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Hydrological Processes and Vegetation Succession in a Naturally Forested Area of Southern China

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Abstract

Hydrological processes, climate and vegetation factors were monitored in the Dinghushan Nature Reserve of southern China, combining long term records of rainfall, streamflow and soil moisture with more recent observations of water table depth, throughfall and stemflow in three natural forest vegetation communities. Precipitation in the forested hills of the reserve was found to be greater than on the adjacent floodplain, and seasonal variation in runoff was less variable than rainfall. Water table depth in lower catchment areas showed little variation on an annual time scale but fluctuated significantly in response to rain events on monthly or shorter time scales. Soil water content of the upper profile was lower in 1999-2003 than in 1983-1989 in all three forest types, and Masson pine forest was significantly drier than monsoon evergreen broadleaf forest or mixed pine-broadleaf forest, in spite of greater throughfall and less canopy interception in the pine forest. Vegetation changes associated with ageing and natural succession may have important long term consequences for water yield and hydrological processes in forest ecosystems.

Key words: canopy interception, Dinghushan Nature Reserve, stemflow, throughfall, water yield

Introduction

Water balance of forested ecosystems continues to be an important area for research, with increasing focus on understanding mechanisms of hydrological processes at ecosystem and catchment levels (e.g. Nyholm *et al.* 2003, Zhou *et al.* 2002, Aboal *et al.* 1999, Carlyle-Moses and Price 1999, Cantu Silva and Okumura 1996, Haworth and McPherson 1995, Tallaksen 1995). Studies which seek to characterize changes in hydrological processes or water yield with landscape alteration, such as reafforestation, clearfelling or natural disasters often have immediate application to catchment management planning (Zhou *et al.* 2002, Bosch and Hewlett 1982). The complexity of hydrological phenomena, difficulties of quantifying impact factors and interactions at catchment scale and the importance of understanding environmental responses to global climate change underpin a need for ongoing research.

In several countries, concerns for the sustainability of water resources in the face of increasing demands and possible climate change have resulted in physical process-based studies that examine the influence of vegetation on water quality and quantity at catchment scale (e.g. Levia and Frost 2003, Swank and Douglass 1974). Some studies have demonstrated that forest age and stand growth may decrease water yield from experimental catchments (Helvey 1967, Helvey and Patric 1965).

Hydrological processes are tightly connected to other aspects of ecosystem function and the importance of a quantitative understanding extends beyond the prediction of catchment water yield. Stream transport and deposition of organic material may be a significant factor in accounting the carbon balance of terrestrial ecosystems (Schimel *et al.* 2001, Sarmiento and Gruber 2002), and studies are in progress to measure the carbon output from forested ecosystems through streamflow. The quantitative determination of hydrological processes with high precision is particularly important as a basis for research of this nature.

Dinghushan Nature Reserve (Fig. 1) is a significant research area in southern China, incorporated in the UNESCO Man and the Biosphere program in 1978. It provides a rare instance of tropical and subtropical forest and related vegetation types as stages in natural succession, close to the Tropic of Cancer. The natural forested catchments of the reserve are a valuable resource for studies of hydrological processes.

The aim of the work reported here was to quantify the magnitude of the water yield and its yearly variation within the Dinghushan reserve, as a basis for proposed studies of the carbon output carried by streamflow; and to investigate the interactions between hydrological processes and characteristics of the major vegetation types.

The study area

Dinghushan Nature Reserve (23°09′21″ ~ 23°11′30″N, 112°30′39″~112°33′41″E) is located in central Guangdong province in southern China, about

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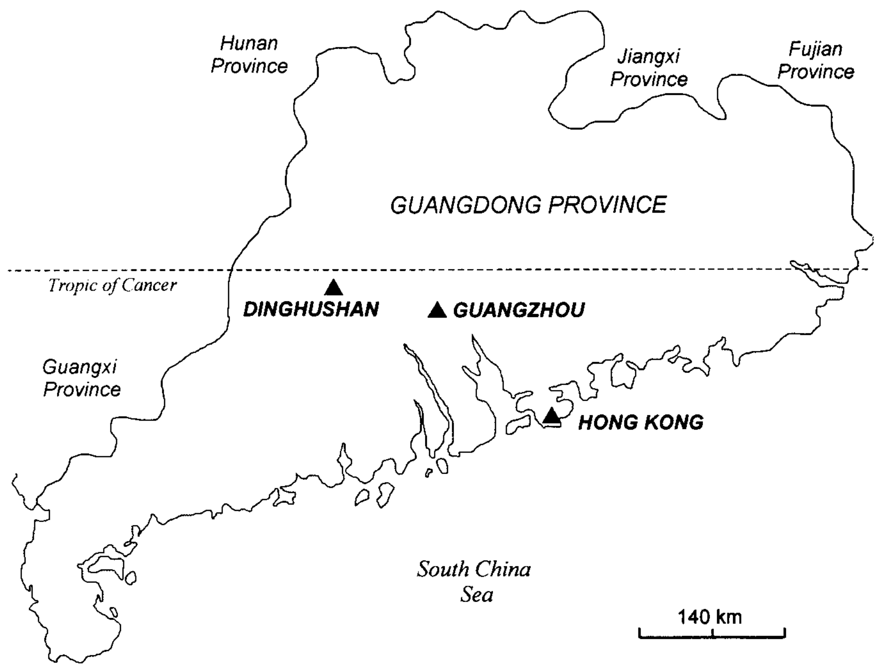

Fig. 1. Location of Dinghushan Nature Reserve in Guangdong province, southern China.

84 km west of Guangzhou (Fig. 1). The area of the reserve is 1156 ha, and elevation ranges from 14 m to 1000 m above sea level. The region has a typical south subtropical monsoon climate, with annual average precipitation of 1678 mm, of which nearly 80% falls in the wet season (April to September). The annual mean temperature and relative humidity are 22.3°C and 77.7%, respectively.

Major vegetation communities in the reserve (Fig. 2) include pine (Pinus massoniana Lambert) forest (PF), mixed pine and broadleaf forest (PBF) and monsoon evergreen broadleaf forest (MBF), which belong to a natural succession sequence (Peng and Wang 1995). River-bank forest, ravine rain forest, lowland evergreen broad-leaved forest, mountainous evergreen broadleaved forest and shrub-grasslands also occur along a vertical gradient from low to high altitude. A total of 1843 plant species have been documented in the reserve, belonging to 267 families and 877 genera. The regional soil type is lateritic red-earth at elevations below 400 m to 500 m, and yellow earth at higher elevations.

