CLARIFYING TURBIDITY — THE POTENTIAL AND LIMITATIONS OF TURBIDITY AS A SURROGATE FOR WATER-QUALITY MONITORING

Paul D. Ankcorn

AUTHOR: Hydrologist, U.S. Geological Survey, 3039 Amwiler Road, Suite 130, Peachtree Business Center, Atlanta, Georgia 30360-2824.
REFERENCE: *Proceedings of the 2003 Georgia Water Resources Conference*, held April 23–24, 2003, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia.

Abstract. The U.S. Geological Survey has several ongoing projects throughout the Nation that use continuous monitoring of instream turbidity to develop estimates of water quality. The recent development of several *in situ* sensors has made it possible to continuously monitor turbidity in "real time." The statistical relations between turbidity and certain sediment or sediment-bound, water-quality constituents have made it possible to provide a "real-time" estimate of concentrations of certain water-quality constituents such as total suspended solids, suspended sediment concentration, various nutrients, and bacteria.

Continuously monitored instream turbidity may provide more accurate concentration predictions than traditional surrogates such as discharge; however, there are many issues and limitations regarding turbidity. These include: (1) different methods and technologies used to measure turbidity, (2) effects that physical properties of the solids and streamwater have on the measurement of turbidity, and (3) the best deployment strategy for measuring instream turbidity.

This paper summarizes the potential and limitations of turbidity as a water-quality surrogate including selected methods and technologies for measuring turbidity, factors that affect turbidity readings, and some of the issues encountered when monitoring instream turbidity. The paper also presents some of the preliminary relations between turbidity and water-quality constituent concentrations for data collected in Gwinnett County, Georgia.

INTRODUCTION

The recent development of several *in situ* sensors has made it possible to continuously monitor turbidity in "real time." The statistical relations between turbidity and certain sediment or sediment-bound, water-quality constituents have made it possible to provide a real-time estimate of concentrations of certain water-quality constituents such as total suspended solids (TSS), suspended sediment concentration (SSC), various nutrients, and bacteria. In Oregon, continuous turbidity data are being used to estimate suspended sediment loads in the North Santiam River Basin. In Georgia, in addition to operating the largest turbidity-monitoring program in the Metropolitan Atlanta area, the U.S. Geological Survey (USGS), in cooperation the National Park Service (NPS), is using real-time turbidity to estimate fecal coliform bacteria concentrations in the Chattahoochee River. These real-time estimates are posted on the World Wide Web at URL: http://ga2.er.usgs.gov/bacteria/. There is a need to find a surrogate for continuous monitoring of water-quality conditions because traditional sampling techniques often are labor intensive and costly; data collection can be potentially unsafe during runoff events; and, most importantly, there typically can be long time delays between sample collection, chemical analysis, and the posting of results. In addition, concentrations of water-quality constituents generally vary during runoff events; and traditional techniques that provide water-quality constituent concentrations, such as discharge for sediment flux, may not be representative of the overall runoff hydrograph. Turbidity monitoring provides a more "direct view" of conditions within a stream and, when calibrated to the cross section during hydrologic events, may indicate changing conditions that could otherwise go undetected. There are many unresolved issues, however, concerning the collection of turbidity data. For example, different measurement methods may not give comparable results, and the instrumentation and methods are not standardized. Additionally, the physical properties such as size, shape, and color of the suspended solids may bias the turbidity reading. Finally, it is important to develop an equipment-deployment strategy so that instream turbidity data accurately reflect stream conditions. This paper addresses some of these turbidity issues and presents some preliminary findings on the relation between turbidity and selected water-quality properties from data collected by the USGS in Gwinnett County, Georgia.

LIMITATIONS

Units and Methods of Measuring Turbidity

Turbidity is a measure of the collective optical properties of a water sample that cause light to be scattered and absorbed rather than transmitted in straight lines. The higher the concentration of suspended particles, the higher the scattering and absorbance of light, and thus, the higher the turbidity value of the water sample. Primary contributors to turbidity include clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, plankton, and microscopic organisms (American Public Health Association and others, 1998). Turbidity can be reported in nephelometric turbidity units (NTU), Formazin turbidity units (FTU), or Formazin attenuation units (FAU)—depending on the technology or method used. All of these units are derived from and are traceable to the primary standard Formazin polymer. A standard, in this sense, is a solution of known value that can be used to adjust the instrument to read the known value. All standards are traceable through a system of lot numbers. Currently, depending on the particular application, the USGS has approved the following methods for measuring turbidity: USEPA method 180.1 (U.S. Environmental Protection Agency, 1979), ISO 7027 (International Organization for Standardization, 1999), and GLI method 2 (Great Lakes Instruments, Inc., 1992). If the turbidity measurement is used for U.S. regulatory purposes, then only USEPA method 180.1 is approved. Various turbidity methods and differences among them are listed in Table 1. Also note that the turbidity range for each method does not span the range of turbidity commonly measured in the field.

