Hydrology and hydrochemistry of a montane rainforest catchment in Queensland, Australia

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Abstract Hydrometric and hydrochemical monitoring have been carried out at Birthday Creek experimental catchment, Queensland, since 1988. The montane site lies in the Wet Tropics World Heritage Area at an altitude of 1000m, and supports relatively undisturbed rainforest. The area experiences a seasonal climate with monsoon depressions and cyclones bringing 80% of the annual precipitation between November and March. Approximately 40% of incident precipitation is lost as annual evaporation. The catchment soils are highly responsive to precipitation with hydrometric and hydrogeochemical studies suggesting that overland flow and shallow subsurface storm flow are the dominant hydrological pathways during storm events. Nevertheless, the granitic bedrock forms a significant aquifer which sustains baseflows. Streamwater is circumneutral (mean pH=6.66) and the ionic composition is dominated by Na and Cl (concentrations 5.1 and 6.2 mg l^{-1} respectively). Alkalinity and base cation concentrations are low, reflecting the weathering history of the site. Nutrient concentrations also are low due to efficient forest nutrient cycling. Baseflow chemistry is spatially and temporally constant in the catchment, but streamwater becomes increasingly dilute during rainstorms as overland flow and soil-derived water provide the main sources of streamflow.

INTRODUCTION

Hydrological processes in rainforests of the humid tropics are highly susceptible to the impact of land conversion (Bruijnzeel, 1990). Given the widespread clearance and disturbance of rainforests throughout much of the humid tropics, there is a need to characterize processes operating in relatively undisturbed ecosystems to aid the development of sustainable land management strategies for this sensitive zone (Bonell & Balek, 1993). In a recent review of hydrological studies in tropical rainforests, Bruinzeel (1990) noted that most investigations focused on lowland watersheds and there was a dearth of studies in montane environments. To help redress this imbalance, we report the preliminary findings of an integrated hydrological and hydrochemical study based in the wet tropics of Queensland, Australia. The montane rainforests of

Australia are particularly important as they form the headwaters of many large river systems that are vital regional water resources in the earth's driest continent (Department of Primary Industries, 1993). Moreover, both forests and streams in this area are characterized by extremely high levels of biodiversity (Lake, 1995). The specific aims of this paper are: (i) to provide a tentative water balance for a small experimental catchment; (ii) identify the principal hydrological pathways generating stream runoff and (iii) outline the main hydrochemical characteristics of the stream under baseflow and storm conditions.

STUDY AREA

The Birthday Creek experimental watershed lies in the Paluma range of the Wet Tropics World Heritage Area, 80 km north of Townsville, Queensland (Fig. 1). The stream drains a 40-ha catchment which spans an altitudinal range from 840 to 900 m and ultimately drains into the Burdekin River. The underlying geology is predominantly comprised of granites, microgranites and volcanics that are Carboniferous to Permian in age. Highly weathered Krasnozems of low fertility are the dominant soil cover, which supports a simple notophyll vine rainforest (Tracey, 1982). Some of the more accessible parts of the catchment interfluves were selectively logged in the early 1960's, though the disturbance was relatively low with 8-12 trees ha^{-1} being harvested (Congdon & Herbohn, 1993). The area has been managed for conservation purposes since the Wet Tropics World Heritage Area was established in 1988.