Dinghushan nature reserve contains two watersheds, designated as the eastern watershed and western watershed, with areas of 613.2 ha and 542.8 ha respectively. In the eastern watershed, all the vegetation types mentioned above are represented, distributed among a number of sub-catchments. All the data presented here were obtained from the eastern watershed.

Method

Meteorological factors

Climatic data were obtained from a weather station located on a low grass-covered hilltop near the south-eastern corner of the reserve, belonging to Dinghushan Forest Ecosystem Research Station, CERN (Chinese Ecosystem Research Network), at an elevation of 100 m above sea level. Additional rainfall data for comparative purposes were obtained from a weather station maintained by the China Meteorological Bureau at Gaoyao, 10 km south of the Dinghushan station at an elevation of 41 m above sea level.

Runoff

The runoff in the perennial stream flowing from the eastern watershed was monitored automatically and continuously by a measurement weir and streamflow recorder. The observed runoff is composed of substrate flow (baseflow) and surface flow (stormflow). By assuming that surface flow occurs only on rain days and that mean substrate flow does not differ significantly between rain days and rainless days, the periodic substrate and surface flows may be estimated separately from runoff and rainfall observations as:

$$\begin{cases} R_{ss} = (1 + \frac{n_2}{n_1})\sum_{i=1}^{n_1} R_{ss_i} \\ R_{sf} = R - R_{ss} \\ n = n_1 + n_2 \end{cases} \qquad (1)$$

where R is runoff (mm) in a given period of n days

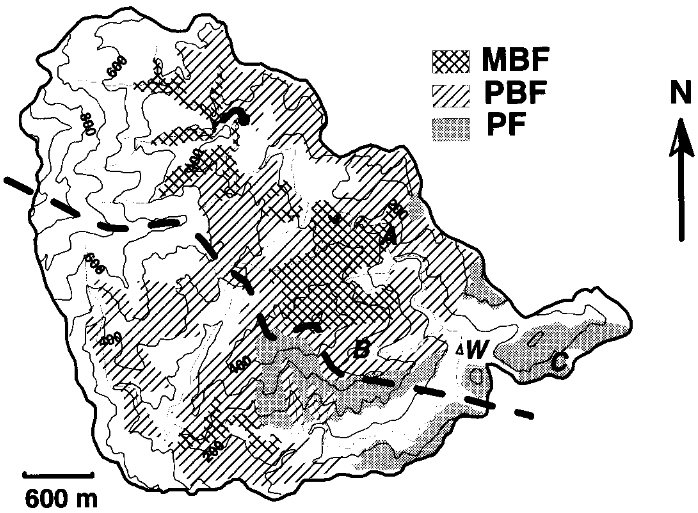

Fig. 2. Watersheds and major vegetation communities in Dinghushan Nature Reserve. PF, pine forest; PBF, mixed pine-broadleaf forest; MBF, monsoon evergreen broadleaf forest. Dashed line marks the divide between the eastern and western watersheds. *A*, MBF subcatchment; *B*, PBF subcatchment; *C*, PF subcatchment; *W*, streamflow monitoring weir.

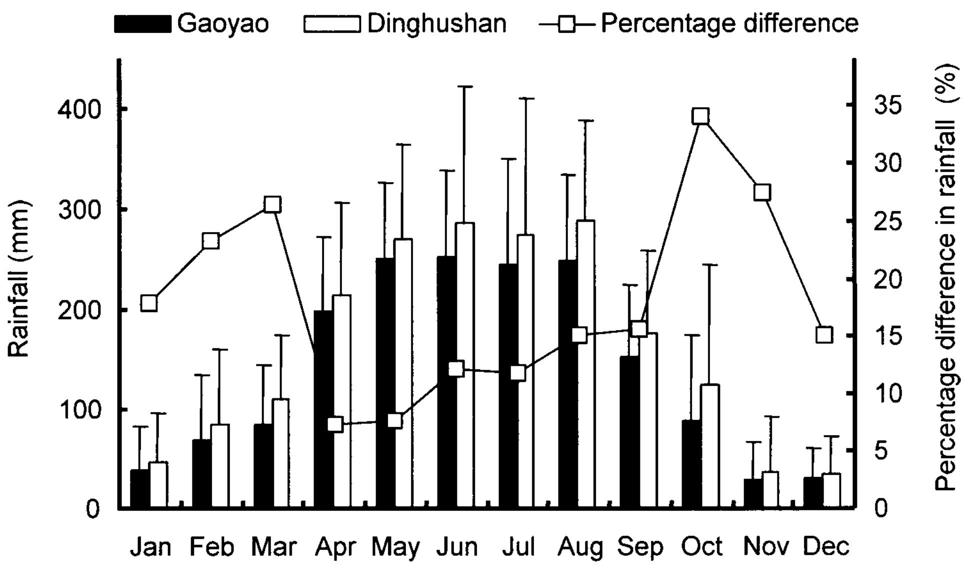

Fig. 3. Comparison of average monthly rainfall over 22 years between 1975 and 2002 at Gaoyao and Dinghushan. Error bars represent one standard deviation.

including n_1 rainless days and n_2 rain days; R_{ss} is total substrate flow (mm) and R_{sf} is total surface flow (mm) in the period; and R_{ss_i} is substrate flow (mm) in rainless day number i ($i = 1,2 \cdots n_1$). This simple method for hydrograph separation is not suitable for application to single storm events because the average baseflow over a season may exceed daily discharge on some days. However, on a seasonal time scale as applied in this study the method provides a valid estimate of the contributions of surface and substrate flow to total runoff, within the limits of the stated assumptions. Separation of observed seasonal discharge into estimated seasonal means of surface and substrate flow allows a more detailed analysis of the relation of streamflow to seasonal and annual rainfall variation.

Soil water and groundwater

From 1983 on, soil water content was measured at monthly intervals by neutron probe, in three sub-catchments containing forest types PF, PBF and MBF, respectively. Each sub-catchment contained 10-15 measurement points distributed over a range of altitude. At each point, water content was monitored at three depths (0-15 cm, 15-30 cm and 30-45 cm). Water table depth was recorded manually at intervals of 5 days in a monitoring well located in the lower part of the eastern watershed, at an altitude of 28 m.

