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Temporal variability in a midwestern stream during spring[1]

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Introduction

In this paper we describe temporal variability in physical factors, water chemistry and algal biomass in a midwestern stream during spring 1989. Our purpose was to determine how these parameters responded to varying flow regimes in the short-term, and to provide a source of information for others to assess how short-term variability might affect various stream sampling regimes.

Site description

Samples were collected from Hinkson Creek, Boone County, Missouri, USA, at a site within the city limits of Columbia near a U.S. Geological Survey gauge (USGS number 06910230). At this point it is a third order stream that drains 19,570 ha. The long-term average annual discharge at the sampling site is $0.38\,m^3 \cdot s^{-1}$, median discharge is $0.18\,m^3 \cdot s^{-1}$ and the maximum daily discharge is $130.6\,m^3 \cdot s^{-1}$. Bottom materials are composed of cobble in the runs and riffles, with some exposed bedrock. Pools and backwater areas are covered by sand and silt, with some exposed clay. Land use in the catchment is: 29 % forest, 15 % pasture, 49 % row-crop agriculture; 7 % urban, and < 1 % water.

Prairie-timber and prairie soils in the watershed are well drained but are easily erodible. These soils generally have low natural fertility but can be used for agriculture when limed and fertilized. Bedrock material for these soils is Pennsylvanian shales with some sandstone and limestone. At the sampling site bedrock is Mississippian cherty limestone (USDA 1962).

Rainfall was recorded at a station located within the watershed about 8 km from the sample site. The average annual rainfall is 996 mm with 1295 mm of evaporation and 229 mm of runoff (MDNR 1986). Discharge values were obtained from the USGS.

Methods

Samples were collected daily between 11 am and 1 pm from March 1 through May 22, 1989. Multiple samples collected during a five-day study of Hinkson Creek (unpublished) showed total phosphorus, total nitrogen and algal chlorophyll values from mid-day collections were within one standard deviation of the daily mean.

Samples of 1 l were taken at the middle depth of the water column at four points across the stream. Samples were combined and in the laboratory subsamples were drawn for analysis of suspended chlorophyll (Chl) and phaeophytin after Knowlton (1984) and Sartory & Grobbelaar (1986); total phosphorus (TP) after Prepas & Rigler (1982); total nitrogen (TN) by second derivative measurement of persulfate oxidized samples (Crumpton et al. 1992); ammonia nitrogen (NH) after Stainton et al. (1977); soluble reactive phosphorus (SRP), nitrite-nitrate nitrogen (referred to as nitrate), specific conductance, turbidity, nonvolatile suspended solids (NVSS) and volatile suspended solids (VSS) by the methods of APHA (1985). Travel time from stream to laboratory was under 10 minutes.

Benthic Chl and phaeophytin were sampled from rocks and sediment two times per week (Tuesday and Thursday). Samples were taken by randomly selecting 15 rocks along a 7 m transect across the head of a riffle. An area $3.14\,cm^2$ was scraped from the surface of each rock with an exacto knife and the material was washed into a scintillation vial. In the laboratory samples were filtered through a glass fiber filter and analyzed by the method for suspended Chl. Sediment samples for Chl determination were collected from an adjacent pool by inverting polyethylene culture tubes into the sediment at 15 points evenly spaced along a 10 m transect. These samples were filtered in the same manner as samples scraped from rocks. All Chl values were corrected for phaeophytin.

In the data analysis we used correlation as a simple exploratory technique to show general associations among discharge and daily measurements of solids and water chemistry in stream water. We recognize that autocorrelation can result in time series data and treat these values accordingly.