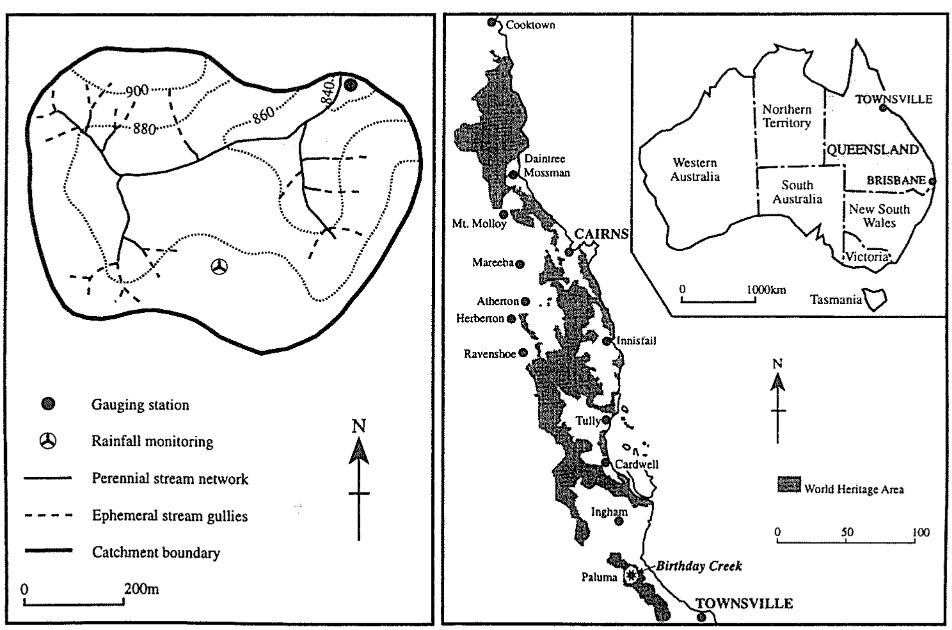

Fig. 1 Location of study area and topography and instrumentation in the Birthday Creek experimental catchment.

The region is subject to a monsoon climate characterized by hot, wet summers and mild, dry winters. Mean annual precipitation is about 2600 mm with approximately 85% of this falling between November and April. This reflects the influence of the monsoon trough which brings moist air to the north of the study area and results in the frequent occurrence of tropical depressions and cyclones (Sumner & Bonell, 1988). Mean monthly temperatures range from 16 to 20°C between October and March and from 13 to 16.5°C between June and August.

INSTRUMENTATION AND METHODS

Streamflow has been measured at Birthday Creek since 1988 and a Westdata capacitance probe currently is used in conjunction with a v-notch weir. Two tipping bucket raingauges also are located within an artificial clearing in the catchment. Since August 1995, streamwater samples have been collected at approximately weekly intervals for hydrochemical analyses and an ISCO autosampler has been installed for more frequent streamwater collections during rainstorms. In addition, baseflow hydrochemical surveys of streamwater have been conducted. All samples are analyzed for a variety of determinands at the Australian Centre for Tropical Freshwater Research at James Cook University using standard methods described by Elsenbeer *et al.* (1994). Physical and chemical properties of catchment soils have been described by Krt (1990) and Congdon & Herbohn (1993), respectively.