Issues that Affect Turbidity Measurements

The methods listed in Table 1 vary in many aspects. One of the primary differences is the reporting units, which is a concern because of comparability (i.e., NTU may not be equal to FTU or FAU). Although all units are derived from a Formazin standard, the different methods result in different turbidity values for a given sample. The methods also differ in the wavelength of the incident light source, which may cause variance in turbidity due to the effect of the color of the particles in the water sample. In addition, the location and number of detecting elements may vary from method to method. The compounding result is that different methods/instrumentation used to measure turbidity will yield different turbidity results. Also, the properties of particles in the sample—such as color, shape, and size distribution—may impact turbidity readings. "Turbidity is not directly related to particular types of particles or their respective shapes" (Sadar, 2002a). The Hach Company found that samples containing particles that strongly absorb incident light, such as organic material, will prevent a significant portion of incident light from reaching the detecting system and, therefore, result in an artificially low turbidity value (Sadar, 2002b). At wavelengths of 850 nanometer (nm) or greater however, light absorption caused by naturally occurring color may not affect turbidity readings (e.g., Pavelich, 2002). The Hach Company also found that light scatter depends on the size of the particle and the wavelength of the incident light source; large particles scatter long wavelengths more effectively than short wavelengths; therefore, the amount of light scatter, depends greatly on the wavelength of the source (Sadar, 2002b). The different methods and technologies used to

Table 1. Comparison of selected turbidity methods

[USEPA, U.S. Environmental Protection Agency; ISO, International Organization for Standardization; GLI, Great Lakes Instruments, Inc.; NTU, nephelometric turbidity units; FTU, Formazin turbidity units; FAU, Formazin attenuation units; nm, namometer; cm, centimeter]

	USEPA Method 180.1	ISO Method 7027 (diffuse radiation)	ISO Method 7027 (attenuated radiation)	GLI Method 2
Water-quality criteria	Drinking water	Drinking water	Wastewater	Drinking water
Unit and range of method	0–40 NTU (dilution permitted)	0–40 FTU (dilution permitted)	40–4,000 FAU	0–40 NTU (dilution permitted)
Incident light source	Tungsten lamp	Photodiode	Photodiode	Photodiode
Wavelength	400–600 nm	860 nm +/-30nm	860 nm +/-30 nm	860 nm
Angle of detector	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 or polymer microspheres	Formazin polymer	Formazin polymer	Formazin polymer
Secondary standard	Polymer microspheres	Polymer microspheres	Polymer microspheres, cubes, or filaments	Polymer microspheres

Based on Ziegler, 2002.

measure turbidity indicate that turbidity is not an absolute value, but a relative value representing a qualitative measurement that can yield different readings based on the method used.

Deployment Strategies

Whatever instrumentation or method is used to continuously monitor turbidity, a sonde deployment strategy should be implemented to ensure that the measured turbidity reflects actual conditions within a stream reach. In Georgia, the USGS uses the following strategy for deploying continuous turbidity sensors.

- The turbidity sensor should be located where mixing of the stream is adequate and where the position of the *in situ* sonde is representative of the entire cross section at low, medium, and high flow. Cross-sectional measurements should be made regularly to ensure that the location is representative of the stream cross section.

- The streamflow velocity should be sufficient to flush the sonde, thereby reducing the fouling caused by debris. Debris trapped by the sensor can cause artificially high turbidity readings.

- The installation design should ensure that the sonde can be safely serviced/retrieved at all ranges of stage.

- The sonde should be adequately protected during high flow. The sonde can be encased in a housing that will not affect the measurement but will protect the sonde from fouling by debris during high flows.

- The sonde should be at proper depth for accurate turbidity measurements during low flow and should be located far enough above the bottom of the streambed to minimize the negative effects of suspended bedload on the turbidity measurements during high flow.

If the above conditions are met, then turbidity sensor readings likely will be representative of the stream cross section across a wide range of flow conditions.

POTENTIAL OF TURBIDITY AS A WATER-QUALITY SURROGATE

Studies, such as the one conducted by the USGS in Oregon, have illustrated how continuous turbidity monitoring can provide a more accurate estimate of suspended-sediment concentration than discharge. The relation between turbidity and suspended-sediment concentration at two streams in Gwinnett County, Georgia, where turbidity is monitored continuously is shown in Figure 1. The streams drain small watersheds of 10.1 and 5.4 square miles each. The land use in each watershed is predominantly residential. The suspended-sediment concentration and turbidity for a composite sample were collected using equal width increment sampling techniques (Wilde and others, 1998). The results are preliminary and further analysis is needed; however, the r^2 value of a linear regression of turbidity on suspended-sediment concentration was statistically significant ($p<0.05$) and accounted for 75 and 98 percent of the variance in turbidity at the two sites.