Throughfall and stemflow

Throughfall in the three vegetation communities was collected by cross-shaped troughs (four for each site) with a horizontal area of 2.25 m^2, and was measured using a fluviograph (Zhou 1997). Thirty trees adjacent to each site where throughfall was monitored were selected for stemflow measurement (Gash 1978), to represent the range of diameters and species present in each catchment. An open PVC tube was wrapped around the stem of each tree and led to a tipping bucket rain gauge for measurement of stemflow. Throughfall and stemflow were monitored from April 1999 to April 2000, during which 61 rain events occurred.

Leaf area index and canopy cover

Leaf area index and canopy cover were measured four times each year by hemispherical photography using a CI-110 digital plant canopy imager (CID Inc., Vancouver), with ten sampling sites in each community.

Results and Discussion

Precipitation at Dinghushan and Gaoyao

Daily rainfall in the forested hills of the reserve was compared with that recorded 10 km south at Gaoyao, on an extensive floodplain used predominantly for cropping, for monthly observations over the periods 1975 to 1986 and 1993 to 2002. Yearly rainfall averaged 1678 mm at Gaoyao and 1942 mm at Dinghushan (Fig. 3), hence rainfall was 15.7% greater in the reserve than in the surrounding region. The difference was greater in the dry season, when average rainfall was 30.0% higher at Dinghushan compared to 12.2% in the wet season. This seasonal effect is due to differences in the variability of rainfall between locations during the wet and dry seasons. Differences in monthly rainfall (Dinghushan – Gaoyao) during the dry season varied from 142 mm to -29 mm, but in the wet season the range was 284 mm to -156 mm. The lower frequency of major rain events during the dry season leads to greater variability between locations. Wet season rainfall amounted to 80.0% and 77.6% of the yearly total for Gaoyao and Dinghushan respectively. The more even seasonal distribution of rainfall in Dinghushan reserve is expected to be favorable to the forest ecosystems there.

Monthly rainfall at Dinghushan (Fig. 4) showed a statistically significant correlation with that at Gaoyao, suggesting that precipitation in both places is controlled by the same atmospheric systems, and the observed rainfall differences are a result of local differences in topography and vegetation. As seen from Fig. 5, the forest vegetation communities and complex ravine topography in the reserve are associated with a cooler and more humid environment than Gaoyao at all times of the year. The forest canopy is rough by comparison with the cropland near Gaoyao, and forest evapotranspiration will increase the humidity of the air in and above the canopy. For an air mass with a given vapour content moving across the region, these conditions may bring about more frequent and longer or more intense rain showers in the forested reserve area.

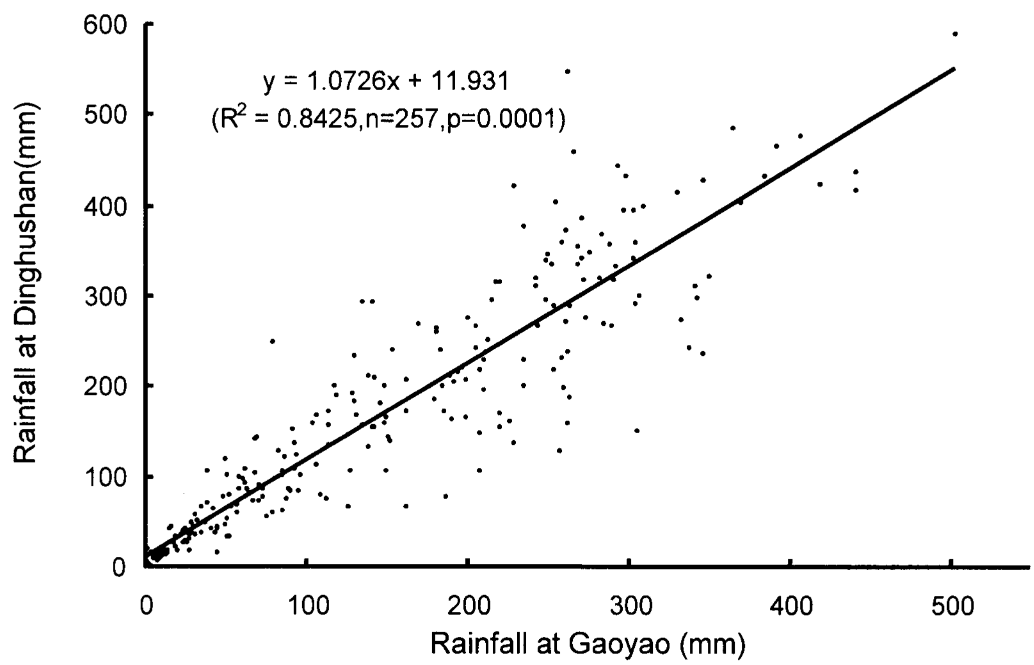

Fig. 4. Monthly rainfall recorded at Dinghushan and Gaoyao weather stations in 1975 – 1986 and 1993 – 2002.

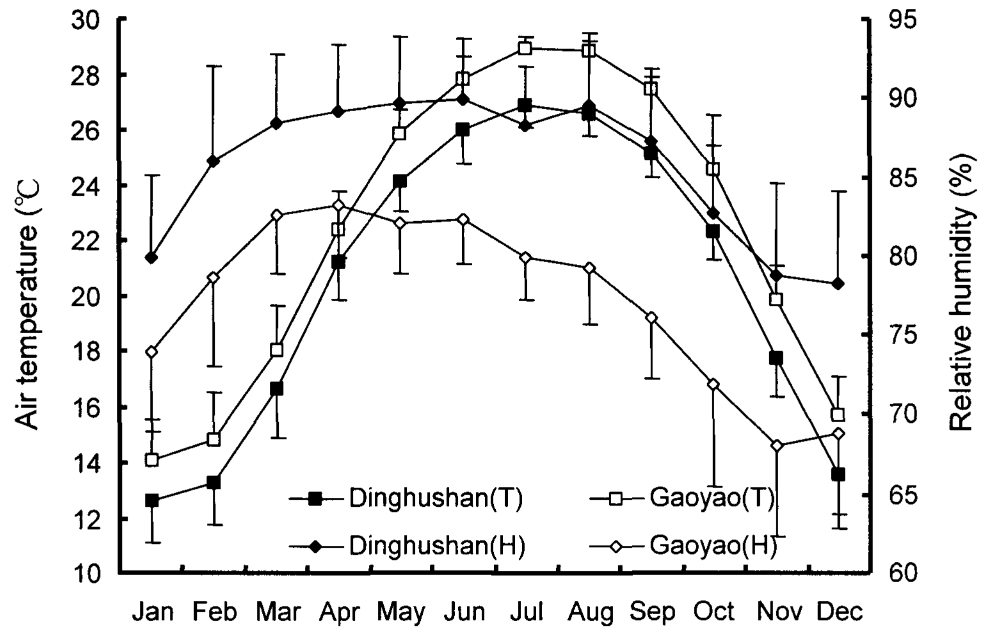

Fig. 5. Mean monthly air temperature and relative humidity recorded at Gaoyao and Dinghushan over 22 years between 1975 and 2002. Error bars represent one standard deviation.