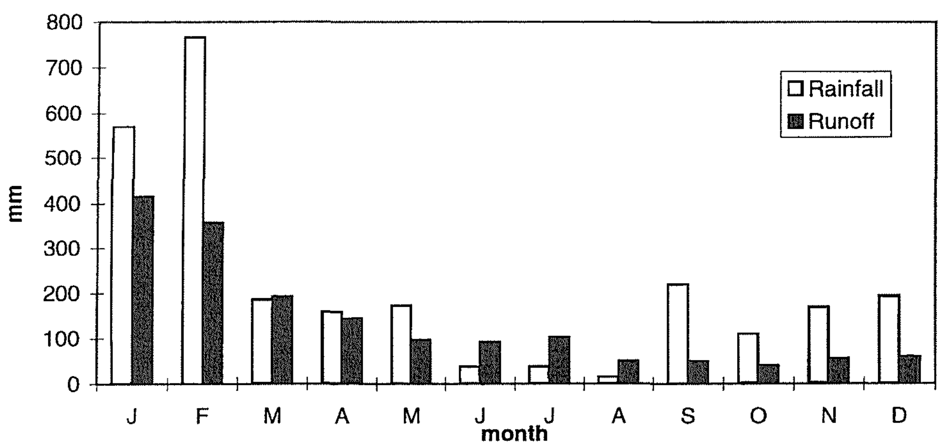

Fig. 2 Mean monthly rainfall and runoff at Birthday Creek experimental catchment

CATCHMENT HYDROLOGY

Water balance

The annual flow regime of Birthday Creek closely reflects climatic seasonality (Fig. 2). The mean daily flow of the third order stream is 0.02 m^3 s^{-1} which is 4.5 mm d^{-1} of runoff, giving a total mean annual runoff of approximately 1650 mm. Most runoff occurs during the wet summer months and significant groundwater stores sustains baseflows throughout the winter. As with most studies in rainforest catchments, water balance estimates must be viewed with caution due to difficulties in measuring high flows accurately, particularly during cyclones, and due to inaccurate descriptions of catchment boundaries. Nevertheless mean annual evaporation can be tentatively estimated at 980 mm or 38% of gross precipitation. This is within the range of evaporation estimates quoted in previous montane rainforest studies (Bruijnzeel, 1990). Soils moisture deficits due to evaporation accumulate during dry winter months resulting in low runoff in the early summer wet season (Fig. 2).

Soil hydrology and catchment hydrological pathways

The dominant Krasnozem soils at Birthday Creek have a 10-cm deep, organic-rich horizon overlying a clay-rich subsoil dominated by weathered granite (Table 1). Saturated hydraulic conductivity (K_s) measurements made using a well-permeameter show that the surface organic horizon is highly permeable (K_s=15 m d^{-1}) compared with the underlying clay-rich subsoil (K_s=0.2 m d^{-1}). This reflects the presence of macropores in the upper horizon due to abundant tree roots and intense biological activity. With increasing depth in the mineral soil, hydraulic conductivity continues to decrease (0.02 m d^{-1}) due to the high clay content and the reduced abundance of tree roots. These soil characteristics are similar to those reported in other humid tropical environments, including the much more extensively studied Babinda experimental catchment in the lowland tropics of Queensland near Cairns (Bonell *et al.* 1981; Bonell & Balek, 1993).

Table 1 Selected mean physical and chemical properties of Birthday Creek soils (K_s- saturated hydraulic conductivity, CEC- Cation Exchange Capacity & %BS-percentage base saturation).

Depth	K_s[1] (m d^{-1})	pH[2]	CEC (meq 100g^{-1})	%BS
0-0.1 m	15.00	3.85	6.29	42
0.1-0.2 m	0.20	4.05	3.22	22
0.2-1.0 m	0.06	-	-	-

[1]After Krt (1990)
[2]after Congdon & Herbohn (1993)

A conceptual model of storm hydrological pathways thus can be hypothesized from soil characteristics, catchment topography and field observations. The perennial stream network of Birthday Creek flows within valleys incised into the plateau, which characterizes the catchment interfluves. The perennial stream network is fed by a series of deep gullies which carry ephemeral streams which only flow during and after heavy rainstorms (Fig. 1). A total of 173 rain days occur each year, however only 26 days produce larger events with precipitation totals exceeding 10mm and only 8 days with over 100mm. The gullies, in turn, are fed by several shallow topographic hollows which drain the catchment interfluves. During rainstorms, the hydraulic conductivity of the upper soil profile is sufficiently high to allow even intense tropical rain (intensity of 60 mm h^{-1}: 2 year return period) to infiltrate. During prolonged rainstorms however, reduced permeability in the subsoil dictates that infiltrating water is deflected laterally on the steep catchment slopes and then into the stream and gully networks. In the shallow topographic hollows, continuing rainfall and/or delivery of water from upslope causes of the upper soil horizons to become saturated and overland flow is generated, which results in substantial ephemeral flows in the gully network.

The rapid response of the catchment is showed in the hydrograph produced by Cyclone Sadie in February 1994 (Fig. 3). In this extreme rainstorm where over 1,100 mm of rain fell in 40 h, the hydrograph responses rapidly to individual rainfall pulses (which exceeded intensities of 30 mm h^{-1} for prolonged periods) and the rapid response could only occur as a result of "new" water being transferred rapidly to stream channels by overland flow. Moreover, the high runoff coefficient for the event, tentatively estimated at over 0.90, shows that a relatively small proportion of rainfall infiltrated to depth.

