Total Suspended Solids-Turbidity Correlation in Northeastern Wisconsin Streams

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Abstract

Knowledge of sediment loading is fundamental to assessing non-point source pollution in streams. The cost of collection and analysis of sediment samples could be reduced if total suspended solids (TSS) can be accurately estimated from continuously monitored turbidity. This poster presents TSS-turbidity correlations for three high sediment-yielding tributaries to the Lower Fox River in northeastern Wisconsin. Continuous turbidity measurements were matched with 195 TSS samples from automated event samplers and manual low-flow samples collected during WY2004. R^2 values for linear regressions exceeded 0.95 for the four sites analyzed. Regressions were site specific and significantly different from each other. Flow did not have a significant effect on the regressions. We hypothesize that differences between sites are due to variances in watershed hydrologic response, soils, bank sediment characteristics and land use/cover. Loads from turbidity-derived TSS concentrations were within 10% of loads calculated using TSS observations.

Introduction and Project Objectives

Estimation of sediment loading in a stream typically requires utilizing automated flow and event samplers to collect a limited number of TSS samples for laboratory analysis. Others have found that continuously monitored turbidity measurements may closely correlate with TSS concentrations in streams (Christensen 2000). Turbidity is a measure of the decrease in transparency of stream water as light is scattered by suspended matter (Ziegler 2002). Because optical sensors can be used to continuously monitor turbidity throughout a storm event, turbidity-derived predictions of TSS may yield an accurate estimate of sediment fluctuations with reduced sample costs. Particle properties, such as color, shape, and size distribution, may impact turbidity readings (Ankcorn 2003). Although general TSS-turbidity relationships have been reported, relationships must be established on a site-by-site basis, and reliability may vary due to water color and suspended particle composition (Packman et al 1999).

This poster presents research conducted on Apple, Ashwaubenon, and Baird Creeks in Northeastern Wisconsin as part of a larger watershed monitoring project (Figure 1). Objectives of this study were to:

1) Establish relationships between real-time turbidity and TSS in Lower Fox River watershed tributaries.
2) Determine if the relationships differed between sites or by flow.
3) Compare turbidity-derived loads to those based on TSS samples.

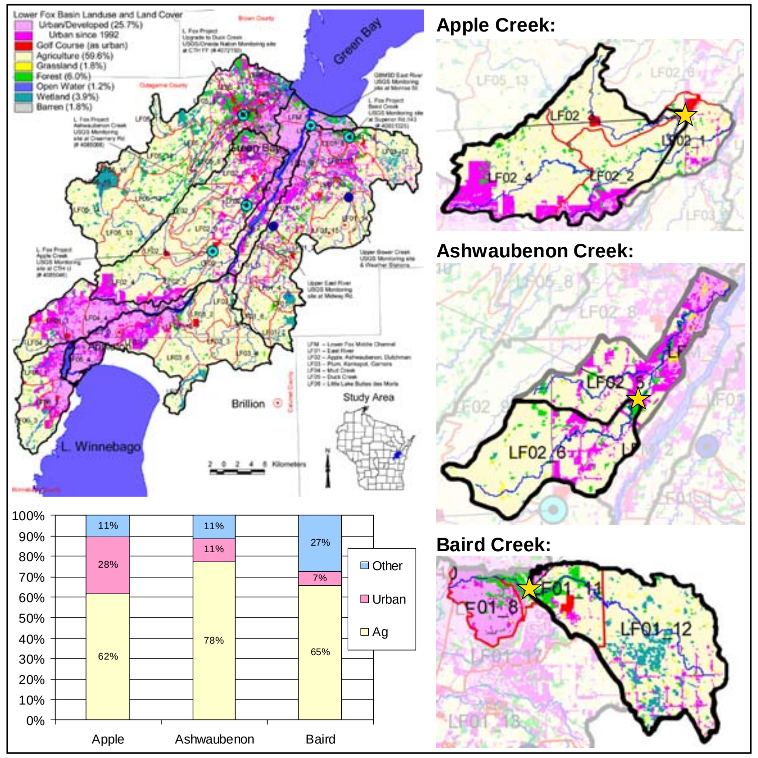

Figure 1. Land use and sampling locations in the Lower Fox River watershed.