Results and discussion

Discharge in Hinkson Creek during the 83-day study ranged between 0.01 and $0.80\,m^3 \cdot s^{-1}$ (Fig. 1, Table 1). This was a low water period; maximum discharge during the study was about five times the long-term median value at this site and orders of magnitude lower than the record

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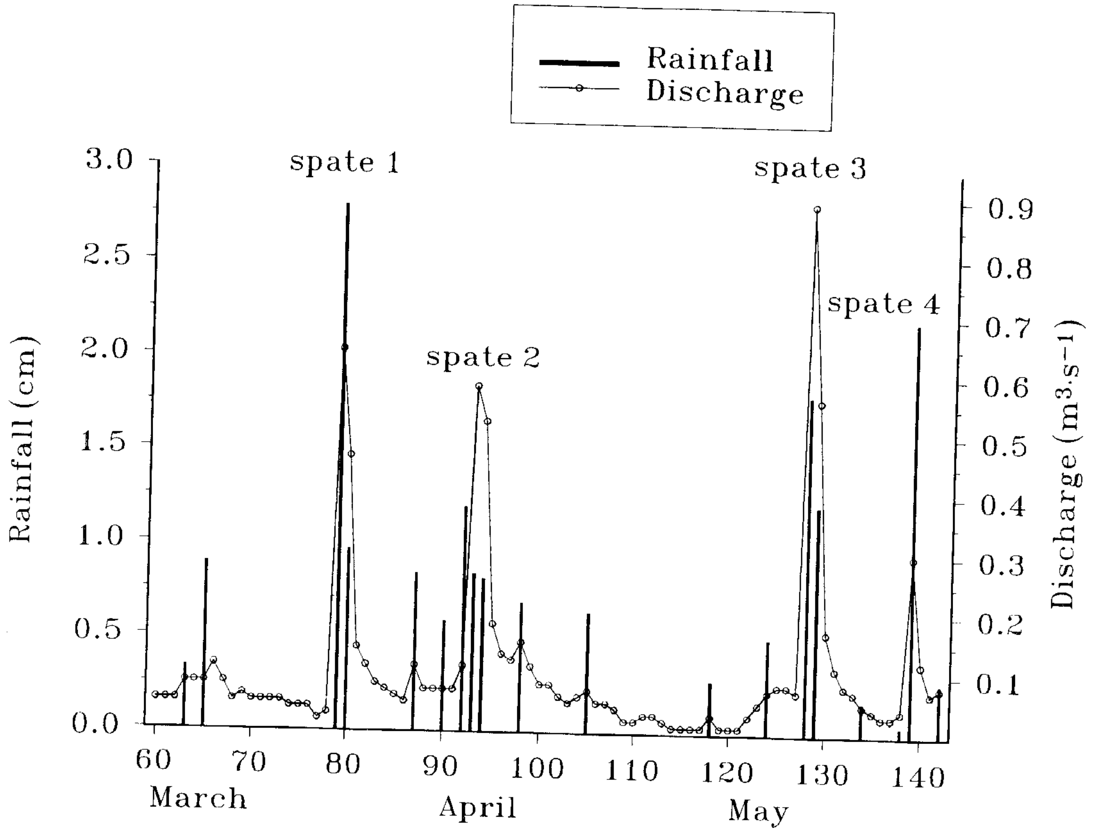

Fig. 1. Response of discharge to rainfall patterns during sampling period.

flood. Four storms caused abrupt increases in stream flow (Fig. 1), but within 1–5 days discharge returned to near prestorm levels. Base discharge was $< 0.10\,\mathrm{m}^3 \cdot \mathrm{s}^{-1}$, this condition occurred 36 % of the time (Table 1).

The four largest storms (Fig. 1) had a dramatic influence on the solids content and water chemistry of Hinkson Creek. During the ascending stage of these spates VSS increased by 20–130 fold, NVSS increased by 25–500 fold and both measurements returned to pre-storm values within a few days (Figs. 2 a, b). Values of VSS and NVSS at base flow were 1.2 and $2.9\,\mathrm{mg} \cdot \mathrm{l}^{-1}$, respectively, and showed little variability over time (Fig. 2 a, b). VSS as a percentage of NVSS ranged from 41 % at base flow to 11 % at maximum flow. In contrast, conductivity was inversely correlated with discharge ($r = -0.76$, log transformed, $n = 83$, $p < 0.001$) and the four largest spates decreased conductivity by 30–67 % (Fig. 2 c). Lowest conductivity values were measured on the descending stage of the hydrograph and thereafter values rose fairly steadily to plateau around $800-900\,\mu\mathrm{S} \cdot \mathrm{cm}^{-1}$. Spates also influenced stream water temperature, decreasing values by 3–10 °C (Fig. 2 d).