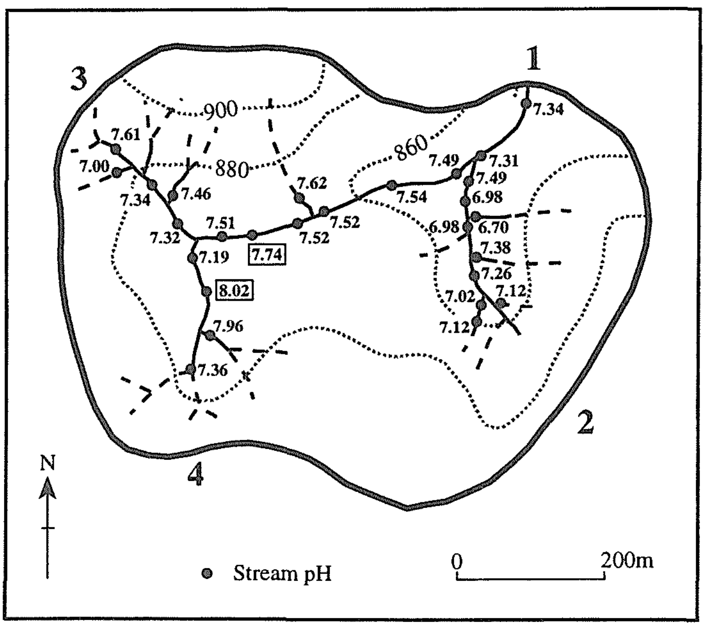

Fig. 3 Rainfall-runoff response during Cyclone Sadie at Birthday Creek 31 January-2 February 1996.

Despite the responsiveness of the catchment, substantial winter baseflows are sustained presumably from a deep groundwater source. This suggests that infiltration to depth probably does occur, despite the low hydraulic conductivity of the subsoil. It is likely that macropores created by tree roots contribute to this process by allowing a limited amount of vertical preferential flow.

CATCHMENT HYDROCHEMISTRY

General characteristics

Streamwater at Birthday Creek is dilute and circumneutral (mean pH 6.66); the ionic composition is dominated by marine-derived solutes, and Cl and Na are the dominant anion and cation, respectively (Table 2). Despite the circumneutral pH, streamwater alkalinity is relatively low, as are concentrations of Ca and Mg. These low concentrations of weathering products reflects the prolonged decomposition sequence of minerals in the bedrock, which has resulted in the long-term leaching of base cations under an intense tropical weathering regime. Consequently, less stable minerals such as feldspars, biotite and hornblende, and more resistant aluminosilicate minerals, have weathered to more stable clays and oxyhydroxides of Fe and Al, resulting in low concentrations of silica and other weathering products. Nutrient concentrations also are low reflecting the efficient cycling processes characteristic of tropical watersheds (Lesack, 1993).

Table 2 Chemical composition (mg l^{-1}) of Birthday Creek (1995-1996): storm flow is highest flow sampled.

Statistic	pH	Alk.	Cl	SO_4	NO_3- (N)	Na	K	Ca	Mg	TOC	SiO_2	Al	Fe
mean (n=16)	6.66	3.34	6.2	2.88	0.015	5.1	0.95	0.48	0.36	1.78	4.1	0.08	0.05
min	5.77	1.6	3.5	1	0.004	3.3	0.8	0.1	0.1	0.4	3.3	0.01	0.01
max	7.92	4.2	7.2	6.3	0.074	6.5	1.2	1.5	0.6	4.7	5.0	0.48	0.18
Stormflow	7.00	2.5	4.3	1.9	0.015	5.1	1.0	0.4	0.2	2.0	-	0.30	0.18

Table 3 Spatial variation of baseflow chemistry (mg l^{-1}) in Birthday Creek and its tributaries (see Fig. 4).

