UNCERTAINTIES IN THE HYDROLOGY OF TROPICAL REFORESTATION: BEYOND "FROM THE MOUNTAIN TO THE TAP"[1]

By Nick A Chappell and Mike Bonell

Large areas formerly covered by tropical forests have been cleared and remain in an unproductive, environmentally unsustainable or degraded state[2]. The recent synthesis 'From the mountain to the tap' and follow-on publicity suggests that reforestation of such areas would have an overriding negative impact on people and the environment. 'From the mountain to the tap' is focussed on relatively dry areas and on the effects on volume flow of water and on relatively short time frames. In contrast, we would suggest that recent research findings within meteorology, hydrology and ecology indicate the longer term impact of tropical forestation to be more likely positive, to strongly depend on climatic conditions and certainly to be much more complex than commonly presented in current debate.

Not seeing the soil for the trees[3]
Ecological findings clearly show that by planting trees in degraded tropical areas, soil biodiversity is increased, which itself improves the soil physical properties thereby encouraging further biodiversity improvements[4]. This soil structural improvement also reduces infiltration-excess overland flow[5]. This is particularly important on steep slopes which have the potential to generate high rates of overland flow[6]. In such areas soil improvement arising from tree planting and growth might have the potential to reduce peakflows of streams during floods. Moreover, the reduction of overland flow certainly slows gully development[7]. This soil conservation benefit is further aided by avoiding the soil tillage normally associated with agriculture[8], and by adding a more protective vegetation canopy in comparison to some cropping systems[9]. The abstraction of subsurface water by trees with the resultant drying of soil and upper layers of regolith can also reduce the likelihood of landslides, particularly where the drift geology is shallow[10,11]. This positive surface drying effect is in addition to the beneficial effect of tree roots on soil shear strength[12]. The overall result of a more stabilised terrain is clearly seen beneath forests planted on formerly degraded terrain in south-eastern USA or central Japan.

Reduced sediment load of rivers
Once reforestation activities are complete, rivers draining from these areas show smaller sediment loads when compared to areas undergoing regular agricultural tillage or urban development[13]. Critically, where plantation management excludes pesticide use or downstream processing chemicals, then rivers are cleaned of the pesticide residues and industrial contaminants associated with former agricultural or industrial activities[14].

Water budget effects of plantation forestry
Most catchment studies in the humid tropics show that newly established tropical plantations evaporate more water directly to the atmosphere in comparison to non-forest vegetation[15,16]. There are, however, five critical issues that mean these findings cannot be simply extrapolated across the humid tropics. These issues are:

- Reduced impact when on deep aquifers

- Reduced impact with forest maturation
- Comparable water demand to the climax forest vegetation
- Reduced impact at large scales due to age mosaic and lower intensity of change
- Reduced impact at large scales due to climate feedbacks

The *first* issue is important given that almost all of these tropical evaporation studies have been undertaken within small catchments on non-aquifer rocks. Where major aquifers are present, water can percolate to great depths of perhaps 100 to 200 m before returning to the surface to generate streamflow. Where this is the case, then the water is soon beyond the depth that trees roots can extract the water to support transpiration. As a consequence differences between trees and more shallow rooted vegetation would be much less[17]. Water budget studies on tropical aquifers are needed.

The *second* issue arises because most tropical studies examining the effect of afforestation on the water budget are undertaken over only the first few years after planting[18]. During the initial phase of tree growth, water use can be very high, but as trees mature, their water demand falls. For example, eucalyptus, a tree with one of the highest water uses during the initial phase of growth, had a lower water use in comparison to non-forest vegetation when mature[19]. More tropical water budget studies are needed that follow plantation development to maturation.

Where plantations have been established in areas formally supporting a climax vegetation of natural tropical forest, water yields of the mature plantations are often similar or only slightly greater than the natural forest[20,21]. This *third* issue is pertinent to the ideas of environmental sustainability, where the goal might be to minimize the environmental differences between the modified land-use and the natural, climax vegetation.

The *fourth* issue relates to the scale of investigation of most water budget studies in the tropics. In this region there are few such studies undertaken on large watersheds perhaps 1000 km^2 in area. If the limited large scale data is examined, then it does indicate that the effect of plantation development on water yield at this scale is insignificant when compared with the natural cycles in the riverflow or evapo-transpiration caused by climatic variations[22]. In part, the forest effect is small because of the considerable range of stand age seen at this scale and the lower intensity of land-use change[23].

The effect of scale on climate feedbacks also adds uncertainty to our extrapolations from small-scale, tropical water budget studies. When water budgets are examined at very large scales of perhaps 10,000 km^2 or larger, the effect of changing vegetation cover on evapotranspiration can significantly affect the regional production of rainfall. This has been shown in recent simulations of Global Climate Models[24,25]. Large-scale deforestation of the West African forest region may have led to reducing rainfall[26]. The implication being that extensive forestation of such areas (once mature) would enhance soil-water, groundwater and riverflow through intensification of the hydrological cycle. Several studies note that the scale dependence of the forest – rainfall generation phenomena is partly related to the increasing heterogeneity of the land cover[27].

The last hydrological benefit of plantations that we would like to highlight relates again to changes to the soil. Extensive and marked reductions in the soil permeability following industrial development, land degradation or some forms of agriculture could significantly reduce the infiltration and subsequent recharge of deeper strata, in comparison to permeable forest soils[28,29]. Where these soils overlie deep aquifers, then the enhancement of recharge by plantation development could be greater than the short term reductions in recharge due to a slightly greater transpiration. There are early indications that this effect is observed in the Western Ghats region of India. More aquifer recharge studies throughout the tropics are required to fully evaluate the sometimes competing effects of plantations on soil and canopy processes.