TP values closely followed fluctuations in discharge (Fig. 3 a, Table 1). At base flow TP was $38-58\,\mu\mathrm{g} \cdot \mathrm{l}^{-1}$ and values of $> 300\,\mu\mathrm{g} \cdot \mathrm{l}^{-1}$ coincided with the ascending stage of storms; concentrations fell abruptly thereafter (Fig. 3 a). TP values were highly correlated with VSS and NVSS ($r = 0.88$ and 0.85, respectively, log transformed, $n = 83$, $p < 0.001$), suggesting that P values during floods were largely associated with particulates carried by overland flow and materials resuspended from the stream bed (RIGLER 1979). At the peak discharge of each storm, SRP (Fig. 3 b) comprised < 20 % of TP and SRP increased as a proportion of TP during the descending stage and base flow.

Values of TN ranged from 330 to $2320\,\mu\mathrm{g} \cdot \mathrm{l}^{-1}$ during the study (Table 1). Like TP, peak values of TN occurred during spates (Fig. 3 b) when con-

Table 1. Summary statistics of variables measured in Hinkson Creek, March 1 – May 22, 1989.

Variable	unit	n	mean	mode	1st quartile	maximum	minimum
Discharge	$m^3 \cdot s^{-1}$	83	0.11	0.05	0.04	0.89	0.01
Turbidity	nTu	83	36.0	3.3	3.2	650	1.3
NVSS	$mg \cdot l^{-1}$	83	57.7	2.8	2.9	1242	1.4
VSS	$mg \cdot l^{-1}$	83	8.2	1.0	1.2	134	0.8
Temperature	°C	83	13.8	16.0	9.5	25.0	1
Specific Conductance	$us \cdot cm^{-1}$	83	725	882	668	914	290
Phosphorus, Total	$\mu g \cdot l^{-1}$	83	134	38	58	849	33
Phosphorus, Soluble Reactive	$\mu g \cdot l^{-1}$	83	31	10	16	125	4
Nitrogen, Total	$\mu g \cdot l^{-1}$	83	693	460	410	2320	330
Nitrogen, Nitrate	$\mu g \cdot l^{-1}$	79	96	<5	<5	760	<5
Nitrogen, Ammonia	$\mu g \cdot l^{-1}$	18	70	30	28	260	<5
Chlorophyll, suspended	$\mu g \cdot l^{-1}$	83	9.1	1.8	4.0	130.8	0.9
Chlorophyll, cobble	$mg \cdot m^{-2}$	19	78.7	–	–	183	14.0
Chlorophyll, sediment	$mg \cdot m^{-2}$	18	61.9	–	–	169	10.0

centrations increased by 5–8 fold over base levels (410 to 460 $\mu g \cdot l^{-1}$). TN was highly correlated with VSS and NVSS ($r = 0.79$ and 0.78, respectively, log transformed, $n = 83$, $p < 0.001$), suggesting that, like TP, particulate forms of N were important at high flow.

Whereas TP declined rapidly after each spate (Fig. 3 a), TN required 4–6 days to return to base values as discharge receded (Fig. 3 b). This difference between TN and TP was most pronounced during storms in early spring, and likely resulted from elevated nitrate levels entering the stream with groundwater (Fig. 3 d). During the descending hydrograph groundwater was an increasing proportion of stream flow, as demonstrated by increasing conductance values following each flood (Fig. 2 c). Nitrate accounted for as much as 40 % of the TN content of stream water immediately after large spates in early spring.

