STREAMWATER DISSOLVED ORGANIC CARBON AND TOTAL DISSOLVED NITROGEN: EFFECTS OF TIMBER HARVEST IN THE GEORGIA PIEDMONT

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REFERENCE: *Proceedings of the 2011 Georgia Water Resources Conference*, held April 11–13, 2011, at the University of Georgia.

Abstract. A paired watershed experiment of silvicultural best management practices first initiated in 1973 and harvested in 1974/75 was harvested for a second time in 2004. During the current harvest, BMPs were updated to reflect current guidelines. Stream water yield and physical and chemical attributes were monitored for one year pre-harvest and one year post-harvest. Here we report results for dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) concentrations and fluxes. In the treatment watershed, no response to harvest in the discharge-concentration relationship was observed. Based on double mass curves, however, the yield of DOC and TDN increased in the treatment watershed as a result of increased stream water fluxes, although the increased mass of DOC or TDN loss was relatively small.

INTRODUCTION

Forestry best management practices have been developed to protect water quality during harvest and subsequent site preparation. Of particular interest has been the effect of harvest on water yield, sediment yield, and nutrient fluxes (Aust and Blinn, 2004; Jackson et al, 2004). In upland watersheds similar to those studied here in the Piedmont region of Georgia, research has often found harvest and site preparation to increase water yield and peak flows, sediment loads, and nutrient fluxes, although the magnitude of the increase has typically been modest (Hewlett et al., 1984; Van Lear et al., 1985; Swank et al., 2001).

The paired watersheds of the current study in the B.F. Grant Memorial Forest in Eatonton, GA where previously monitored from 1973 to 1978 and harvested in 1974/75 to quantify harvest effects on erosion, temperature, water yield, stormflows, and dissolved minerals (Hewlett 1979; Hewlett and Fortson 1982; Burns and Hewlett 1983, Hewlett and Doss 1984; and Hewlett et al. 1984). These same watersheds were re-instrumented and monitored from 2002 to 2005 and harvested in 2004 to once again test the effectiveness of current BMPs. Changes in BMPs over these decades largely focused on increased width of streamside management zones. Results relative to water yield and sediments have been reported (Jackson et al., *accepted*). These results demonstrate an increase in water yield and in sediment transport, although sediment inputs from roads were reduced and no temporary stream crossings were used during the current harvest.

Results for nutrient loads have not been previously reported and here we focus on fluxes of dissolved organic carbon and total dissolved nitrogen.

MATERIALS & METHODS

The study streams are first-order perennial streams (with ephemeral tributaries including remnant agricultural gullies) draining adjacent watersheds in the BF Grant Memorial Forest in Putnam County in the Piedmont of Georgia. The forest is managed by the Warnell School of Forestry and Natural Resources at the University of Georgia. The treatment stream drains a watershed of 32.5-hectares and the reference a watershed of 42.5 hectares (See Hewlett 1979 for soil and topographic maps of the watersheds).

The ~28-yr-old forest was clearcut harvest between 18-Dec-2003 to 21-Jan-2004 using rubber tired feller-bunchers. Per Georgia BMP guidelines streamside Management Zones (SMZ) were 12m where slopes were slight (<20%) and 21m where slopes were moderate (21-40%). The interior of the SMZ was not thinned although that is allowed under the BMPs.

Streamflow and nutrient monitoring began on 27-Mar-2002 and ended on 15-Jan-2005. Pre-treatment monitoring spanned 20 months from 27-Mar-2002 to 1-Dec-2003. Post-harvest monitoring lasted approximately one year from 10-Jan-2004 to 15-Jan-2005. Four foot H-flumes left from the Hewlett study in the 1970s were re-instrumented with pressure transducers and ISCO™ automated samplers. Stage data was taken in five-minute intervals and the ISCO™ was set to begin sampling at predetermined stage heights. Samples for chemical analysis were a mix of stromflow events collected with the ISCO™ as well as periodic grab samples.

Water samples were returned to the laboratory in Athens, filtered through 0.4 µm polycarbonate filters, and stored at 4ºC for later analysis. Dissolved organic carbon and total dissolved nitrogen were run simultaneous on a Shimadzu VCN after acidification <pH 2 and purging with purified air.

RESULTS

The time series of stream water samples demonstrated a 20-fold variance in both DOC and TDN concentrations (Fig. 1). There was some seasonality evident with concentrations increasing in the summer months. The average concentrations between the watersheds in the pre-harvest period based on daily concentrations (i.e., multiple storm flow event measurements for a single day are not treated as independent samples) differed for DOC ($p<0.001$ for a non-parametric Kruskal-Wallis rank test) but not for TDN ($p=0.38$) (Fig. 2). Post-treatment concentrations between the watersheds differed for both elements ($p<0.01$) but sample sizes were small, particularly in the reference stand and all available data had elevated concentrations.