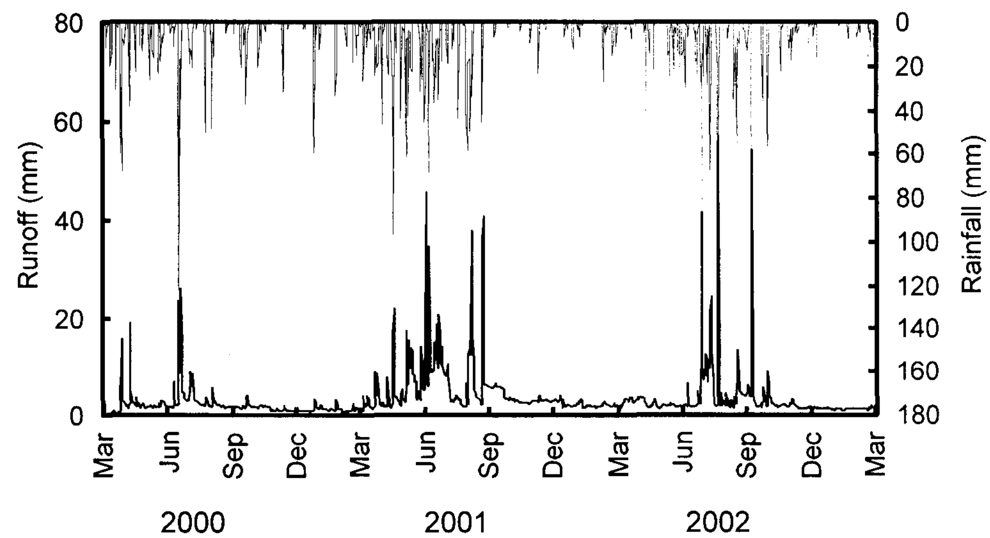

Fig. 6. Daily precipitation and hydrograph for the eastern watershed during the period April 2000 to March 2003.

Runoff

During the three-year period April 2000 – March 2003, total precipitation was 5454 mm, and rainfall in the wet and dry seasons amounted to 76.8% and 23.2% respectively. The total runoff was 3628 mm, of which 69.2% occurred in the wet season and 30.8% in the dry season. The average runoff coefficient (runoff as percentage of rainfall) of the eastern watershed over the three years was 66.5%, with wet season and dry season values of 60.0% and 88.2%, respectively.

Bosch and Hewlett (1982) summarized 94 catchment experiments from around the world and showed that the water yield from less than 15% of these catchments exceeded 65% of precipitation. The calculated value of 66.5% for Dinghushan characterises the forested reserve catchment as one of high water yield, although it is possible that rainfall in the upper catchment was higher than that recorded at the weather station.

The observation that the difference in water yield between dry and wet seasons was less than the seasonal difference in rainfall also points to the effect of catchment water storage in providing a sustained outflow, mitigating the high seasonal rainfall variation. The daily hydrograph and precipitation during the observation period are shown in Fig. 6. The coefficient of variation $\delta/\overline{X}$ (δ - standard deviation, $\overline{X}$ - average value) was 1.47 and 2.70 calculated over all days for daily runoff and rainfall, respectively, confirming that daily runoff over the three years is much less variable than daily rainfall. The coefficient of variation calculated only over rain days was 1.42 and 1.49 for runoff and rainfall, respectively. Comparing daily runoff and rainfall on rain days showed a highly significant correlation (R^2 = 0.35 for 426 observations). The correlation was also calculated over all days to seek evidence for a lag in the response of runoff to rainfall. Correlation between daily runoff and the current day's rainfall was highly significant (R^2 = 0.29 for 1095 observations) but the correlation with the previous day's rainfall was stronger (R^2 = 0.34) demonstrating a lag time of about one day between rainfall and its integrated effect on catchment outflow at the monitoring station.

In accordance with Eq (1), runoff can be separated into substrate flow and surface flow and the parameters in Eq (1) for each season over the three-year monitoring period are shown in Table 1. The annual number of days with and without rain were generally similar for

Table 1. Parameters of Eq (1) for the eastern watershed in April 2000-March 2003.

Year	Season	n_1	n_2	R_{ss} (mm)	R_{sf} (mm)	$R_{ss}+R_{sf}$ (mm)	P (mm)	$\frac{R_{ss}}{R_{ss}+R_{sf}}$	$\frac{R_{ss}}{P}$	$\frac{R_{sf}}{P}$	$\frac{R_{ss}+R_{sf}}{P}$
Apr 2000-	Wet	94	89	358.8	150.2	509	1178.9	0.71	0.3	0.13	0.43
Mar 2001	Dry	129	53	197.5	32.7	230.2	512.1	0.86	0.39	0.06	0.45
Apr 2001-	Wet	81	102	845.6	408.4	1254	1737.2	0.67	0.49	0.24	0.72
Mar 2002	Dry	141	41	481.3	15.1	496.4	206.3	0.97	2.33	0.07	2.41
Apr 2002-	Wet	102	81	515.5	232.9	748.4	1271.8	0.69	0.41	0.18	0.59
Mar 2003	Dry	122	60	364.7	25.6	390.3	548.1	0.93	0.67	0.05	0.71
Total		669	426	2894.2	734.1	3628.3	5454.4				

P-precipitation (mm)