Methods

Fully automated flow and water sampling stations were established in cooperation with the Wisconsin USGS Office in 2003. Standard methods were used for gaging streamflow and for collecting, processing, and analyzing water samples (Shelton 1994, Figure 2). Stage-triggered event samples were collected at the USGS gaging stations. In addition, a manually-activated sampler was located at a site upstream of the USGS station on the North Branch of Baird Creek. Biweekly low-flow samples were collected at each site using the equal width increment (EWI) method. YSI-6200 multi-parameter sondes were also deployed at each site and logged T, pH, DO, specific conductance, depth, and turbidity at 10 minute intervals (Figure 3). The optical turbidity sensors had automated wipers to reduce fouling.

Figure 2. Refrigerated ISCO sampler.

Figure 3. YSI-6200 sonde.

Sonde data was processed to exclude anomalous observations due to sediment deposition and equipment-associated false spikes in turbidity. Linear regression analysis was performed using Microsoft Excel 2003 and SAS 9.1 (SAS Institute 2003) to generate predictive relationships between TSS and turbidity. Comparisons were made between sites and between event versus low-flow samples and samples taken on the rising versus falling limbs of flow event hydrographs. There were not sufficient data to test for the significance of seasonality.

Results

Annual precipitation was about 10% below the 30 year average. However, November, May and June were a combined 218 mm (+202%) above average. This rainfall led to several major runoff events during the study period.

Figure 4 shows an example of the automated data and TSS event samples collected at each site. This figure illustrates:

- The dynamic real-time response and variability of turbidity in events.
- The close correlation between turbidity and TSS.
- The need for data processing to remove false-spikes and erratic responses of the optical sensor during high flows.

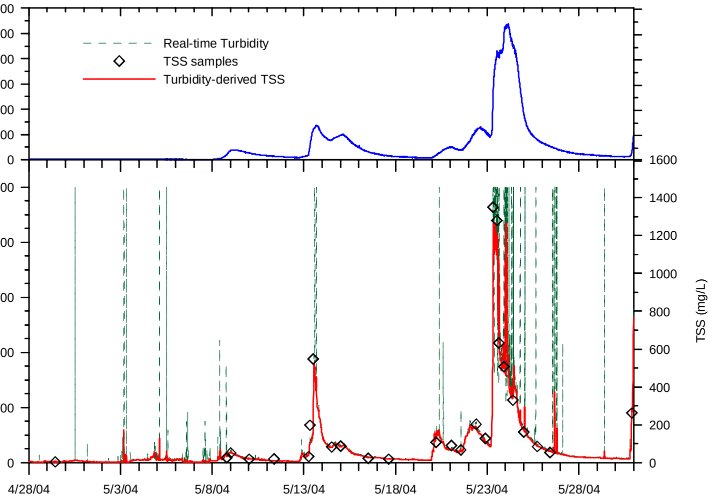

Figure 4. Discharge, TSS concentration, and turbidity data from 28 to 31 April 2004 at the Apple Creek USGS Station.