During much of March nitrate fluctuated between 100 and 340 $\mu g \cdot l^{-1}$ (Fig. 3 d); at the same time SRP values fluctuated between 20 and 100 $\mu g \cdot l^{-1}$ (Fig. 3 c). This was likely a period of nutrient subsidy (Meyer et al. 1988) from runoff and groundwater inputs from low-magnitude storms which had only minor effects on discharge and conductance (Figs. 1, 2 c). Later in the study, storms of similar magnitude did not produce nitrate pulses in Hinkson Creek. In fact, nitrate was rarely above the limit of detection (5 $\mu g \cdot l^{-1}$) during April and May (Fig. 3 d), and reached a peak of only 100 $\mu g \cdot l^{-1}$ following several days after a large storm in mid-May. Like nitrate, base values of SRP decreased in late spring to between 10 and 16 $\mu g \cdot l^{-1}$ (Fig. 3 b). Presumably biological uptake by the terrestrial community was not important in early spring, but later in the growing season there was little nitrate, and perhaps SRP, to flush from the groundwater during storms (Tate 1990). Autotrophic activity, microbial uptake and denitrification may also have contributed to low nitrate and SRP measurements in late spring (Grimm et al. 1991, Bachmann et al. 1991, Grimm & Fisher 1984).

Ammonia was measured infrequently, but available data show it was present at lower concentrations than nitrate in early spring. During early May, however, it seems ammonia was the primary inorganic nitrogen source in the stream (Fig. 3 e). Ammonia increased 10 fold during the third spate and returned to normal within one day. A small number of measurements suggest the base value in late spring was from 10 to 30 $\mu g \cdot l^{-1}$.

Suspended Chl ranged from 0.9 to 131 $\mu g \cdot l^{-1}$ (Table 1) during the Hinkson Creek study. Peak Chl values coincided with the major spates (Fig. 4 a) and closely followed the hydrograph (Fig. 4 d). During March suspended Chl at base flow was about twice the value measured at base flow during May (10 versus 4 $\mu g \cdot l^{-1}$). On average, 45 % of suspended Chl was phaeophytin (Fig. 4 a); values were typically < 20 % in early spring and > 40 % later in the study.

Benthic Chl on cobble and sediment substrates ranged between 80 and 180 $mg \cdot m^{-2}$ in early-March (Figs. 4 b, c). The first spate reduced cobble and sediment Chl by 50 %, and values were further reduced 65 % during the second spate (Figs. 4 b, c, d). Scouring of this material during spates accounted for the reduction in benthic Chl

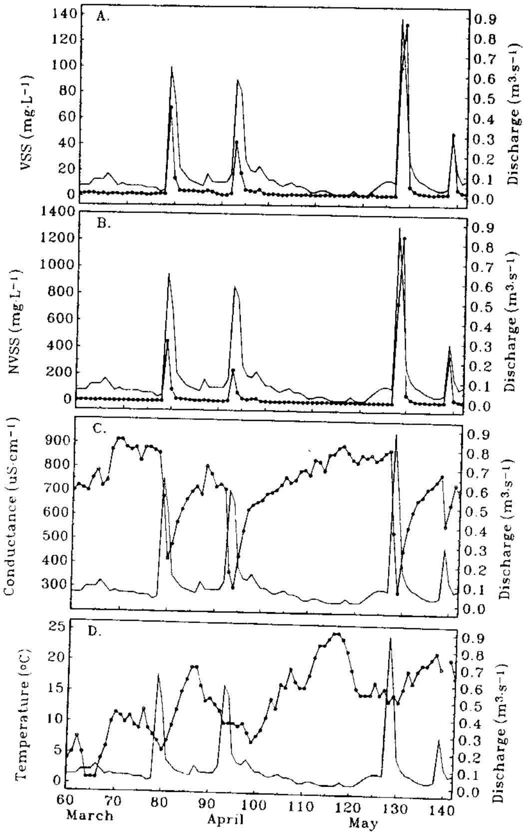

Fig. 2. Response of physical variables to discharge during sampling period. A. Volatile suspended solids, B. Non-volatile suspended solids, C. Specific conductivity, D. Temperature.

