacaosta, 2002), which is much smaller than possible particles sizes of sediment.

The color of water can cause a negative bias in measurements by attenuating the light in colored samples using USEPA Method 180.l. The color of the darkened (more “black” colored using Munsell soil charts) sediment particles has been shown to substantially affect measurements with optical backscatter meters, and it is expected that nephelometers would give a similar negative bias in measurements depending on the mineralogy of the sediment (Sutherland and others, 2000). All nephelometers can be affected by the grain size and orientation of the sediment in a sample (Sadar, 1998).

Storage of turbidity data and comparability of measurements are concerns, especially when developing a relation with suspended sediment. Because instruments of widely different configurations, methods, and potential color effects are used and commonly report in NTU, it is not likely they will yield similar turbidity values. However, the ability to measure turbidity continuously and to relate these measurements to suspended sediment and sediment-associated constituents, such as fecal coliform bacteria (Christensen and others, 2000), is a valuable tool in describing transport of these constituents.

Research and standard protocols are needed in the following areas in order to improve the use of turbidity as a reliable surrogate for suspended sediment:

(1) Data storage needs to identify the method and instrument used. A suggested reporting convention would include the method, light wavelength, detector orientation, and number of sources and detectors. Data possibly could be reported as a beam attenuation coefficient value rather than relative to an arbitrary standard of formazin.

(2) The effects of grain size, color, and mineral composition need to be defined and documented. These effects probably can be calibrated with suspended-sediment samples collected over the range in turbidity conditions at the same time that continuous turbidity measurements are made.

(3) A priority should be given by standard organizations to approve a reproducible method and instrument design that will provide reliable readings for different water types—drinking water, natural water, and wastewater. A draft certification program for continuous turbidity monitors written by the United Kingdom Environment Agency (2001) is under review to improve instrument/method comparability.

(4) Comparisons need to be done between different turbidity meters and methods and samples collected and analyzed for suspended-sediment concentration and grain size.

REFERENCES

American Society for Testing and Materials, 2000, Annual Book of ASTM Standards, v.11.01, part 31, Water, Standard D1899-00. Philadelphia, American Society for Testing and Materials, pp. 179-184.

Christensen, V.G., Jian, Xiaodong, Ziegler, A.C., 2000, Regression Analysis and Real-Time Water-Quality Monitoring to Estimate Constituent Concentrations, Loads, and Yields in the Little Arkansas River, South-Central Kansas, 1995-99. U.S. Geological Survey Water-Resources Investigations Report 00-4126, 36 pp.

Clesceri, L.S., Eaton, A.D., Greenberg, A.E., (editors), 1998, Standard Methods for the Examination of Water and Wastewater (20th ed.). American Waterworks Association and Water Environment Federation, 2-8 and 2-9, 1200 pp.

Davies-Colley, R.J., Smith, D.G., 2001, Turbidity, Suspended Sediment, and Water Clarity-- A Review. Journal of American Water Resources Association 37 (5), pp. 1085-1101.

Great Lakes Instruments, Inc., 1992, Turbidity Measurement. Milwaukee, WI, Technical Bulletin Number T1 rev 2-193, 7 pp.

International Organization for Standardization (ISO), 1999, Water Quality-Determination of Turbidity, Method 7027. 18 pp.

Omega Engineering, 2001, Turbidity Measurement. accessed March 8, 2001, at URL www.omega.com/techref/ph-6.html

Papacosta, K., 2002, Turbidity Calibration From Another Perspective. accessed March 25, 2002, at URL www.apsstd.com/brochure/pointsoffact2.html.

Sadar, M.J., 1998, Turbidity Science. HACH, Technical Information Series-Booklet No. 11, 26 pp., accessed March 25, 2002, at URL www.hach.com/ASP/categories.asp.

Sutherland, T.F., Lane, P.M., Amos, C.L., Downing, J., 2000, The Calibration of Optical Backscatter Sensors for Suspended Sediment of Varying Darkness Levels. Marine Geology, 162, pp.587-597.

U.S. Environmental Protection Agency, 1979, Methods for Chemical Analysis of Water and Wastes. 600/4/79/020, 180.1-1 to 180.1-3.

United Kingdom Environment Agency, 2001, Specification of MCERTS Performance Standards and Conformity Testing Procedures. Accessed January 15, 2002, at URL www.environment-agency.gov.uk/commondata/105385/turbidity.pdf