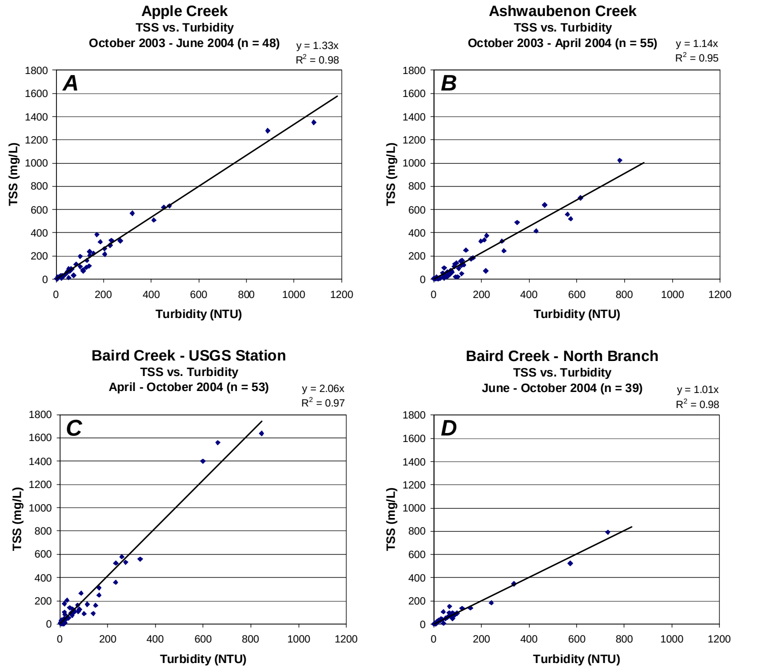

Figure 5. TSS-turbidity relationships for Apple Creek (A), Ashwaubenon Creek (B), Baird Creek USGS Station (C) and the Baird Creek North Branch site (D).

Linear regressions for the four sites are presented in Figure 5. The results show the following:

- The relationship between TSS and turbidity was highly significant at the 0.05 confidence level for all four sites.
- The slope of the TSS vs. turbidity line ranged from 1.01 to 2.06.
- In no case was the intercept significantly different from zero.
- All TSS-turbidity between-site relationships are significantly different from each other at the 0.05 confidence level.
- The Ashwaubenon-Baird (North Branch) relationship was the closest ($p = 0.0178$ compared to $p < 0.0001$ for all others). Statistically, however, they are different from each other.
- Flow (event vs. low-flow) and hydrograph position (rising vs. falling) did not have a significant effect on the regressions.

Load Comparisons

Real-time turbidity measurements from Apple Creek were processed with an algorithm that replaced observations that were >0.3 standard deviations from the running median with a 70-minute median value. These turbidity values were converted to TSS using the Apple Creek regression (TSS = 1.33 x Turbidity) and matched to 15 minute discharge values to calculate instantaneous and daily loads (Figures 5A, 4). The turbidity-derived TSS loads were compared to loads calculated by USGS scientists using TSS observations and graphical interpolation software (metric tons).

Period	Turbidity Loads	USGS Loads	Difference
14 April – 22 May	312	348	-10.2%
14 April – 30 May	2458	2327	+5.7%
10 – 20 June	1170	1125	+4.0%

Figure 6. Baird Creek at Superior Road during a runoff event, Fall 2003.

Figure 7. Event samples showing sediment concentration change during a storm.

Figure 8. Ashwaubenon Creek during May 2004 storm events: (A) May 14, (B) May 23.

Conclusions

- Turbidity of the three creeks within the Lower Fox River Watershed is highly dynamic, and increased turbidity measurements coincided with runoff events and sharp rises in stream discharge.
- Turbidity and TSS concentrations were highly correlated for our data sets, but the TSS-turbidity relationship appears to be site specific. We hypothesize that these differences result from different sediment particle properties and varying hydrological responses from urban and agricultural land uses.
- The two Baird Creek sites displayed the largest difference despite being located only 1 mile apart. A study by Fink et al. (2005) found that development and bank erosion on urbanizing tributaries contributed significant amounts, and likely different, sediment particles above the USGS station but below the North Branch site.
- No significant difference was found due to event vs. low-flow or hydrograph position. The effect of seasonality was not analyzed due to lack of data from equipment fouling.
- Turbidity-derived sediment loads were similar (+/- 10%) to TSS sample load methods.

Continuous turbidity monitoring appears to be a reasonable surrogate for TSS prediction in Apple, Ashwaubenon, and Baird Creeks, and may provide long-term, cost effective and rapidly available information on watershed sediment delivery due to changes in land use. Refining multi-probe sonde deployments for turbidity monitoring could contribute to fewer false spikes and/or equipment fouling and, thus, more complete data sets and higher relationship confidence. Research on suspended particle properties would also provide information needed to better explain site-to-site differences in the TSS–turbidity relationships.

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