DIEL TURBIDITY FLUCTUATIONS IN STREAMS IN GWINNETT COUNTY, GEORGIA

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Abstract. Continuous turbidity data have been collected since 2001 at 12 water-quality monitoring stations in Gwinnett County, Georgia, as part of a cooperative agreement between the U.S. Geological Survey and the Gwinnett County Department of Public Utilities. With one of the largest real-time turbidity monitoring networks in the nation, this program has led in the development of deployment strategies and data management practices. Though the technology used in continuous monitoring of turbidity is relatively new, sinusoidal diel turbidity fluctuations have been observed at 11 of the 12 Gwinnett County monitoring stations, as well as in other geologic and climatic settings in the United States during baseflow conditions. The fluctuations are represented by elevated turbidity values that occur near sunrise, followed by a decrease throughout the day, with lowest values occurring near sunset. Evening values show a gradual increase through the night to sunrise. Turbidity fluctuations do not show seasonality, except that they are not observable during rainy periods, when stormwater runoff dominates flow conditions. Several mechanisms for turbidity variation—including instrumentation effects, sediment transport, and biological activity—are considered. Coincidence of turbidity and dissolved oxygen fluctuations supports biological activity as a cause of diel turbidity fluctuations. Diel fluctuations in turbidity may have implications for studies that use turbidity as a surrogate for other water-quality properties, such as requiring correction factors for studies that report bacteria concentrations during low-flow conditions.

BACKGROUND

Water-quality monitoring stations on the small, sandy headwater streams of Gwinnett County are equipped with stage sensors, rain gages, in situ water-quality monitors, and automatic samplers (Fig. 1). At each station, water-quality samples are collected and analyzed for suspended solids, biological and chemical oxygen demand, nutrients, suspended sediment, fecal coliform, and trace metals during baseflow conditions and storm events. The continuous and individual sample data are available online at *http://nwis.waterdata.usgs.gov/ga/nwis/qwdata*. This combination of hydrograph-based sampling and continuous data is used to satisfy regulatory requirements and to assess the impact of urbanization on water quality (Landers and others, 2002). Diel fluctuations in baseflow turbidity have been observed at all 12 of the Gwinnett County monitoring stations, as well as at monitoring stations in Michigan, Kansas, and Oregon (Morse and others, 2002; Thomas Wilch, Albion College, Dept. of Geological Sciences, written commun., 2004; provisional data from Kansas, and Oregon, U.S. Geological Survey, 2004). The phenomenon of diel turbidity fluctuations is of interest as a potential indicator of biological activity and because of its potential impact on the determination of surrogate water-quality relations.

Turbidity, which causes water to appear cloudy, is caused by the presence of suspended and dissolved matter such as clay, silt, finely divided organic matter, plankton and other microscopic organisms, organic acids, and dyes (ASTM International, 2003). Turbidity is addressed in the Safe Drinking Water Act of 1974, but no U.S. Environmental Protection Agency (USEPA) standard exists for turbidity in natural systems. Although many technologies are available to measure turbidity, some are better suited than others to dynamically measure turbidity within a stream, and many benchtop instruments are not field-deployable. The technologies used in this study and in other studies examined for this paper (Christensen and others, 2001; Morse and others, 2002) include the Hydrolab DataSonde® 4, Yellow Springs Instruments models 6026 and 6136, and Yellow Springs Instruments model 6026 modified to increase maximum detection limits. All of these sensors are capable of reading at a precision of 0.1 standard turbidity units; however, all produce records with a large amount of "noise" as compared to data for other water-quality properties. These sensors use near-infrared light sources, but vary in the number of light beams and detectors, and in the angle between source and detector. Near-infrared technologies compensate for color interference. Because the sensors used are not affected by color changes, only processes that change properties or concentrations of suspended matter are addressed as the causes of turbidity fluctuation. Sediment can be "stirred up" from the streambed, precipitated in the water column, delivered by point- and nonpoint-source discharges, or deposited from the atmosphere. Colloidal materials, bubbles, and living suspended organisms can also contribute to turbidity (Anderson, 2004).