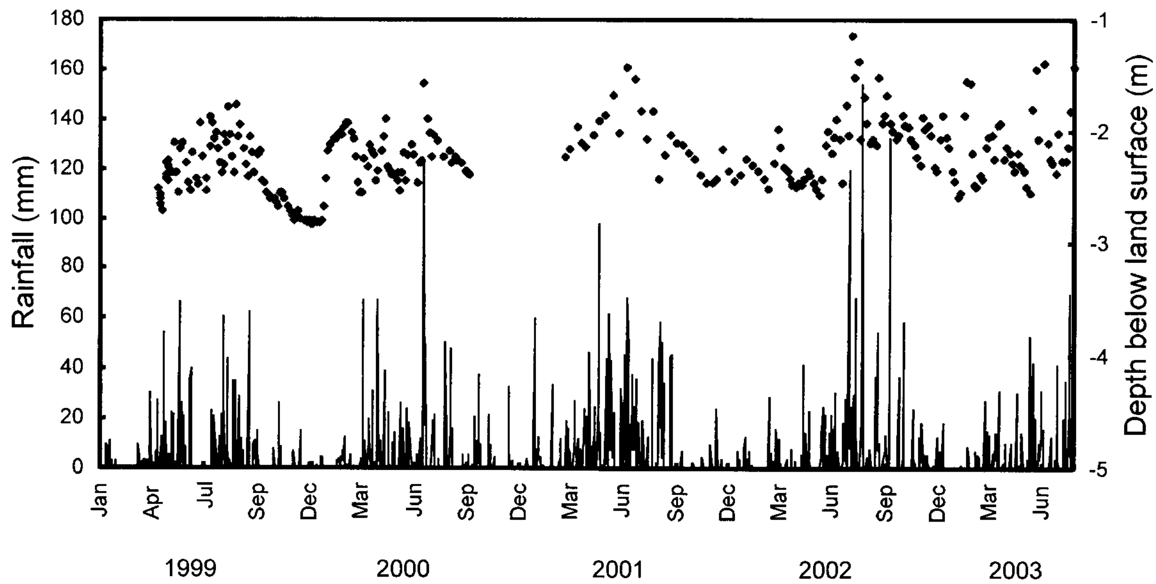

Fig. 7. Water table depth and daily precipitation at Dinghushan for the period January 1999 to August 2003.

the three hydrological years. Although there was not much variance in annual precipitation (1691.0 mm to 1943.5 mm) for the three years, the annual runoff varied greatly from 739.6 mm to 1750.4 mm. This does not conflict with the earlier observation that daily runoff varied less than daily rainfall, since variations in annual totals between years are unrelated to the day to day variation within years. Greater variation in annual discharge than in annual rainfall is in part the result of a higher runoff ratio during periods of high precipitation.

Abnormally high runoff in 2001-2002 was a result of unusually high precipitation, with the wet and dry season rainfall of 1737.2 mm and 206.3 mm amounting to 89.4% and 10.6% of the annual total, respectively. High wet season rainfall made not only a bigger substrate and surface flow at that time, but also a larger than usual substrate flow in the early months of the following dry season. In combination with the low dry season rainfall of 206.3 mm, the substrate flow of 481.3 mm led to an extreme value of 2.41 for the seasonal ratio of runoff to rainfall. The daily mean substrate flow on rainless days decreased steadily from 4.8 mm in October 2001 to 2.4 mm in January 2002 and 1.8 mm in March 2002, reflecting the drainage of water stored in the soil and groundwater of the upper catchment during the previous wet season.

Water table depth

Water table depth was continuously monitored at intervals of 5 days from April 1999 to August 2003. Observations corrected for differences in altitude of individual wells are compared with rainfall in Fig. 7. The average depth of the water table was 2.22 m, with a maximum observed depth below the land surface of 2.84 m in January 2000 when monthly rainfall was 15 mm and minimum of 1.14 m in July 2002, following 160 mm of rainfall in the preceding three days. Despite this high seasonal variation, the annual mean depths of 2.38 m, 2.27 m, 2.08 m, 2.13 m and 2.11 m for the years 1999 to 2003 show no significant change ($p>0.05$) in water table depth over the period. As the yearly rainfalls varied considerably from 1269 mm in 1999 to 2060 mm in 2001, this suggests that the eastern watershed has sufficient storage capacity to maintain the lower catchment watertable at a stable level on an annual time scale.

However, on shorter time scales the water table clearly fluctuates in response to rainfall. Fig. 8A shows a statistically significant correlation between the monthly mean water table depth and rainfall in the same month. To examine the shorter-term water table variation, rainfall in periods of 1 to 20 days preceding each individual measurement was averaged. Correlation analysis showed that water table depth was most strongly related to the average rainfall over 16 days (Fig. 8B), indicating that the integrated effect of catchment scale rainfall on water table depth in the lower catchment persists for up to 16 days.

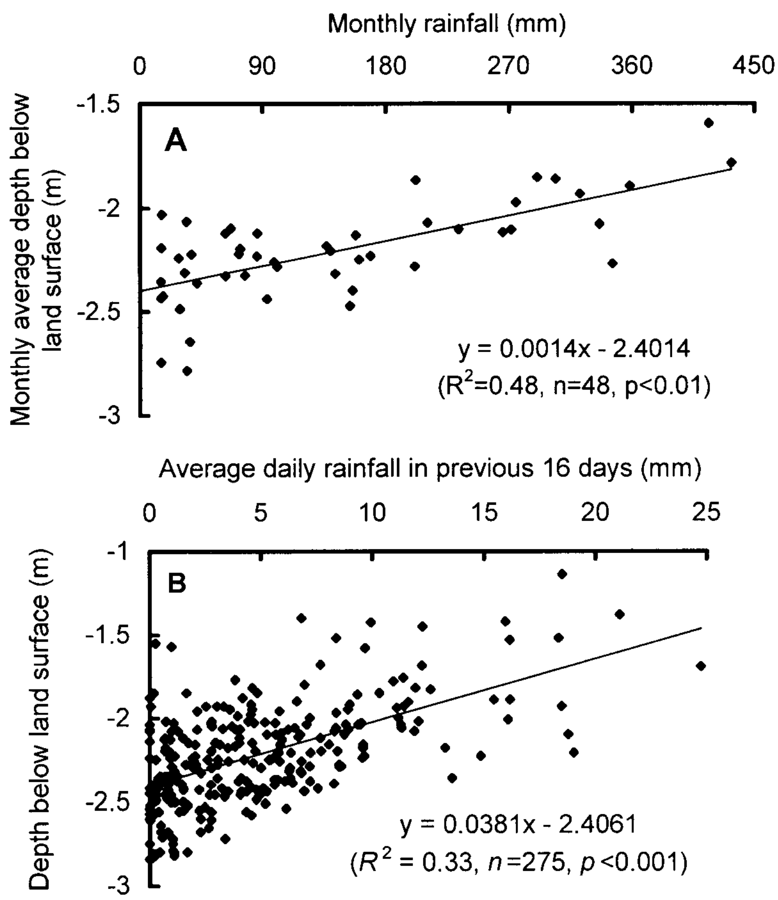

Fig. 8. Correlations of water table depth with average rainfall on different time scales. A: monthly mean values. B: daily mean values, over a period of 16 days preceding water table observations.

