Stream chemistry, solute fluxes and mesoscale land-use change in Amazônia

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SUMMARY:
Synoptic sampling streams in Rondonia draining areas between 5 km^2 and 10,000 km^2 shows enhanced dissolved Si and cation loads in base flow waters and enhanced cation loads at high flows in catchments dominated by pasture and young secondary growth as defined by a spectral mixing classification of Landsat TM imagery. During the dry season, concentrations of both dissolved Si and total cations were higher in deforested areas than forested areas, while during the wet season, only total cation concentration was significantly enhanced. For forested catchments, linear relationships exist between solute concentrations and fluxes in stream waters and the percent of the basin occupied by soils with greater than 50% base saturation. This relationship was used to calculate concentrations and fluxes that would be expected before deforestation for the deforested catchments.

MOTIVATION
Studies in both temperate (Likens et al 1970) and tropical ecosystems (Williams and Melack 1997, Bruijnzeel 1991) indicate that anthropogenic disturbance of terrestrial plant communities increases solute yields to streams. However, variations in this "land use signal" due to changes in soil and discharge are not well documented, especially in the tropics. To better understand the effects of land-use change on solute yields from tropical watersheds, a synoptic sampling of streams in watersheds with differing land-use intensity, soil type, and basin size was carried out in Rondônia, Brazil during both wet and dry seasons.

FIELD AREA:
The Brazilian state of Rondônia lies in the southwestern Brazilian Amazon. Tertiary sediments in northern Rondonia intersect with the Brazilian craton in the state's center, with arenitic sandstones in the southeast. The topography is relatively flat in the northern and southernmost parts of the state, and in the center is gently undulating with occasional rocky hills and small massifs. Soil types include highly leached oxisols in the north, ultisols and alfisols on the craton, and sandy soils in the southeast. The undisturbed forest cover consists of closed and open tropical forest in the north and center, with occasional savannas in the southeast (Proje to RADAMBRASIL, 1978). Rainfall averages 2500 mm/year with the wet season lasting from October to April.

The state has been colonized by loggers, ranchers and farmers since the 1970s, and land use has been dominated by replacement of forest with grassland for cattle ranching, though some pasture has reverted to secondary forest.

METHODS:
Stream water samples were collected from each watershed during the dry season (August 1998) and wet season (late January-early March, 1999, see Figure 1 for hydrograph and sampling dates for one stream). They were filtered in the field with Gelman GFF 0.7 μm filters. Additional samples at 4 streams with discharge stations were collected between October and December, 1998, and were filtered in the lab within 24 hours of collection. Cations were analyzed by atomic absorption spectrometry and dissolved Si by the colorimetric acid-molybdate method.

Watershed boundaries were digitized in a geographic information system using 1:100,000 scale topographic maps and the coordinates of collections recorded with a global positioning system. Land use was determined from 1996 Landsat TM images classified by spectral mixture analysis (SMA) using endmembers selected visually from the image. 'Deforested' for this study refers to pastures of varying age and young or secondary forest as recognized by SMA. Natural grasslands in the south were classified individually via image interpretation. Watershed soil characteristics were determined from digitized soil maps and soil profile analyses from the Sigteron project by Tecnosol.

Flux calculations were made for seven streams gauged by the Brazilian agencies Companhia de Pesquisa de Recursos Minerais and the Agencia Nacional de Energia Elétrica. Discharge-concentration relationships were developed for each station, and the average flux calculated for years having discharge data for all stations

To prevent duplicate analysis of streams, only those watersheds where no upstream samples were taken are included in the analysis of the relationships between solute concentration and watershed properties.

RESULTS AND DISCUSSION:

Watershed characteristics

Sampled watershed sizes ranged from 25 to 12,000 km2 (See Figure 2A) for the analysis of concentration-watershed relationships, and from 800 to 33,000 for the flux calculations. Forested watersheds (less than 16% deforested) included both highly leached and highly eutrophic soils (defined as soils with greater than 50% base saturation), while deforested catchments (greater than 40% deforested) occurred more often on eutrophic soils (See Figure 2B and 2D). The deforestation extent ranged from 0 to 75% deforested (See Figure 2C).

Effect of soil type on solute concentrations

Deforested watershed streams had consistently higher concentrations of all solutes in both seasons (See table 1), while forested watersheds have concentrations within the range of streams draining South American shields (Lewis et al, 1995). However, comparison of solute concentrations between forested and deforested watersheds is confounded by variations in soil properties. Average differences between forests and deforested catchments may be exaggerated, since the sampled deforested watersheds contain more eutrophic soils than forested sites (Figures 2C and 2D). To clarify the influence of soil properties on solute concentrations, the relationship between soil type and stream cation and dissolved Si concentrations was established for forested catchments only. Catchment soil type was represented by the percent of each catchment area containing soils with base saturation greater than 50%, refered to below as eutrophic soils. This calculated percent of the catchment with eutrophic soils is strongly correlated with the concentrations of Na^+, Ca^{2+}, Mg^{2+}, K^+, and dissolved Si for forested catchments in both the wet and dry seasons (Figure 3, Table 2). The relationship between solute concentrations and soil type in forested catchments was used to calculate 'background' concentrations for all catchments, which was subtracted from the observed concentration to give a corrected concentration.

The corrected concentrations increase with the extent of deforestation for both cations and dissolved Si during the dry season, while only the cation signal persists in the wet season (Figure 4).

Solute fluxes and cation-specific responses to deforestation

To illustrate the application of the soil-correction method to flux data, the annual flux of cations and dissolved Si in kg/ha was calculated for seven streams with discharge stations. Each station was visited once during the dry season and between four and seven times during the wet season to capture concentrations at varying discharge (See Figure 1 for hydrograph and sampling dates for one stream). To investigate the influence of the dry season samples on the concentration-discharge relationship and calculated flux rate, fluxes were calculated using concentration-discharge relationships from 1) both seasons and 2) the average of wet season concentrations. The

sensitivity of flux estimates to additional data was assessed by augmenting the current year's data with data from Mortatti (1986) for five stations. The difference between fluxes calculated with the current and augmented data sets was less than 5% for all stations for Ca^{2+} and Mg^{2+}, less than 10% for all but one station for dissolved Si, and less than 20% for all station but one for Na^{+} and K^{+}. The calculated fluxes for all catchments fall within the range for tropical catchments on oxisols and ultisols (Table 2, Bruijnzeel, 1991).

As with the concentration data, comparing flux data between forested and deforested catchments is complicated by differences in soil properties between catchments. For forested catchments, the fluxes of cations and dissolved Si are related to the percent of eutrophic soils in the catchment (Figure 5A). This tentative soil-flux relationship for forests was used to calculate a corrected flux for the seven discharge stations. The corrected flux rates vary markedly for the different cations and dissolved Si. For areas with greater than 25% deforestation, the average flux rate is higher for Ca^{2+} and Mg^{2+}, and the same as or lower than the calculated forested background levels for Na^{+}, K^{+} and dissolved Si. (Table 2 and Figures 5C and 5D). The sensitivity of dissolved Si, Na^{+} and K^{+} flux calculations to inclusions of additional data suggests that they should be more intensively monitored for accurate estimates of their flux rates, particularly for smaller catchments.

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