We would acknowledge that exceptions can be found to the beneficial effect of forestation cited here[30]. The lack of long-term and large-scale analyses of the hydrological impact of tropical forestation should, however, make scientists at least, more cautious about portraying tropical forestation as either wholly negative or wholly positive.

Contact information:
Dr Nick A Chappell,
Lancaster Environment Centre,
Lancaster University,
Lancaster LA1 4YQ
UK

E-mail: n.chappell@lancaster.ac.uk

Dr Mike Bonell,
UNESCO Division of Water Sciences,
1 Rue Miollis
73732 Paris Cedex 15
France

E-mail: m.bonell@unesco.org

[1] NR-International (2005), *From the Mountain to the Tap, http://www.frp.uk.com*
[2] Gisladottir and Stocking, 2005, *Land Degrad. Develop*., 16: 99-112
[3] Bruijnzeel, L. A., 2004. Agriculture, *Ecosystems & Environment* 104, 185-228.
[4] Bardgett *et al.*, 2001 *Ecosystems* 4: 421-429
[5] Hairsine *et al.*, 1992 *Austr. J. Soil Res*., 30: 249-264
[6] Zaslavsky and Sinai, 1981*J. Hydraul. Div.*, 107: 37-52
[7] Gardner and Gerrard, 2005 *Int. J. Sustain. Dev. World Ecol.*, 9: 59-73
[8] Kimaro *et al.*, 2005 *Soil & Till. Res.*, 81: 97-108
[9] Nearing *et al*., 2005 *Catena* 61: 131-154
[10] Ramsay, 1987 *IAHS* 167: 239-250
[11] Keppeler *et al.*, 1994. in *Effects of Human-Induced Changes on Hydrologic Systems*
[12] O'Loughlin and Watson 1981 NZ J. For. Sci., 11: 183-185
[13] Ismail, 1997 *IAHS* 245: 91-100
[14] McClain, 2004 *Ecohydrology*, CABI
[15] McNaughton and Jarvis, 1983, in *Water deficits and plant growth*
[16] Bruijnzeel 1990, *UNESCO*; Scott et al., 2004, in *Forests, Water and People in the Humid Tropics*
[17] cf. Table 35 Kirby et al., 1991 *Institute of Hydrology Report* 109
[18] Bruijnzeel, 1990, *UNESCO*
[19] Vertessy et al. 2003, *Australian Forestry* 66: 55-61
[20] Table 4 in Bruijnzeel, 1990 *UNESCO*
[21] Scott *et al*., 2004 in *Forests, Water and People in the Humid Tropics*
[22] Chappell & Tych, Adv. in Wat. Resour., in sub; Chappell *et al*., *For. Ecol. Manage*., in prep
[23] Vertessy et al., 2003, *Australian Forestry* 66: 55-61
[24] Costa, 2004 in Forests, Water and People in the Humid Tropics
[25] Voldoire and Royer, 2004 *Climate Dynamics* 22: 857-874
[24] Zheng *et al*., 1999 *Science* 286: 1537-1540

[25] Baidya *et al*., 2003 *J. Geophys. Res.*, 108: 8854
[28] FAO, 1999 *Poverty alleviation and food security in Asia: land resources*
[29] Bonell, 2004 in *Forests, Water and People in the Humid Tropics*
[30] Bonell and Bruijnzeel, 2004 *Forests, Water and People in the Humid Tropics*; Chappell, 2005, *Suiri Kagaku* 48: 32-46

QUESTIONING LONG-HELD BELIEFS ABOUT FORESTS AND FLOODS

By Thomas Enters and Patrick B. Durst

The driving force behind many environmental policies are powerful assumptions about the links between forests and water, particularly flooding. Each year, devastating floods affect the personal and economic fortunes of millions of people. Each catastrophic flood is accompanied by heart-wrenching images of shocked individuals sitting on rooftops, awaiting rescue or the receding of rampaging flood waters. Sympathetic people from all walks of life cannot help but to be moved by the stark scenes of desperation. Conscientious policy makers and politicians leap to identify and remedy the perceived causes of the devastation. Upland farmers and loggers – especially in developing countries – are typically blamed for clearing and degrading forests, which are widely believed to protect against such calamities.

In many people's minds, the use and abuse of forests in watersheds represents the main cause of massive lowland floods. The causal link between deforestation or forest degradation in the uplands and floods in the lowlands seems intuitive to many. Unfortunately, the reality of hydrological systems is far from simple and hard evidence of the link is sparse.

Hydrological systems are, in fact, extremely complex and it is difficult to disentangle the impacts of land use from natural phenomena. Although several scientific studies have been conducted on the relationship between forests and floods, the limited – sometimes also contradictory – results have often been used to make sweeping generalizations that are inappropriate, misleading, or patently wrong.

Little distinction is made between what we know and what we think we know, which greatly contributes to a general confusion on the issue. Much of this confusion has a long history and relates to the so-called "sponge theory", which appears to have been developed by European foresters at the end of the 19th century and rapidly spread to other continents.

According to this popular line of thinking, forests act as a sponge soaking up water during rainy spells and releasing it evenly during dry periods. The simplicity of the theory makes it intuitively appealing. Unfortunately, the popular theory fails the test of close scientific scrutiny. While forest soils usually have higher water infiltration and storage capacities than non-forest soils, it should be recognized that deep soils in general have higher water storage capacities than shallow soils irrespective of vegetative cover. Equally important is that much of the rain that falls on forests areas is consumed – quite extravagantly, in fact – by trees and does not serve to increase low, dry-season riverflows.