Effect of Natural Climatic Cycles on Rainfall-Stream Runoff (P-Q) of a 44 ha Catchment Recovering from Selective Tropical Forestry

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In order to understand the potential impact of the recovering vegetation on the catchment hydrology, through for example, the growth of vegetation on logging trails and its impact on overland-flow generation (Douglas et al., 1995), long-term record of rainfall (P) and stream flow runoff (Q) are required to examine the total evaporative losses, as reflected in the P-Q data. Despite this fundamental importance, there are very few water balance studies undertaken within tropical catchments following a single selective harvesting period (Bruijnzeel, 1990, 1996; Yusop, 1996). This means that the impacts of sustainable (*i.e.*, non-clearfell) forms of forestry on catchment water yield are still debated (Bruijnzeel, 1990; Chappell *et al.*, 2004). The problem is confounded further in the Southeast Asian tropics by the recent acknowledgement of the impact of natural cycles in the climate associated with the El Niño Southern Oscillation (ENSO). Such natural cycles may have a significant effect on the purely natural dynamics of the hydrological components.

This study presents an analysis of the eight years rainfall and river flow data of a small catchment (called Baru Catchment) affecting by a single selective forest harvesting. The 44 ha Baru Experimental Catchment is in the Danum Valley area of the Ulu Segama Forest Reserve, Sabah, Malaysian Borneo (4°58' N and 117° 48'E). The average annual rainfall (1986-1999) received at the nearby Danum Valley Field Centre (DVFC) meteorological station was 2,712 mm, but varies with the impact of the El Niño Southern Oscillation (ENSO) from, for example, 1,520.7 mm in the 1997/8 drought year (where the water-year is from the 1 May - 30 April) to 3,791 mm in 1995/6 (Bidin and Chappell, 2003). The catchment is within a melange geological unit, which comprises of siltstones, sandstones, cherts, spilites, and tuffs (Leong, 1974; Gasim *et al.*, 1988). Soils are dominated by Haplic Alisols (Chappell *et al.*, 1999). The catchment, like the region, has an undulating topography with altitude ranging from 120 to 250 m. The slopes around the catchment divide are approximately 18-25°, declining generally to 10° near the main stream, but with short slopes of up to 45° where outcrops of sandstone and tuff occur. Indeed, there is a high density of ephemeral channels in the region, which when incorporated with the perennial stream channels, give a very high drainage density of 20 km km^{-2} (Walsh and Bidin, 1995). This density is even higher if the skidder trails and gullies created during logging are considered.

The Baru Catchment was selectively logged in 1988/9 and the encompassing logging coupe experienced a timber extraction rate of 79.9 m^3ha^{-1} (Moura Costa and Karolus, 1992). A highly heterogeneous mosaic of remnant forest and forest disturbed to different degrees was left in the area (Bidin, 2001; Bidin *et al.*, 2003). Some recovery in the forest (Tangki, In prep.) and erosional processes (Douglas *et al.*, 1995; Douglas, 1999) has been observed in the years following the timber harvesting.

To examine whether the inter-annual dynamics in P-Q are attributable to changes in the re-growth of the selectively logged forest, the effects of the climatic dynamics must be identified. Such climatic cycles may have a significant impact on the short and long term behaviour of the water balance (Chappell *et al.*, 2000, 2001; Bidin, 2001). Changes in the longer-term P-Q (called the 'drift'), perhaps related to changes in the evaporative losses from the forest, will be identifiable once inter-annual cycles (associated with physical phenomena) are removed. Within this study, the strength of seasonal climatic cycles and the possibility that longer-term cycles related to phenomena such as ENSO could be affecting the P-Q data-series was assessed by applying the Dynamic Harmonic Regression (DHR) model of Young *et al.*, (1999). This model was applied to the monthly rainfall (P), riverflow (Q) as well as the P-Q data to allow greater explanation. Data for the eight-year and seven-month period from August 1988 to February 1997 inclusive are used for this analysis.

The model was then used to identify (separately) within-year or 'seasonal' cycles (S_t). Additionally, by combining these seasonal cycles, with the inter-annual cycles and the drift, a model of the rainfall, the riverflow and the P-Q data was produced and the level of explanation ('efficiency') quantified.