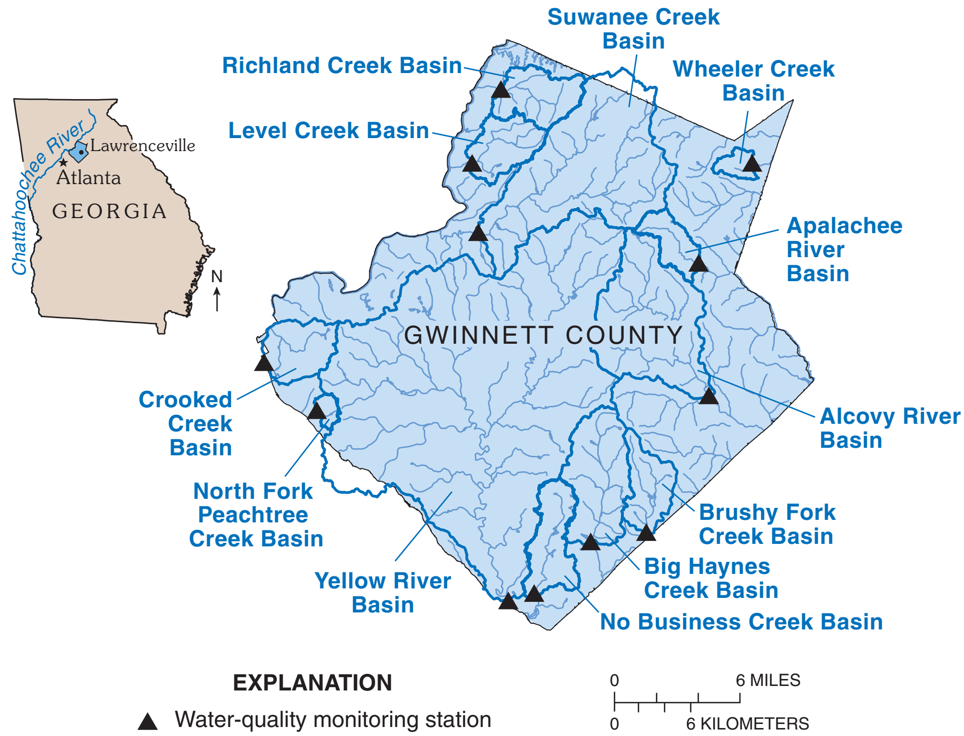

Figure 1. Location of water-quality monitoring stations in Gwinnett County, Georgia.

Factors Affecting Turbidity Measurements

The use of similar sensor technologies allows a valid comparison of data sets, but calls into question whether the phenomenon might be an artifact produced by the sensors. Sensors in natural streams are exposed to diel variations in air temperature, water temperature, and direct sunlight. If appropriate compensation for temperature, or direct sunlight effects, is not built into the sensor, then readings might not accurately reflect the optical properties of the stream and diel fluctuation might simply reflect variation in other factors that affect turbidity measurements.

Changes in stream velocity or depth could affect turbidity measurements by varying the stream's ability to suspend material from the streambed. Inorganic material could also precipitate or dissolve in the water column producing variations in turbidity. Changes in dissolved oxygen concentration and pH commonly exhibit diel fluctuations and control chemical stability. Scott and others (2003) observed diel fluctuations in colloidal and dissolved iron due to organic acid-enhanced photoreduction of ferric iron ($Fe3+$) to ferrous iron ($Fe2+$) in a mine drainage-impacted stream with pH 3.8 to 4.0. Iron concentrations in Gwinnett County streams are much higher than those observed in the acid drainage, and concentrations of dissolved organic carbon are similar (U.S. Geological Survey, 2003).

