Pathways of nutrient flow in an Eastern Amazon watershed.

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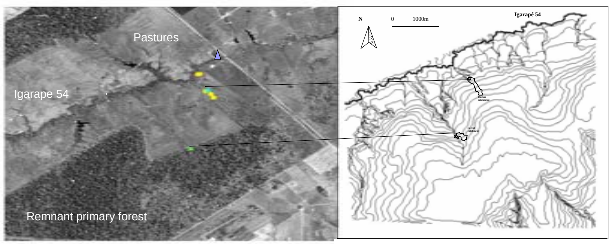
Abstract

To investigate pathways of nutrient flow to streams we combine data from numerous flow paths in the 200 km^2 watershed of Igarapé Cinqueta e quatro in Fazenda Vitoria Paragominas, Brazil. Flow paths include rainwater, forest throughfall, forest and pasture surface runoff, upland groundwater wells, near-stream groundwater wells, and a single riparian zone well. A geochemical mixing model with end-member mixing is used to assess discharge fractions from specific flow paths. Using a graphical approach, K and Ca were determined to be well behaved end-member tracers. The volume-weighted mean concentrations of three end-members (pasture surface runoff, upland groundwater, and hyporheic groundwater) geometrically encompass ~85% of the streamwater concentrations. A principle components analysis using seven solutes indicates, however, that as many as five end-members may be appropriate. Solution for the discharge fractions using three end-members over two annual cycles of high and low flows demonstrates that during the low flow periods of the year hyporheic groundwater are predominant contributing ~70% fractional discharge. As stream flows increases pasture runoff has increasing importance with fractional discharge increasing from 0 to ~20%. More interesting, perhaps, is the increasing importance of upland groundwater during these same periods with fractional discharge increasing from 20 to ~80%, on average. Pressure waves (i.e., a rapid forcing of groundwater to the stream from increased pore pressures due to rainfall inputs) may be an important process in this watershed.

Research site and methods



Modified from de Moraes et al., 2006

Figure 1. Fazenda Victoria ranch in Paragominas, Pará, Brazil (2° 59' S, 47° 31' S). The left-hand graphic is a 2002 IKONOS image of a subsection of the watershed. The right-hand graphic is a topographic map (5m contours) of the same subsection. The perennial stream, Igarapé 54, bisects the watershed of which 13,000 ha is upstream of our sampling station within the ranch. The ranch was first established in the early 1970's and has been ~80% deforested since that time. Average annual precipitation is 180 cm, although there is a long dry season stretching from June to October. Igarape 54 has been sampled relatively consistently since 1996 while other solutions such as throughfall, litter leachates, surface runoff, soil solutions, and groudwaters have been sampled over various annual periods. In the current work solutions collected from 1999 to 2002 are utilized for the mixing model analysis. Green triangles indicate the locations of forest and pasture microbasins that served as collection centers; yellow circles are groundwater wells; and the blue triangle the stream sampling location. During this period solutions were collected on a nearly daily basis. Samples were analyzed of pH, conductivity, alkalinity, dissolved organic carbon (DOC), total dissolved nitrogen (TDN), NO_3, NH_4, total dissolved P (TDP), Ca, Mg, K, Na, Cl, SO_4, Si, Al, Fe.

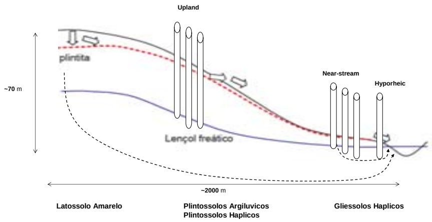


Figure 2: Schematic representation (not to scale) of hillslope profile from stream to plateau. Arrows indicate hypothesized water flow pathways and wells indicate the topographic position of sampling. Soils on the landscape (soilscapes) from a catena of deep Oxisols (Haplustox) on plateaus, Ultisols (Haplustult) intermixed with plinthite on side slopes, and redoximorphic Ultisols (Aquults) along the stream channel.

Table 1: Soil chemical characteristics for profiles along the soilscape in Fazenda Vitoria, Paragominas. Latossolos (n=3) were collected under mature forest in 1996, Plintossolos (n=3) within managed pasture in 1999, and Gleissolos (n=1) within riparian forest in 2000. Note the accumulation of carbon in the surface soils within the riparian forest as well as the extremely low base cation concentrations.