The concentration of DOC and TDN increased with discharge in both watersheds, although post-harvest in the reference watershed sample size limited the significance of the regression relationships (Fig. 3 and 4). In the treatment watershed the slope of the regression relation

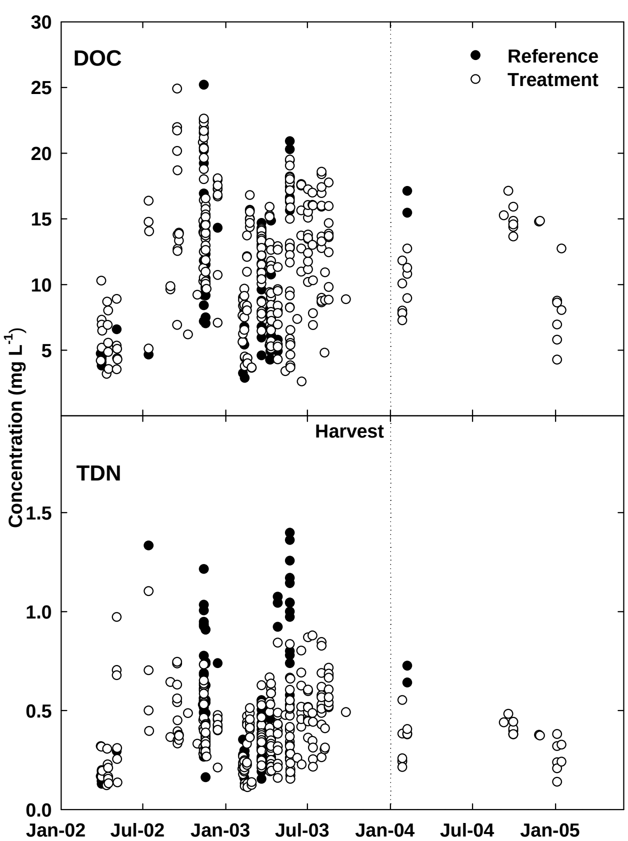

Figure 1. Time-series of stream water samples. The record includes stormflow events and thus multiple samples on particular days. The relationship was unchanged after harvest for both DOC and TDN ($p>0.1$ for test of slopes).

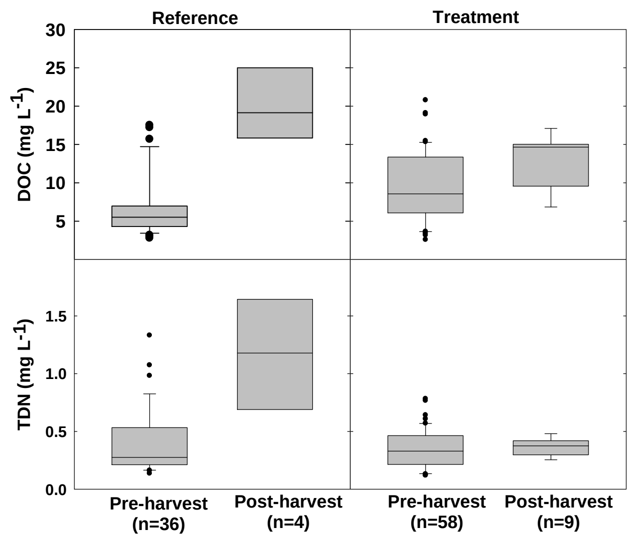

Figure 2. Average (unweighted) daily stream water concentrations pre and post-harvest.