Predatory invertebrates and fish foraging on benthic materials can agitate bed sediment. Some predatory invertebrates shift from opportunistic to nocturnal foraging patterns in the presence of fish, whereas others exhibit nocturnal patterns regardless of fish presence. Grazing invertebrates, which are themselves particles in the water column, exhibit increased nocturnal drift and decreased daylight drift as an antipredator response that minimizes exposure to visually foraging, drift-feeding fishes (Lobón-Cerviá and Rincón, 1997). Nocturnal activities commonly peak immediately before sunrise (Elliott, 2000; Lobón-Cerviá and Rincón, 1997; Huhta and others, 1999).

Fluctuations in primary productivity of plankton and bacteria, which live suspended in the water column, could change turbidity readings. Diel variation in primary productivity can be observed through fluctuations in dissolved oxygen saturation and chlorophyll concentration, and is directly related to sunlight. Respiration—such as glucose oxidation, fermentation, and gas production—peaks just before sunrise (Bell and others, 1981). Roos and Pieterse (1992) identified a diel cycle in photosynthesis rates of plankton, with ultraplankton responding quickly to sunrise and decreasing photosynthesis rates through the day.

METHODS

Continuous water-quality and streamflow data including stage, discharge, water temperature, specific conductance, pH, and dissolved oxygen were plotted in time series with turbidity to compare diel turbidity fluctuations with other measured properties from all 12 Gwinnett County water-quality monitoring stations. Chemical analyses of individual samples were not used in data analysis because all baseflow samples have been collected in early to mid-morning.

Instrument effects were investigated using two different experiments. A sonde was deployed on a laboratory test bench in a setup designed to mimic field deployment. The sensors were immersed in tap water mixed with fine clays with low settling velocity. Water-quality data were collected every 15 minutes for 10 days using an electronic data logger (EDL). Ambient fluorescent lights were on in the lab on weekdays, and off continuously during weekends. The tap water was warm when the experiment began. Only physical and chemical water properties were monitored. Biological activity was not monitored.

In addition to the laboratory experiment, an in situ stream experiment was conducted. Two different turbidity sensor technologies were deployed for 3 weeks during November 2004 at the U.S. Geological Survey (USGS) water-quality monitoring station on Brushy Fork Creek near Loganville, Georgia. The instruments both use a near-infrared (780–900 nm) light source; one uses a single light source and detector at a 90-degree Celsius (ºC) incident angle, whereas the second uses multiple light sources and a combination of detector readings (Anderson, 2004). Data are reported in formazin nephelometric units (FNU). Both sondes were also equipped with water temperature, specific conductance, pH, and dissolved oxygen sensors. Data were collected every 15 minutes using an EDL for the primary instrument and internal logging for the second instrument.

RESULTS

The laboratory experiment yielded no diel fluctuations in turbidity. The turbidity decayed from a high of 224 FNU when the clays were first stirred up by the addition of tap water, to 15 FNU at the end of the experiment. Water temperature cycled with an amplitude of 1ºC each day. Specific conductance varied by only 3 microsiemens per centimeter over the course of the experiment, pH varied between 7.2 and 7.4. Dissolved oxygen concentration decreased gradually in the stagnant tap water, from an initial concentration of 7.8 milligrams per liter (mg/L) to 6.8 mg/L. None of the measured properties trended with either the light in the room or the turbidity. These results support the conclusion that diel turbidity fluctuations are a real phenomenon in streams and are not an artifact of error in the sensor technology.

Data collected during water year 2004 (October 1, 2003–September 30, 2004) for all 12 Gwinnett sites showed diel fluctuations. North Fork Peachtree Creek's trend is typified by a spiky midday peak, whereas the diel fluctuations at the other 11 sites are smoother sine curves, with peaks near sunrise and troughs near sunset. Half of the water year 2004 record for these 11 sites contains diel fluctuations. The remainder of the record is composed of peaks associated with storms, flat record during baseflow, or data too noisy to distinguish baseflow patterns owing to sensor fouling.