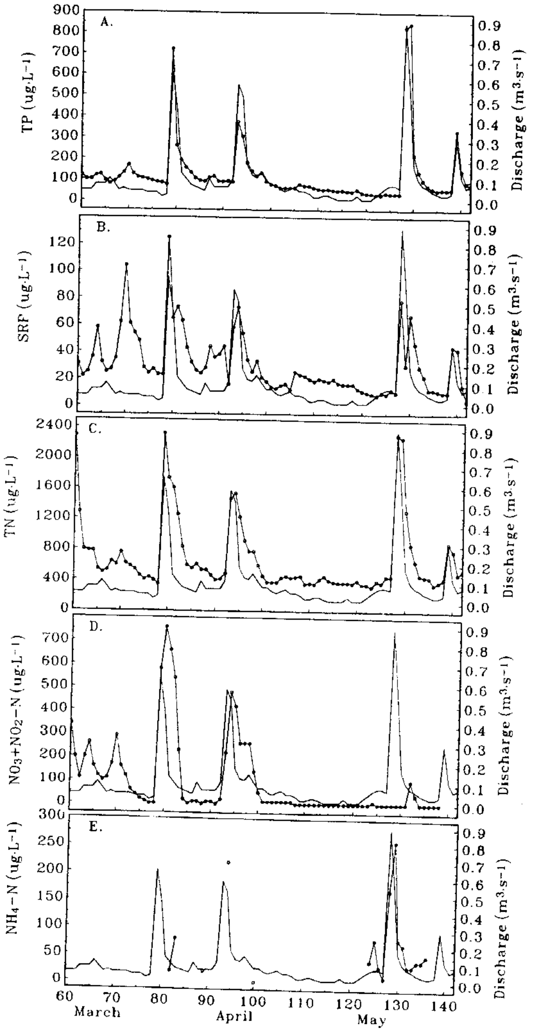

Fig. 3. Response of chemical variables to discharge during sampling period. A) Total phosphorus, B) soluble reactive phosphorus, C) total nitrogen, D) nitrate + nitrite nitrogen, E) Ammonia nitrogen.

and concurrent increase in suspended Chl (Blum 1954, Lohman et al. 1992). Scouring of benthic Chl would have also contributed to increases in TN and TP during floods (Rigler 1979).

Benthic Chl on cobble rebounded to 158 mg · m^{-2} after the second spate, but declined through late April – May (Fig. 4 b). Sediment Chl generally remained low throughout April and May except for a period when biomass reached 63 mg · m^{-2} (Fig. 4 c). This decline roughly coincided the development of a canopy cover by the terrestrial vegetation; less light may have affected growth and, along with higher temperatures (Fig. 2 d), may have contributed to a shift in species composition from predominantly *Cladophora* sp. to *Mougeotia* sp. and *Spirogyra* sp. (Smith 1950). These species are more susceptible to detachment during floods than *Cladophora* and may have accounted for the sharp increase in suspended Chl during the third spate. Also, phaeophytin measurements matched or exceeded benthic Chl pigments (Figs. 4 b, c) during late spring, suggesting that periphyton was largely composed of senescent cells at the time of the third spate. In contrast, during early spring some 30 – 40 % of the benthic biomass was phaeophytin, suggesting that periphyton was composed of a high proportion of healthy cells when light and nutrients were abundant.