Location	pH	Cl	SO_4	Na	K	Ca	Mg	SiO_2	Al	Fe
1 Creek	7.3	5.8	1.0	3.1	0.9	0.2	0.9	4.1	0.04	0.03
2 Weir	7.5	5.9	0.8	3.2	1.0	0.1	0.8	4.1	0.03	0.04
3 Road	7.3	5.8	1.4	3.6	1.3	0.2	0.8	5.0	0.04	0.04
4 Rain	7.2	5.8	0.7	2.9	0.5	0.1	0.1	3.3	0.04	0.03

Baseflows

Concentrations of most solutes tend to be highest during baseflows due to longer residence times in the catchment. A baseflow survey (field pH measurements) of the perennial stream network in the catchment was carried out during low flows in 1996, following an earlier survey of the major ion chemistry of the main tributaries of

Birthday Creek (Table 3). Both surveys show that the spatial variation in baseflow chemistry is very limited, suggesting a well-mixed groundwater source in the catchment. During the February 1996 survey, pH exemplifies this constancy (Fig. 4). The two highest pH values show the localized bedrock influences on streamwater chemistry as they occur where the creek crosses diorite dikes. The diorite dikes contain mineralized calcium-carbonate veins, which due to there high weatherability, contribute to the streamwater buffering.

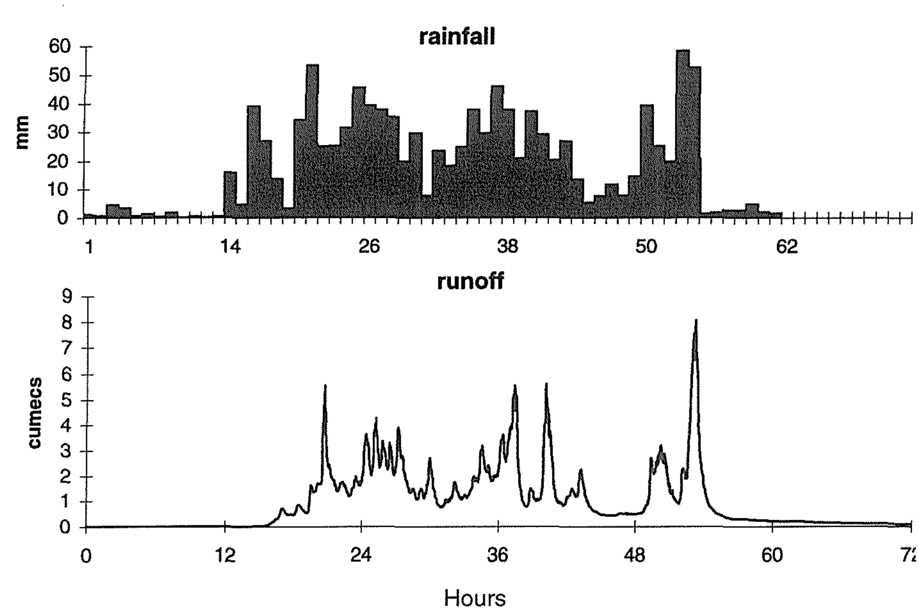

Fig. 4 Spatial variation of pH in Birthday Creek during the 1996 baseflow survey. (Numbers 1-4 correspond to sites listed in Table 3).

Storm runoff

Attempts have been made to monitor hydrochemical changes during rainstorms in recent wet seasons. Due to logistical and technical problems, the streamwater hydrochemical response was only determined for relatively small events. The streamwater hydrochemical response of selected solutes to a 22.6 mm rainstorm on 6 February 1996 is shown in Fig. 5. The rain fell over 30 min. and produced an almost instantaneous streamwater response. The pH of streamwater decreased from 7.4 to 7.0 and total organic carbon concentrations increased. The fact that no overland flow was observed during the event suggests that soil derived water provided a substantial proportion of streamflow, along with direct throughfall into the stream channel. Calcium concentrations decrease which also is consistent with a dilution of groundwater during the rainstorm. These results are similar to those reported by Elsenbeer *et al* (1994) for the Babinda catchment. However, in this rainstorm,

subsurface stormflow seems to have been the dominant source of storm runoff as little overland flow was observed. Presumably during larger events, the infiltration capacity of the catchment soils will cause more overland flow which in turn, will cause the chemistry of streamwater towards the composition of throughfall and ultimately rainfall, though further work monitoring large events and characterizing the chemistry of end members is required to support
this hypothesis.