The relation between turbidity, stream stage, and discharge can be observed using data from Crooked Creek near Norcross, Georgia, a USGS water-quality monitoring station located 0.6 miles upstream of Crooked Creek's confluence with the Chattahoochee River. Dams regulating the Chattahoochee, as well as a difference in drainage areas of the Chattahoochee River (1,170 square miles) and Crooked Creek (8.87 square miles) create a lag between storm peaks at the two sites.

Four inches of rain, as measured at the Crooked Creek monitoring station between June 16 and 19, 2003, resulted in a peak discharge of 1,300 cubic feet per second and peak turbidity of 1,200 FNU in Crooked Creek on June 17. Crooked Creek's stage and turbidity returned to baseflow levels by June 22, and then a second increase in stage occurred (Fig. 2*B*), corresponding to flooding from a dam release on the Chattahoochee River from June 23 to 27. The discharge of Crooked Creek was uniform throughout the period of backwater flooding, as confirmed by the discharge plotted in Figure 2*C*. Diel fluctuations in turbidity recorded at Crooked Creek were unaffected by transitions between a backwater condition and normal baseflow (Fig. 2*A*). This lack of response indicates diel fluctuations in turbidity are independent of stream velocity and water depth, and therefore unrelated to physical sediment transport.

Storm events and baseflow were observed during the field experiment at Brushy Fork Creek. The two turbidity sensor technologies compare well for the full range of observed turbidity values, with a correlation coefficient of 0.76. Both technologies recorded diel fluctuations in turbidity during two 5-day dry periods. No changes were observed in the specific conductance, gage height, or pH records during baseflow periods; however, diel fluctuations were observed in both water temperature (Fig. 3*C*) and dissolved oxygen (Fig. 3*B*). Cycles in water temperature and turbidity have different patterns. Water temperature increases rapidly in the morning, peaks in the afternoon, and decreases slowly overnight. Cycles in dissolved oxygen are coincident with turbidity fluctuations (Fig 3*A*), with gradual increases through the day and steep declines near sunset.