Soil water dynamics

Monthly records of soil water content in the three sub-catchments of PF, PBF and MBF succession communities were available for the periods 1983 to 1988 and 1999 to 2003 (Fig. 9). Soil water content was lower during the latter period in all three forest communities. The negative slopes of regression lines fitted to the observations indicate a long term decrease in soil water content in addition to the seasonal fluctuations associated with climate variation. This negative trend was statistically significant for MBF ($p<0.05$), but not for PF and PBF.

Table 2 compares mean soil water content and its standard deviation for two periods, 1983-1985 and 2001-2002. The data suggest that both the mean water content and its variability have decreased since the earlier period of monitoring. Lower soil water content in the upper 45 cm of the profile may imply that the water storage of these vegetation communities is decreasing due to changes in canopy cover and evapotranspiration. If this results in seasonal water stress the consequence may be a reduction in growth rates and possible changes in species composition of the ecosystems.

A statistical comparison of annual mean soil water content in each of the three vegetation communities showed that PBF and MBF did not differ significantly ($p>0.05$), whereas PF was significantly drier than either of the other two communities ($p<0.01$). This implies that the natural succession of PF to PBF is associated with an increase in soil water content, while the further succession to MBF is not even though the structures of the two communities differ considerably. Differences in canopy interception, transpiration, understorey growth and soil surface evaporation between communities may all contribute to their differing soil water content.

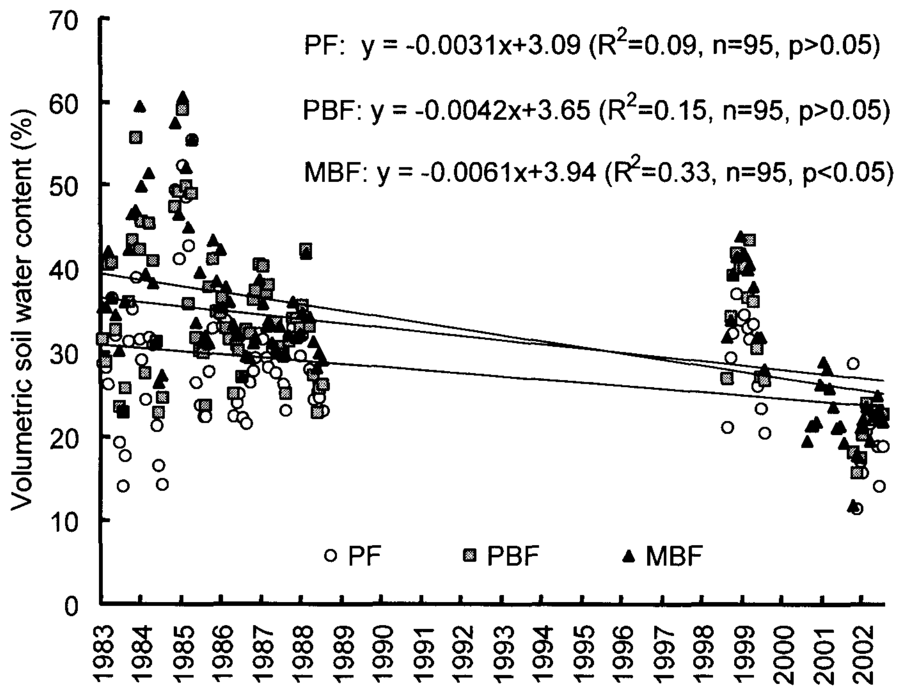

Fig. 9. Monthly observations of volumetric soil water content at 0-45 cm depth in three vegetation communities at Dinghushan during the period 1983 to 2002 (mean of 10 to 15 observations in each community). PF, pine forest; PBF, mixed pine-broadleaf forest; MBF, monsoon evergreen broadleaf forest.

Table 2. Mean and standard deviation (δ) of soil water content for two monitoring periods in three sub-catchments at Dinghushan.

	1983-1985		2001-2002	
	Average	δ	Average	δ
PF	3.11	1.11	1.89	0.45
PBF	3.73	1.02	2.09	0.27
MBF	4.12	1.01	2.2	0.35

Throughfall and stem flow

The relationship between the amount of throughfall and precipitation measured at the weather station was linear for the three communities (Fig. 10). Local variations in rainfall in the subcatchments due to altitude and aspect differences were assumed to be negligible for these comparisons. The R^2 values of linear regressions relating throughfall and precipitation decreased from PF through PBF to MBF. Total throughfall as a percentage of total precipitation also decreased with succession stages, being 82.8%, 75.0% and 60.9% for PF, PBF and MBF, respectively. Incomplete canopy cover and a relatively small leaf area index in PF (Table 3) allow greatest throughfall with relatively little interaction between rainfall and canopy elements. The multi-layered canopy structure, high leaf area index and 93% canopy cover in MBF favour interception of rainfall by leaves and branches followed by indirect rather than direct throughfall, while the transitional PBF community displays throughfall characteristics intermediate between those of PF and MBF.

Stem flow as a percentage of precipitation in the three communities was 1.9%, 6.5% and 8.3% for PF, PBF and MBF, influenced by differences in foliage, branching and bark characteristics. Stem flow in PF was limited by rough bark and low foliage interception by its small and needle-shaped leaves. On the other hand, trees of the MBF community are likely to promote stem flow because of high interception by broad fleshy leaves and thick branches of the dominant species.

The relationship between annual stem flow and diameter at breast height (DBH) for PF is shown in Fig. 11. The regression function derived from the Masson pine trees in PF does not fit measurements of stem flow for the same species in the PBF community, demonstrating that the relationship of stem flow with DBH may be controlled by community effects as well as or instead of species characteristics. The pioneer community PF is almost monospecific, with only occasional broad-leaved tree species. The relatively low stand density allows a broad crown to develop in mature trees, favouring high interception and high stem flow. With succession to PBF, heliophilous broad-leaved species invade the pioneer community, grow to occupy the upper canopy, and replace Masson pine as the dominant species. The resulting reduction in solar radiation reaching the foliage of the Masson pines leads to reduced canopy development and hence less interception and stem flow. As a result of decreased stem flow, transport of water and nutrients to the root system are likely to be reduced, contributing to the removal of microhabitat suitable for the survival and regeneration of Masson pines. This illustrates a possible role of stem flow as a positive feedback factor in species competition leading to the succession process from PF to PBF.