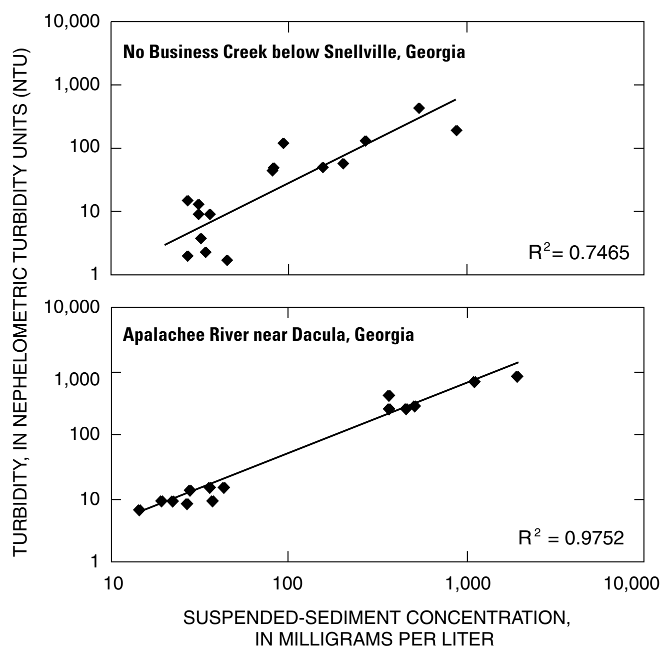

Figure 1. Relation between turbidity and suspended-sediment concentration for two urban streams located in Gwinnett County, Georgia.

SUMMARY

The recent development of several *in situ* sensors has made it possible to use turbidity as a surrogate to continuously estimate concentrations of some water-quality constituents. The USGS has several ongoing projects throughout the nation that use continuous monitoring of instream turbidity to develop estimates of water quality. Continuously monitored instream turbidity has the potential to provide better estimates of related water-quality constituent concentrations compared with traditional surrogate parameters, such as discharge. However, there are many issues and limitations regarding turbidity to consider. Limitations, including different methods and instrumentation for measuring turbidity, do not yield comparable turbidity values. The physical properties of the particles in the water sample yield different turbidity readings depending on the method used. In addition, the *in situ* instrument needs to be deployed so that the monitoring data accurately reflect stream conditions. Even with the described limitations, turbidity may prove to be a more accurate predictive tool of water-quality constituent concentrations than traditional surrogates such as discharge. Linear regressions of turbidity on a cross-section composite, suspended-sediment concentration for streams in Gwinnett County are statistically signifycant, suggesting that turbidity can be used to estimate real-time SSC for those streams.

LITERATURE CITED

American Public Health Association, American Water Works Association, and Water Environment Federation. 1998. Standard methods for the examination of water and wastewaters (20th ed.). American Public Health Association, Washington, D.C., pp. 2-8 to 2-11.

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

International Organization for Standardization (ISO). 1999. Water quality-determination of turbidity, Method 7027. pp. 1–7.

Pavelich, P.M. 2002. Turbidity studies at the National Water Quality Laboratory, Denver, Colo. Published with various abstracts. Turbidity and Other Surrogates Workshop, April 30–May 2, 2002, Reno, Nev. Variously paginated. (Accessed on December 9, 2002, at URL: http://water.usgs.gov/osw/techniques/turbidity.html.)

Sadar, M.J. 2002a. Turbidity instrumentation – an overview of today's available technology. Turbidity and Other Surrogates Workshop, April 30–May2, 2002, Reno, Nev. (Accessed on December 9, 2002, at URL: http://water.usgs.gov/osw/techniques/TSS/sadar.pdf.)

———2002b. Turbidimeter Instrumentation Comparison: Low-level Sample Measurements. Hach technical information series. Pp. 7–10. (Accessed on December 9, 2002, at URL: http://ecommerce.hach.com/stores/hach/pdfs/literature/L7063.pdf.)

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.

Wilde F.D., D.B. Radtke, Jacob Gibs, and R.T. Iwatsubo (eds.). 1998. Collection of water samples In: National field manual for the collection of water-quality data. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9.

Ziegler, A.C. 2002. Issues related to use of turbidity measurements as a surrogate for suspended sediment. Turbidity and Other Surrogates Workshop, April 30–May 2, 2002, Reno, Nev. (Accessed on December 9, 2002, at URL: http://water.usgs.gov/osw/techniques/TSS/ZieglerT.pdf.)