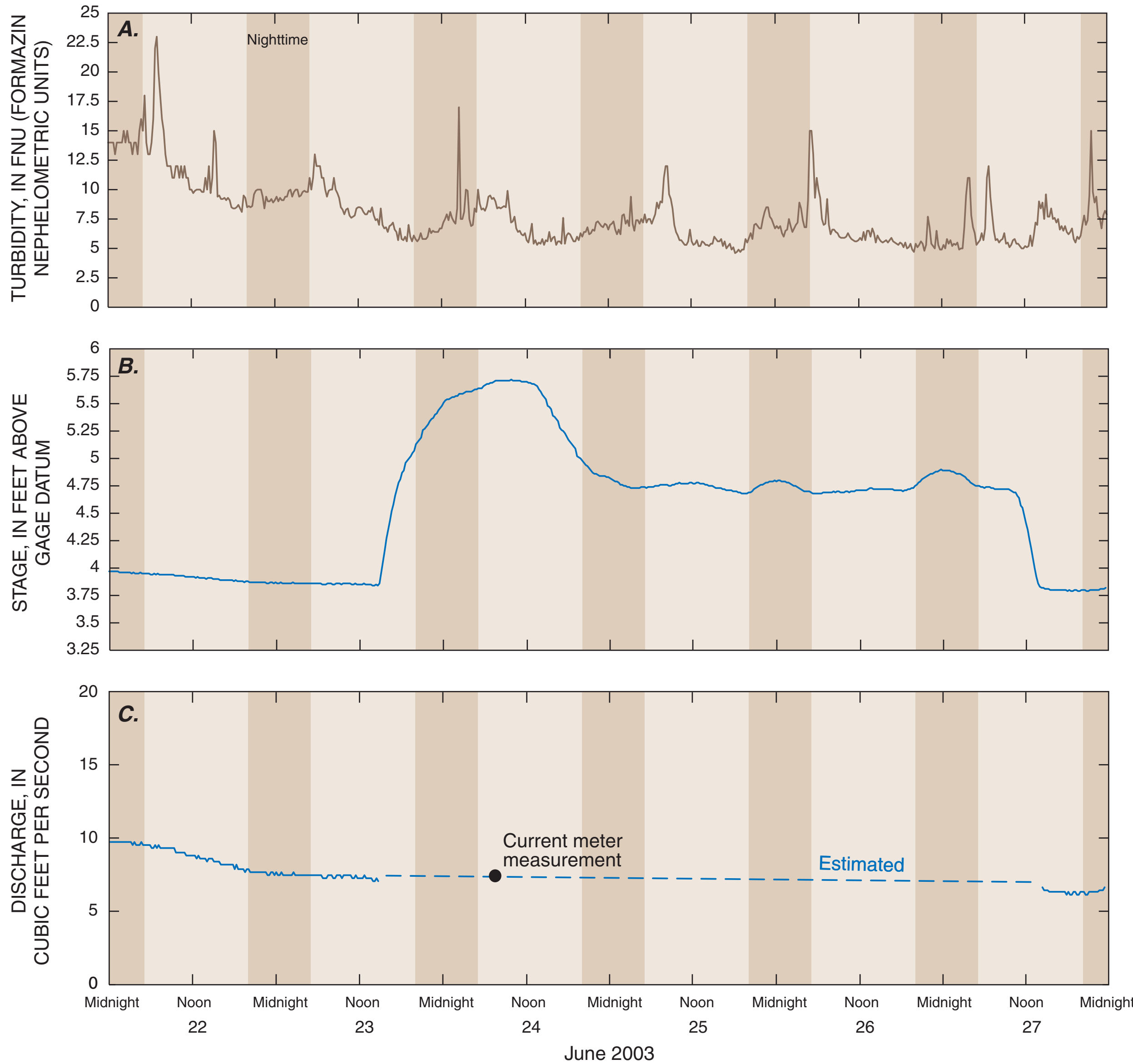

Figure 2. Turbidity, stage, and discharge data for Crooked Creek near Norcross, Georgia June 22–27, 2003.

DISCUSSION

Given the similarity of turbidity and dissolved oxygen fluctuations, and having ruled out many other mechanisms, biological processes are the likely mechanism for turbidity fluctuations. It may prove difficult to separate different biological processes that can affect turbidity fluctuations. There are not sufficient data from this study to identify a specific biological cause. Patterns in fish feeding, predatory invertebrate foraging, grazing invertebrate drift, and primary productivity are inherently coincident because of the structure of the stream food web (Huhta and others, 1999). Diel sampling for suspended sediment composition, chlorophyll concentration, and drifting invertebrates could be used to determine the relative importance of different biological activities in diel turbidity fluctuations. Studies in fish-free streams could also be used to complement existing data.