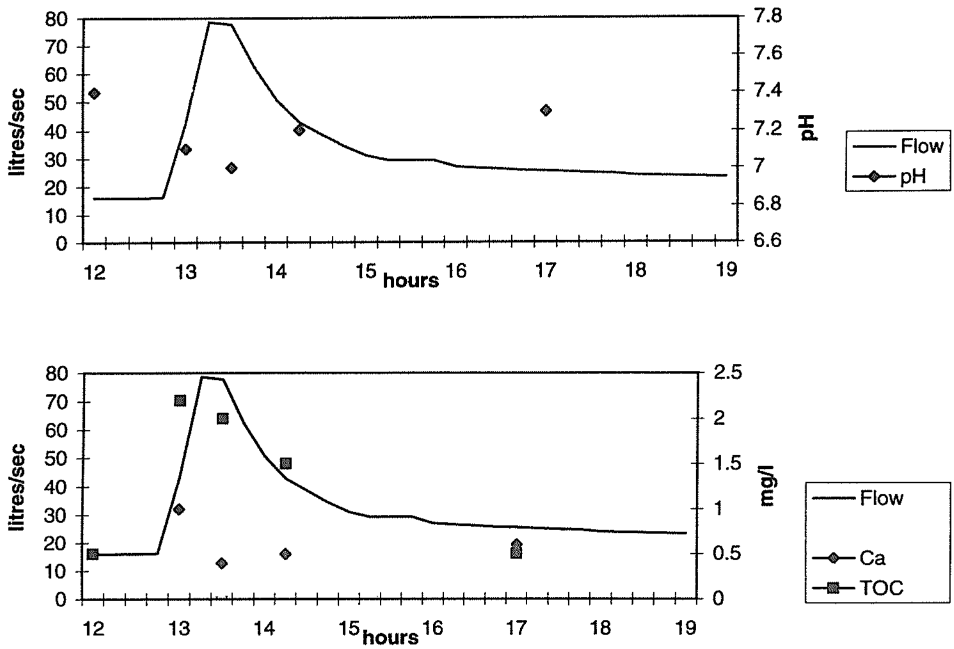

Fig. 5 Hydrochemical variation of Birthday Creek during a rainstorm on 6 February 1996.

DISCUSSION

Preliminary results from Birthday Creek suggest that the main hydrological and hydrochemical processes operating in the montane rainforests of Queensland are broadly similar to those identified in the more intensively studied lowland zone (Bonell *et al.* 1993; Elsenbeer *et al.* 1994). This perhaps is not surprising given the generally similar climate, soils and vegetation that characterize the Queensland wet tropics. The establishment of the Wet Tropics World Heritage Area has resulted in the increased importance of rainforest management for conservation and amenity purposes which will help maintain the integrity of hydrological and hydrochemical processes operating in relatively pristine headwater catchments. However, interest is increasing in rehabilitating degraded land in Queensland where extensive areas were affected by soil erosion and gullying as a result of forest clearance prior to 1988. This study has shown the importance of the upper part of the soil in regulating the hydrology and hydrochemistry of montane catchments. Thus, rehabilitation efforts, and indeed all sustainable land management in this area, must seek to conserve or re-establish this important interface between soil and vegetation systems (Roberts, 1993). This will not only help maintain natural hydrological regimes, but will also conserve good water-quality conditions in the headwaters of many important river systems in Queensland (Department of Primary Industries, 1993). Future work in the catchment will concentrate on rainstorms to assess the extent to which rapidly changing hydrological and hydrochemical conditions influence rainforest stream ecology. Effects on the structure and function of macroinvertebrate communities is the initial focus for research.

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