Soil Type	Depth cm	pHsalt	Carbon %	Ext-P ug/g	Exch-K cmolc/kg	Exch-Ca cmolc/kg	Base Saturation %
Latossolo	0-10	3.8	2.4	1.6	0.09	1.25	69
	10-20	3.7	1.4	0.6	0.04	0.40	39
	20-50	4.0	1.0	0.2	0.02	0.20	35
	50-100	4.1	0.5	0.1	0.01	0.07	26
	100-200	4.3	0.3	0.1	0.00	0.05	43
Plintossolo	0-10	3.8	1.4	3.6	0.09	0.67	57
	10-20	3.8	1.0	2.5	0.04	0.31	34
	20-50	3.9	0.6	1.4	0.02	0.33	36
	50-100	3.9	0.4	0.6	0.02	0.21	26
	100-200	4.0	0.3	0.3	0.01	0.10	19
Gleissolo	0-10	3.8	4.2	1.4	0.17	0.05	17
	10-20	3.8	1.3	0.7	0.02	0.01	6
	20-50	3.9	0.8	0.8	0.01	0.02	10
	50-100	4.0	0.5	0.2	0.00	0.01	3
	100-200	3.9	0.3	0.4	0.00	0.01	2

Table 2: The geochemical mixing model approach solves the following set of simultaneous equations to quantify the fractional input of each type of solution (e.g. pasture surface runoff, hyporheic groundwater, and upland groundwaters).

$$f_{\text{surface}} + f_{\text{hyporheic gw}} + f_{\text{upland gw}} = 1$$

$$[Ca]_{surf} f_{surf} + [Ca]_{lat} f_{lat} + [Ca]_{grdwtr} f_{grdwtr} = [Ca]_{stream}$$

$$[K]_{surf} f_{surf} + [K]_{lat} f_{lat} + [K]_{grdwtr} f_{grdwtr} = [K]_{stream}$$

Results

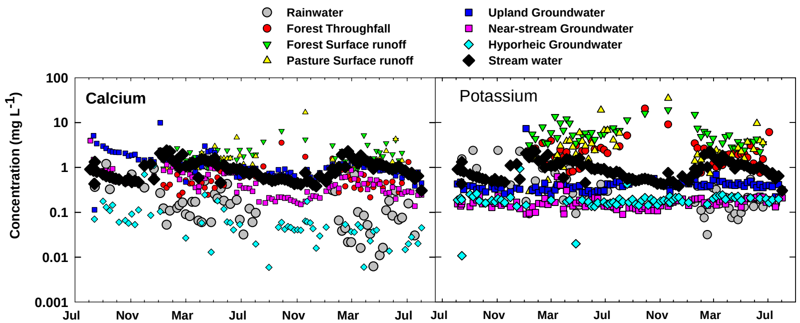


Figure 3. Ca and K concentrations for all sources of solutions collected during the July 1999 to September 2001. The is a clear seasonal pattern in stream water concentrations for both Ca and K with concentrations increasing during the rainy season. There is also a relative strong segregation in the concentration of surface sources (i.e., throughfall and surface runoff) relative to subsurface sources (i.e., groundwaters). The upland groundwater well is ~60 m from the stream with depth to the water table of ~18m. The riparian well is 1m from the stream edge and can be inundated at times or up to 50 cm below the surface.

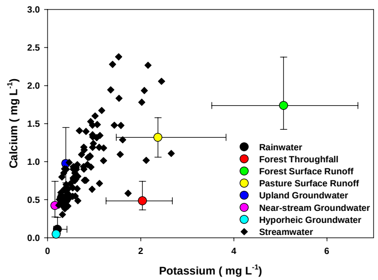


Figure 3. End member mixing diagram for K-Ca concentrations. The black diamonds are stream water concentrations for all years of collection. The colored circles are median values for the various solutions and the cross marks are the inter-quartile range (i.e., 25 and 75 percentile). In an ideal case all stream water points would be enclosed by the lines of triangle connecting the median values of three end-member solutions.

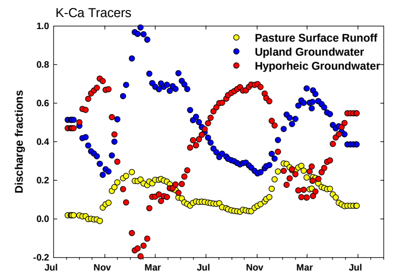


Figure 4. Solution for discharge fractions utilizing a 2-tracer 3-end-member model. Fractions indicate the contribution required from each source to estimate streamwater concentrations. Clearly, during the Jan. to Mar. period for 1999 the three end-members were insufficient to describe stream concentration. Over two annual hydrographs hyporheic groundwater are predominant during the low flow periods of the year (~70% fractional discharge). As stream flows increases pasture runoff has increasing importance with fractional discharge increasing from 0 to ~20%. More interesting, perhaps, is the increasing importance of upland groundwater during these same periods with fractional discharge increasing from 20 to ~80%,

Conclusions

The current analysis demonstrates that stream water concentrations of K and Ca can generally be defined by a proportional mixing of surface and ground water solutions. Increasing surface source water during the rain season is to be expected and the estimated input of ~20% is consistent with hydrologic models for the site. The role of hyporheic groundwaters indicates a potential important role for riparian areas in controlling streamwater concentrations, at least during low flow periods of the year. The increasing importance of upland groundwater during the rainy season is an interesting result that suggests pressure waves caused by large rainfall events may accelerate groundwater flows.