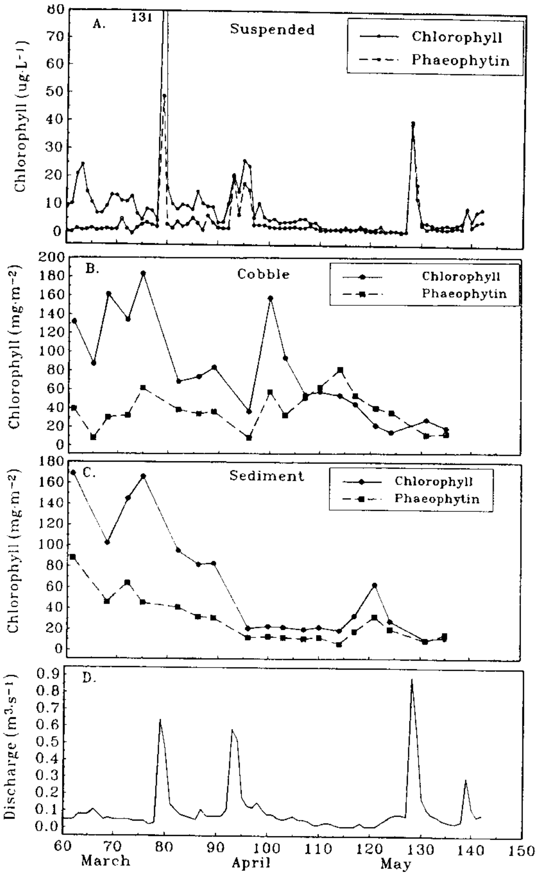

Fig. 4. Response of algal chlorophyll to discharge during sampling period. A) Suspended chlorophyll and phaeophytin; B) Cobble, benthic chlorophyll and phaeophytin; C) Sediment, benthic chlorophyll and phaeophytin; D) Discharge during sample period.

Nitrogen limitation may have influenced benthic biomass in late April–May. Low nitrate values during late spring (Fig. 3 d) suggest that demand was high and low atomic ratios of N : P in the stream water provide strong evidence for nitrogen limitation (TN : TP = averaged < 16, and values of nitrate+ammonia/SRP were typically < 5). Lohman et al. (1991) have experimental evidence that periphytic Chl can be nitrogen limited in central Missouri streams with low nitrate and N : P levels.

Conclusions

This study supports the conclusion by Tate (1990) that flow is a major factor influencing nutrient dynamics in streams. The sharp increase and subsequent fall in TP, TN, VSS and NVSS with spates in Hinkson Creek, parallels results of stream studies by others (Rigler 1979) and demonstrates the conspicuous role of particulates, carried by overland flow and materials resuspended from the stream bed, on these elements. Pulses of nitrate and SRP were associated with small storms in early spring but not later in the study. This seasonal pattern matches the findings of Tate (1990), and others and is attributed to nutrient uptake from soil water by terrestrial vegetation during the summer growing season. Fluvial processes during spates resulted in scour of the periphyton and a concurrent increase in suspended Chl. Suspended Chl concentrations followed the hydrograph closely and support the observation that high-magnitude storms result in scour and export of benthic Chl (Lohman et al. 1992). During early spring, when light and dissolved nutrients were available, periphyton rebounded after spates. Later in the study, when light and nitrogen were potentially limiting, benthic Chl was slow to recover from scour. This was a period when a high proportion of the pigment was phaeophytin.

An objective of this study was to assess how suspended solids, nutrients and algal biomass responded to varying flow regimes in the short-term to determine how this source of variability might affect various stream sampling regimes. Our findings match the conclusions of Meyer et al. (1988) that major floods are a disturbance to the system but that for most variables the response to flow is short lived – many measurements follow the hydrograph quite closely. Therefore, if the objective of a particular study is to characterize the nutrient regime of a given stream, or make comparisons among various systems, it seems appropriate to eliminate the flood events and use base level measurements. We found that TP, TN, VSS and NVSS did not fluctuate much in Hinkson Creek during periods of base flow (Figs. 3 a, c). In contrast, if the objective is to measure export, the flood events would be essential. During our study, 53 % of the TP and 43 % of the TN was exported from Hinkson Creek during the four largest spates. These percentages are similar to values seen in other systems (Rutherford et al. 1987) and would have been larger if the study period had included major floods. We suggest these conclusions be evaluated over a broad range of flow regimes and streams.

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