Table 3. Leaf area index and canopy cover of three forest vegetation communities.

Vegetation community	MBF	PBF	PF
Leaf area index (± S.E.)	17.8±1.2	11.3±1.6	6.6±2.1
Canopy cover	93%	86%	58%

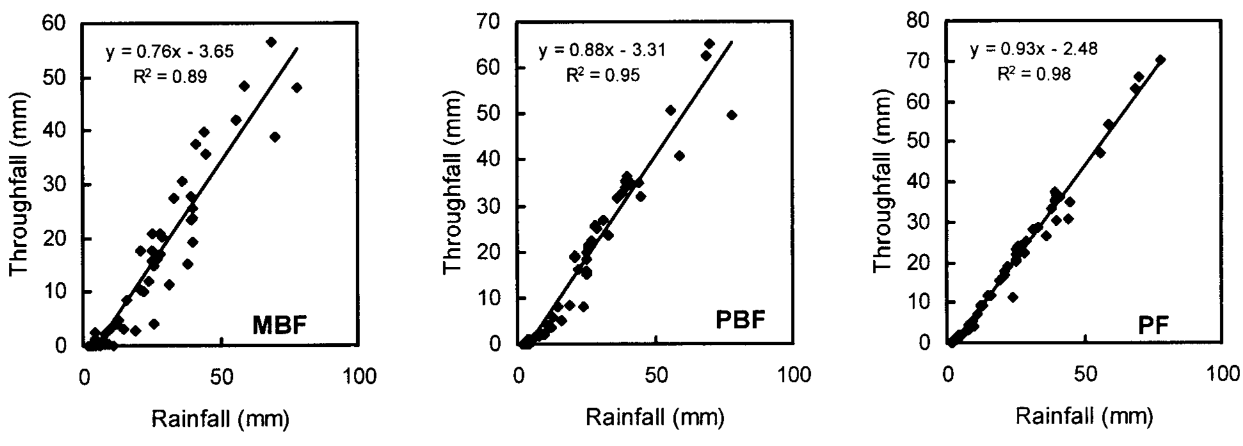

Fig. 10. Throughfall and rainfall in three successional vegetation communities at Dinghushan. PF, pine forest; PBF, mixed pine-broadleaf forest; MBF, monsoon evergreen broadleaf forest.

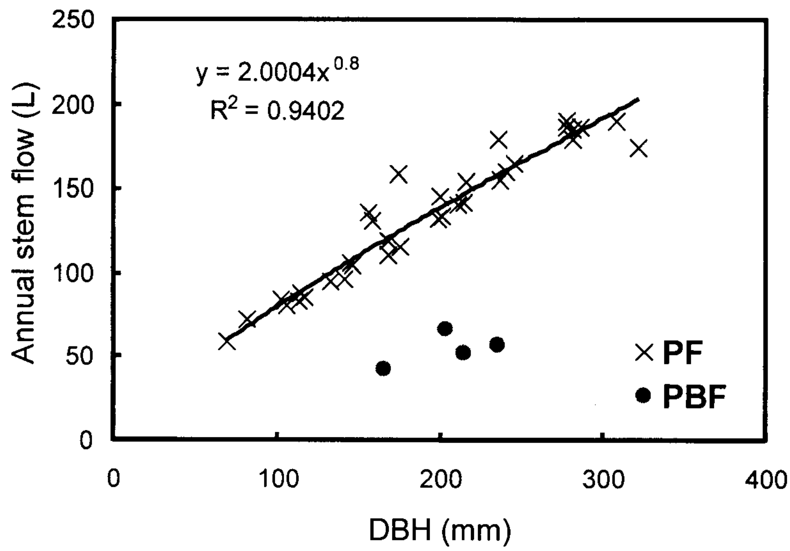

Fig. 11. The relationship between annual stem flow and diameter at breast height (DBH) for Masson pine (*Pinus massoniana*) trees growing in pine forest (PF) and mixed pine-broadleaf forest (PBF) communities.

Table 4. Distribution of rainfall by the canopy for three forest vegetation communities in Dinghushan Nature Reserve.

Forest Community	PF	PBF	MBF
Rainfall (%)	100.0	100.0	100.0
Throughfall (%)	83.4	68.3	59.9
Stemflow (%)	1.9	6.5	8.3
Interception (%)	14.7	25.2	31.8

The stemflow data provide evidence for a similar phenomenon in the transition between PBF and MBF. The total annual stem flow for Schima superba Gardner & Champ. of diameter 6.3 cm within PBF was 1382 L, while the measured value for the same species of diameter 10.4 cm within MBF was only 1365 L. Apparently, Schima superba is not optimally adapted to the MBF habitat, with similar consequences of crown reduction and diminished interception. Reduction in stem flow therefore could help to explain why Schima superba grows well within PBF but often dies within MBF as reported by Peng and Fang (1995).

Canopy interception

Canopy interception by the three communities, calculated from the rainfall, throughfall and stemflow observations, is shown in Table 4. Canopy interception increases with succession stage, from PF to PBF and MBF, consistent with the increasing complexity of community structure and canopy cover. Wu *et al.* (1998) considered MBF to be one of the communities with the highest canopy interception in the subtropical zone. This feature implies greater water use efficiency (less root water uptake for a given amount of biomass production) but reduces the water output from the system to streamflow, by comparison with earlier succession stages.