The DHR model is a recursive interpolation, extrapolation and smoothing algorithm for non-stationary time-series (Young 1998; Young *et al.*, 1999). The model identifies three components in the time-series, *i.e.*,

$$U_{(t)} = T_t + S_t + e_t \qquad [1]$$

where $U_{(t)}$ is the observed rainfall, riverflow or P-Q time-series, T_t is the trend which includes (a) the 'drift' in long-term average data and (b) the inter-annual cycles, S_t is the periodic component related to annual and intra-annual seasonality, and e_t is the white noise. The S_t term is further defined as:

$$S_t = \sum_{i=1}^{R} \left\{ a_{it} \cos(\omega_i t) + b_{it} \sin(\omega_i t) \right\} \qquad [2]$$

where $a_{i,t}$ and $b_{i,t}$ are the Time-Variable-Parameters (*TVPs*) of the model, R is the number of seasonal components, and ω_i are the set of frequencies chosen by reference to the spectral properties of the time-series. Optimisation of the *TVPs* was achieved by first estimating the Noise-Variance-Ratio (*NVR*) of the *TVPs*. This is achieved in the frequency domain by fitting the logarithmic pseudo-spectrum of the DHR model to the estimated logarithmic AutoRegressive (*AR*) spectrum of the observed rainfall series. Once *NVR* parameters are optimised, a single run of two recursive algorithms, the Kalman Filter and Fixed-Interval-Smoothing equations provide estimates of the various components (Young, 1998; Young *et al.*, 1999).

The DHR modelling approach of Young *et al.* (1999) results in relatively high Noise-Variance-Ratio *NVRs* (about $1\text{x}10^{-2}$) that ensures a good model optimisation to the main seasonal components (*i.e.*, those with longest periodicity) observed within the spectra plot. The efficiency of model in predicting all of the components of the rainfall, riverflow, and P-Q time-series (using the high *NVRs*) is 83 %, 86 % and 79 % respectively. This is considered good and worth noting that the modelled time-series closely matches the observed time-series, but also that the uncertainty is high relative to the dominant cyclicity. This is not surprising given that the dominant seasonal cyclicity (*i.e.*, 12 months) is not that pronounced (relative to the other within-year cycles) within the spectral plots. The lack of a strong seasonal cycle within the rainfall (which would propagate to the rainfall and P-Q data-series) is consistent with the Baru Experimental Catchment being located only 5 degrees north of the Equator. Equatorial regions are known to exhibit little seasonality in their rainfall totals (Pettersen, 1958). Indeed, examination of the observed or modelled rainfall time-series shows that it is very difficult to identify which troughs or peaks are leading to the 12-month seasonal cycle. The tendency for relatively small rainfall totals in April (Chappell *et al.*, 2001) is probably the main determinant.

The estimated trend component was then split into a very slowly changing drift and the inter-annual cyclic component by selecting a much smaller *NVR* of $1x10^{-5}$ (Young, 1998; Young *et al.,* 1999). Relative to the uncertainty bands, the riverflow time-series shows a very clear peak in 1989 and at the end of 1995. These peaks coincide with the so-called 'La Nina' peak on the ENSO cycle observed in Insular South East Asia (Wolter and Timlin, 1998). The ENSO cycles are not as clear in the rainfall and P-Q data, partly as a result of the shortness of the data-series giving large uncertainties over the initial few months of the simulation. Shortness of the data-series also resulted the increase in the P-Q from 1996 to 1997 besides the differences in the observed flows during the water-year 1995/6, which probably results from the approximation of the calibration of the river-levels to riverflows.

Taking into account the uncertainties in the data and the modelling, it is clear that no marked drift is apparent within the rainfall, river flow, and P-Q time-series. This is partly because of the short period of data available for the modelling (*i.e.*, 8-years), which means that it is difficult to set an appropriate *NVR* to separate out meaningful inter-annual cycles. Thus it is possible, that some of the drift may have been 'removed' to form part of the inter-annual cycle. It is clearly important to continue the water-balance measurements to allow a stronger basis for the separation of the drift and inter-annual components. Clearly, more reliable modelling and hence more robust conclusions might be able to be made, if future research could undertake a more detailed quality assurance of the water-balance data.

If the lack of a consistent drift in the P-Q is, however, real then it might indicate that changes in the evapotranspirational losses does not change significantly with only 8-years of forest recovery from the first episode of selective logging. Such a conclusion would be consistent with the results of the only other study undertaken over several years following the first episode of selective tropical logging. The authors of this study (Abdul Rahim Nik and Zulkifli, 1994) concluded that many years of forest regrowth following the harvesting year was required to significantly alter the forest structure and hence evapotranspiration.

While it remains unclear as to whether the 8-years water-balance has been affected by a possible terrain and/or vegetation recovery following selective harvesting, there remains the possibility that the riverflow hydrograph shows signs of change with such recovery. With limited analyses (2-dry years and 2-wet years), Bidin (2001) suggest that the flashiness of the Baru Catchment was reducing slightly, perhaps a result of reducing infiltration-excess flow components concomitant with forest recovery.

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