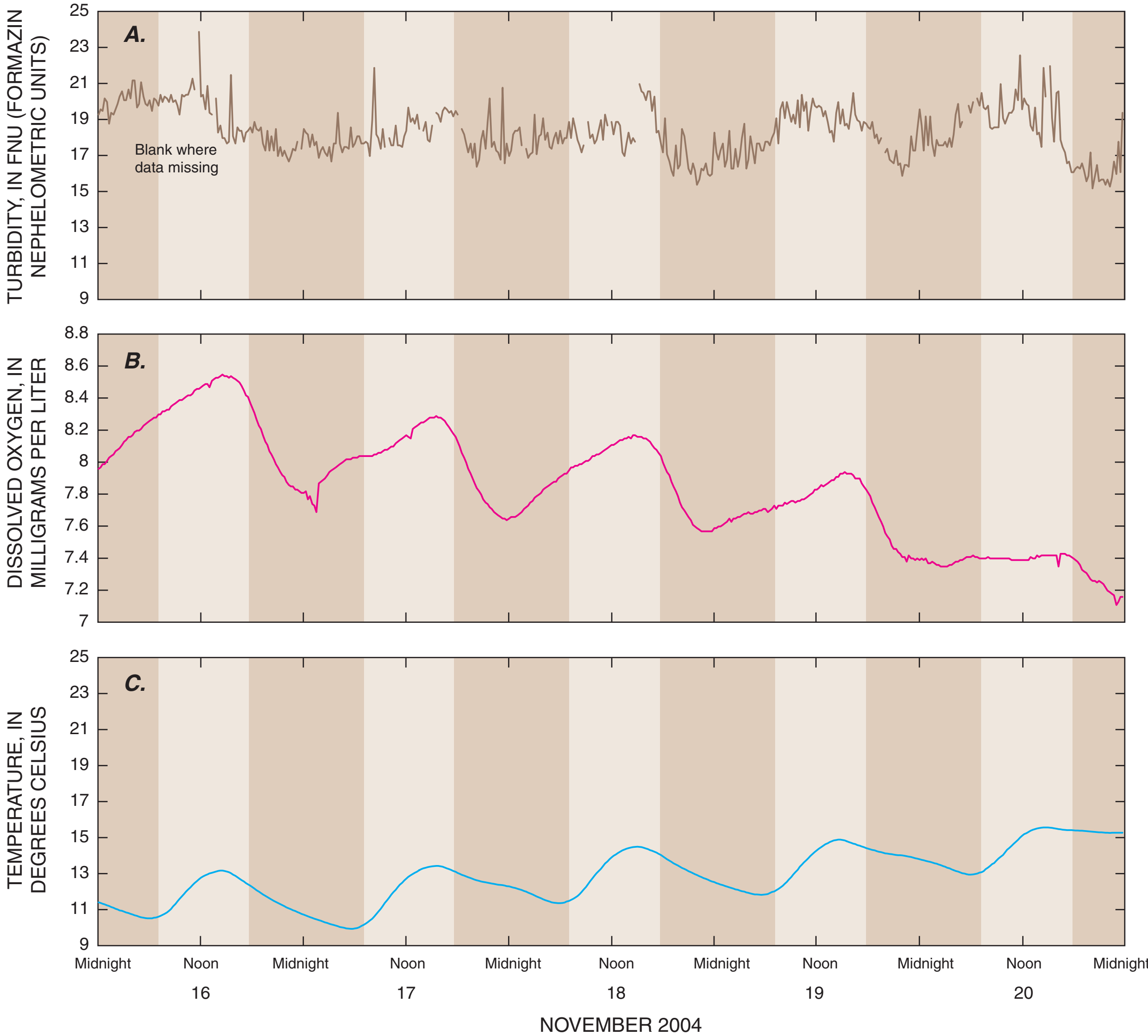

Figure 3. Turbidity, dissolved oxygen, and temperature data for Brushy Fork Creek near Loganville, Georgia, November 16–20, 2004.

Turbidity is commonly used as a surrogate for other water-quality properties that cannot be measured dynamically. Surrogate ratings have been developed for suspended sediment concentration, total suspended solids, *Escherichia coli* and fecal coliform bacteria concentrations, atrazine concentrations, and nutrient concentrations (Christensen and others, 2001). Validity of the surrogate studies is based on a covariance between turbidity and the water-quality property of interest. This covariance may break down during baseflow, when diel fluctuations, likely caused by biological activity, and not by physical or chemical processes, are the largest component of turbidity variations. It should be noted, however, that many of the properties for which turbidity is used as a surrogate are at their lowest concentrations, and hence have their least environmental impact, during baseflow conditions.

The amplitude of diel fluctuations of baseflow turbidity rarely exceeds 10 FNU, two orders of magnitude lower than the high values associated with sediment-laden storm waters. The higher volumes of water discharged from a drainage basin during storms contribute to the conclusion that baseflow turbidity, and the mechanisms controlling it, are of little importance for calculation of annual loads of constituents strongly linked to sediment concentrations. Events with 1000 FNU peaks occur infrequently, however, whereas diel cycling occurs continuously under baseflow conditions. Surrogate studies with focus on streaming data, such as bacteria in recreational waters or suspended materials in drinking water sources, may need to consider corrections for turbidity when diel cycling occurs.

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