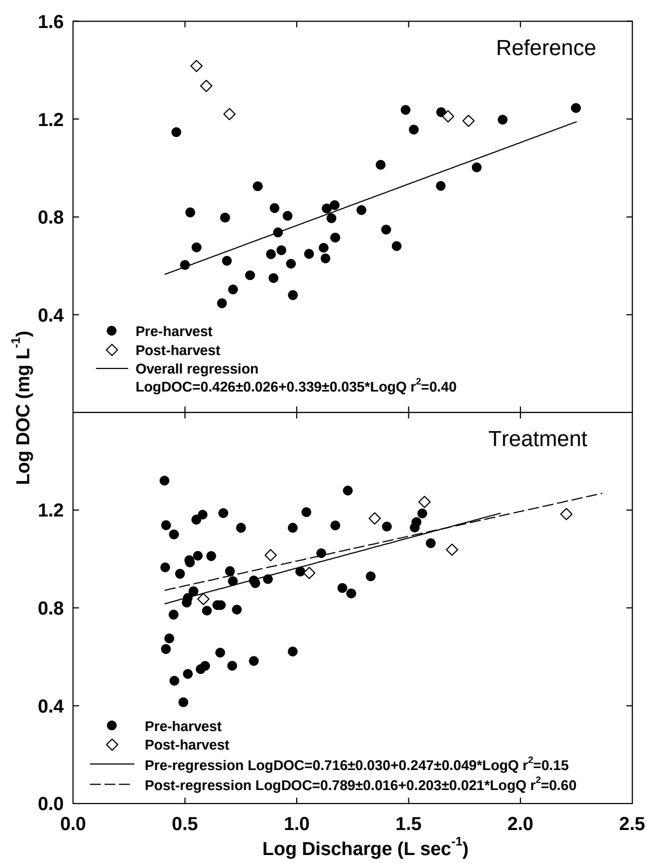

Figure 3. Log discharge – log concentration

relationship for daily stream water concentrations of dissolved organic carbon pre- and post-harvest in both the reference and treatment watershed.

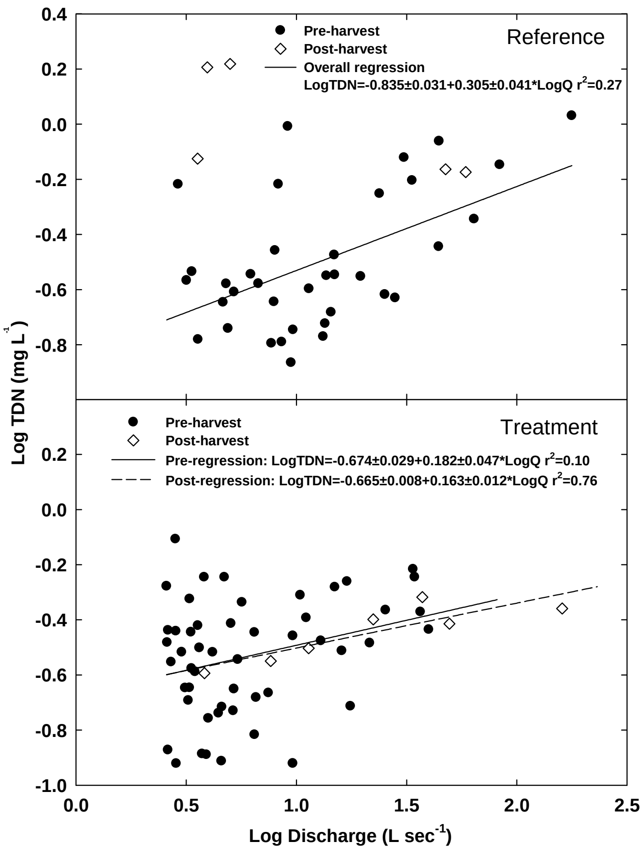

Figure 4. Log discharge – log concentration relationship for daily stream water concentration of total dissolved nitrogen pre- and post-harvest in both the reference and treatment watershed.

Despite a lack of change in DOC and TDN concentration, yield of DOC and TDN estimated using the measured discharge and the discharge-concentration regressions demonstrated an increased yield in the treatment watershed relative to the reference watershed (Fig. 5). The double mass curves have nearly a two-fold increase in the slope of relationships for both DOC and TDN.

The double mass curves were estimated based on the discharge-concentration rating curves but these were quite variable so a second estimate using the volume weighted mean concentration (VWM) of DOC and TDN was also utilized in each watershed both pre- and post-harvest (Table 1). These VWM concentrations were scaled by the water yield in each watershed and period (i.e., pre- or post-harvest) only using days when discharge was measured in both watersheds (i.e., the total fluxes are underestimates). The VWM concentrations had similar increasing trends in both watersheds from the pre- to post-harvest period while fluxes declined in the reference from pre- to post-harvest but increased in the treatment.