Seasonal dynamics of canopy interception by MBF (Fig. 12) demonstrate a similar pattern for interception and rainfall, both reaching a maximum in July and minimum in February. Interception in the wet season was 66.7% of the annual total, which is less than the fraction of annual rainfall falling in the wet season, as a result of higher interception rate (% of rainfall) during the dry season. The canopy interception rate was 83.3% with precipitation of 28.7 mm in February, but only 18.9% for precipitation of 297.8 mm in June. Both the volume of water which may be stored on canopy surfaces and the rate at which it can evaporate are limited by the physical properties of the canopy and

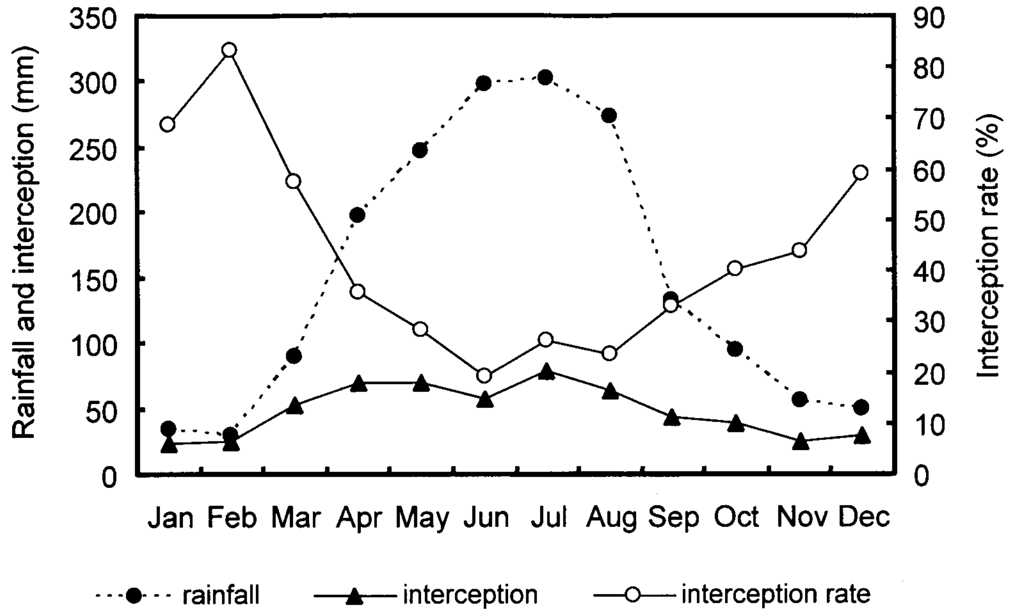

Fig. 12. Monthly rainfall, interception and interception rate (% of rainfall) in monsoon evergreen broad-leaved forest in 1999-2000.

atmospheric environment. The observed interception values of 56 to 79 mm per month during the wet season from April to September suggest an upper limit of approximately 80 mm per month for canopy interception by MBF at Dinghushan.

Interception and evaporation of rainfall by the canopy during the dry season serves to reduce water loss from the soil while the canopy is wet, and tends to decrease the thermal exchange between the underlying surface and the atmosphere. The observed differences in canopy interception between communities therefore may affect the temporal and spatial water distribution and influence the hydrologic processes of the forest ecosystems to some extent.

Conclusions

Results of long term monitoring of hydrological processes in natural forests such as at Dinghushan provide essential information for understanding the interactions of catchment vegetation and hydrology, as a basis for predicting the impacts of natural and imposed vegetation changes on water yield and quality. The studies reported here have demonstrated that topography and vegetation may influence the amount and frequency of rain and modulate the catchment-scale effects of rainfall variation on daily, seasonal and annual time scales, leading to delayed and reduced variation in streamflow and water table depth. Interception and storage of water by vegetation, soil and groundwater are essential elements of this process. Vegetation succession may profoundly affect canopy structure, interception and evapotranspiration, with consequent changes in catchment processes and water yield.

References

Aboal, J.R., Morales, D., Hernandez, M., Jimenez, M.S. (1999) The measurement and modeling of the variation of stemflow in a laurel forest in Tenerife, Canary Islands. J. Hydrol. 221: 161-175.

Bosch, J.M., Hewlett J.D. (1982) A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. J. Hydrol. 55: 3-23.

Cantu Silva, I., Okumura, T. (1996) Throughfall, stemflow and interception loss in a mixed white oak forest (Quercus serrata Thunb.). J. For. Res. 1: 123-129.

Carlyle-Moses, D.E., Price, A.G. (1999) An evaluation of the Gash interception model in a northern hardwood stand. J. Hydrol. 214: 103-110.

Gash, J.H.C., Morton, A.J. (1978) An application of the Rutter model to the estimation of the interception loss from Thetford Forest. J. Hydrol. 38: 49-58.

Haworth, K., McPherson, G.R. (1995) Effects of Quercus emoryi trees on precipitation distribution and microclimate in a semi-arid savanna. J. Arid Environ. 31: 153-170.

Helvey, J.D. (1967) Interception by eastern white pine. Water Resources Research 3(3): 723-729.

Helvey, J.D., Patric, J.H. (1965) Canopy and litter interception of rainfall by hardwoods of eastern United States. Water Resources Research 1(2): 193-206.

Levia, D.F., Frost, E. (2003) A review and evaluation of stemflow literature in the hydrologic and biogeochemical cycles of forested and agricultural ecosystems. J. Hydrol. 274: 1-29.

Nyholm, T., Rasmussen, K.R, Christensen S. (2003) Estimation of stream flow depletion and uncertainty from discharge measurements in a small alluvial stream. J. Hydrol. 274: 129-144.

Peng, S.L., Fang, W. (1995) Studies on dynamics of Castanopsis chinensis and Schima superba populations in forest succession of Dinghushan Mountain. Acta Phytoecologica Sinica 19(1):311-318.

Peng, S.L., Wang, B.S. (1995) Forest succession at Dinghushan, Guangdong, China. Chinese J. Bot. 7(1):75-80.

Sarmiento, J.L. Gruber, N. (2002) Sinks for anthropogenic carbon. Physics Today 55(8): 30-36.

Schimel, D.S., Ciasis, P., Peylin, P., *et al.* (2001) Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. Nature 414: 169-172.

Swank, W.T., Douglass, J.E. (1974) Streamflow greatly reduced by converting deciduous hardwood stands to pine. Science 185, 857-859.

Tallaksen, L.M. (1995) A review of baseflow recession analysis. J. Hydrol. 165: 349-370.

Wu, H.S., Liu, H.P., Huang, D.J. (1998) The interception effect of the monsoon evergreen broad-leaved forest on precipitation in Dinghushan Biosphere Reserve. Trop. Subtrop. For. Ecosys. 8: 146-149.

Zhou, G.Y. (1997) Hydro-thermal theories and their application to an ecosystem. Meteorological Press, Beijing. Pp 173-193.

Zhou, G., Morris, J.D., Yan, J.H., Yu, Z.Y., Peng, S.L. (2002) Hydrological impacts of reafforestation with eucalyptus and indigenous species: a case study in southern China. For. Ecol. Manage. 167: 209-222.

Zhou, G., Wei, X., Yan, J. (2002) Impacts of eucalyptus (Eucalyptus exserta) plantation on sediment yield in Guangdong province, Southern China — a kinetic energy approach. CATENA 49: 231-251.