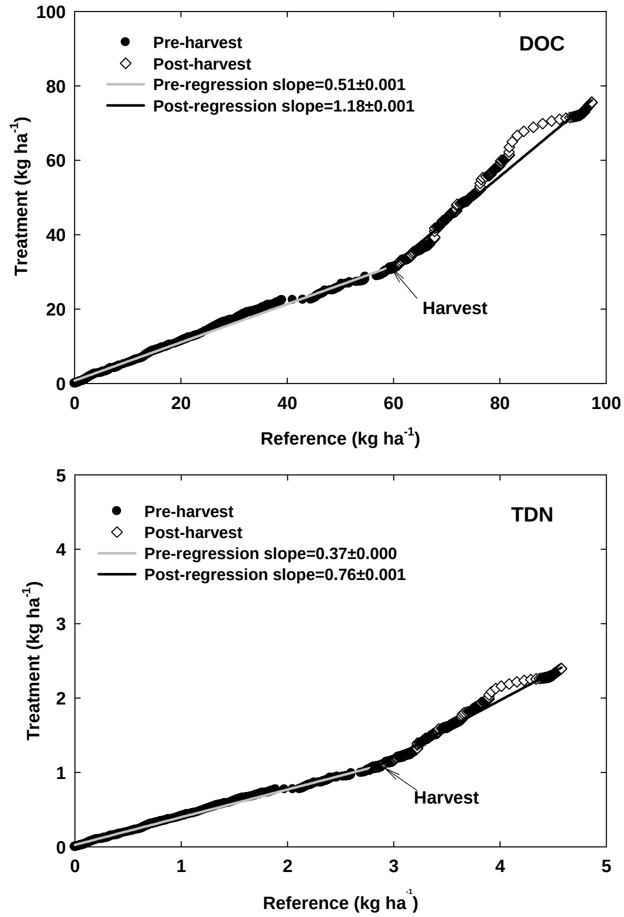

Figure 5. Double mass curves for dissolved organic carbon and total dissolved nitrogen in stream water fluxes pre- and post-harvest.

DISCUSSION

The initial forest harvest in 1974/75 demonstrated increased water yield (25 cm in the first year following harvesting), increased peak flows (30-50%), increased hillslope erosion (5-fold), and increased stream temperature (up to 11ºC on hot days) (Hewlett 1978; Hewlett and Fortson 1982; Burns and Hewlett 1983, Hewlett and Doss 1984).

At this same time, no change was observed shortly after harvest in N concentration of weekly grab samples but increases in stormwater concentrations were observed for NO_3 (4 to 8-fold). No change was observed in Total Kjeldahl Nitrogen (TKN – includes organic N and NH_4-N). For the other inorganic elements, P and Mg were not altered but K, Ca, and Na declined after harvest. Given the increase in water yield there was an estimated increase in NO_3-N exports of 0.2 kg ha^{-1} while losses of some cations

(Mg, Ca, Na) ranged up to 8 kg ha^{-1} (Hewlett 1979; Hewlett et al., 1984).

During the second rotation harvest of this experiment a 63% increase in total stream flow volume and increased peak flows were observed in the treatment watershed after harvest (Jackson et al., *accepted*). There was also evidence for a near tripling of suspended sediment export in the treatment watershed, although the total suspended sediment yields were relatively low (<1000 kg ha^{-1} yr^{-1}).

Table 1. Water yield for the pre- and post-harvest periods based only on days when flow was measured in both watersheds; Volume weighted mean DOC and TDN; and DOC and TDN flux estimated from the yield and mean concentration.

Basin	Period	Water Yield	VWM DOC	VWM TDN	DOC Flux	TDN Flux
		cm	mg L^{-1}		kg ha^{-1}	
Ref	Pre	65.0	11.4±4.2	0.60±0.26	74.1	3.9
	Post	39.7	16.4±4.9	0.75±0.62	65.1	3.0
Trt	Pre	32.6	10.9±1.7	0.38±0.06	35.5	1.2
	Post	34.0	14.2±6.3	0.42±0.12	48.3	1.4

Many of the responses observed in this paired watershed study are consistent with others from the region including those of Van Lear et al.(1985) in the Piedmont of South Carolina or the extensive research in the Coweeta Hydrologic Laboratory in the southern Appalachian Mountains of North Carolina (Swank et al., 2001).

The response in DOC and TDN are consistent with previous research in finding a general seasonality (Fig. 1) as well as an increase in concentration with increasing discharge (Fig. 3 and 4). The discharge-concentration relationship is typically demonstrated during the rising limb of storm hydrographs as water flows through surface organic horizons in route to the stream (Qualls et al., 1991). DOC and TDN response to forest harvest can vary depending on watershed (i.e., presence of wetlands) but even when increases in concentration have been observed change in total flux has remained modest (Hobbie and Likens, 1973). Typically, TDN fluxes have not responded to harvest with larger increases as is often observed for inorganic forms of N (e.g., NO_3 and NH_4) but does cycle closely with DOC (Goodale et al., 2000); a pattern observed here as well. The estimated fluxes of DOC and TDN out of the watersheds (Table 1) are also within the range previously summarized: 10-100 kg ha^{-1} yr^{-1} for DOC and 0-3 kg ha^{-1} yr^{-1} for TDN.

CONCLUSIONS

This second rotation, paired watershed study of BMP effectiveness in maintaining stream water quality continues to demonstrate that losses of DOC and TDN are largely driven by changes in stream water volume and small in magnitude.

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