ASB Partnership for the Tropical Forest Margins
Policybriefs 08

DEFORESTATION & THE MULTIPLE FUNCTIONS OF TROPICAL WATERSHEDS

Are tropical forests indispensable for regulating rainfall and ensuring clean and reliable water supplies?

Old-growth **TROPICAL FORESTS** provide several major 'watershed functions' essential to human survival and local livelihoods. They hold soil in place and help maintain the productivity of the land. They also regulate the quantity and timing of water flows, control sediment loads and so protect water quality. Cutting down tropical forests undermines these valued functions.

But hydrological patterns on the land vary widely from one catchment area to another and between sites or plots within the same catchment. They depend not only on the extent of natural tree cover, but also on a host of other factors. These include rainfall, topography (especially slope), geology, soil type, the area and distribution of food and forage crops, leaf litter over soil, the extent of compaction from livestock and machinery, and the presence of impervious surfaces such as roads and buildings. Some non-forested landscapes have no major problems with watershed functions – so strictly speaking they don't need 'forest' to maintain their water flows.

Thus, a web of human and other factors determines how land will process rainfall and whether the net result will present hazards for local and downstream people. To blame local water-related hazards solely on 'deforestation', while ignoring other key parameters influenced by post-forest land management, is to severely limit one's options in the search for balanced solutions.

Key Questions

1. Are all forests alike ?
Natural forests are ecosystems, not mere collections of trees. Several features of natural forest – its rough surfaces, swamps and other temporary water storage sites make it more able to regulate water flow than a man-made forest.

2. Does forest produce extra rain?
There is evidence that large-scale removal of tropical forest in humid parts of the world affects rainfall during the transition between rainy and dry season. However, effects on annual rainfall are modest (5-10%) relative to inter-annual variability.

3. Does forest affect annual water yield?
Removal of forest initially increases annual water yield. The type of vegetation that follows and the degree of soil compaction determines the water yield in subsequent years.

4. Does forest reduce flooding?
The presence or absence of forests in upland watersheds is not a key contributing factor to the major floods that draw most policy and media attention. However, there is ample evidence that forest cover does affect timing and intensity of floods in small catchments.

5. Does forest reduce erosion, landslides and stream sedimentation?
Forest conversion to other land uses without proper soil conservation measures increases hillslope soil erosion and the risk of shallow landslides.

Reforestation schemes, an area in which governments and aid agencies spend millions of dollars every year, have, unfortunately, all too often been seen as a magic bullet for solving water-related hazards. But there is little evidence such schemes actually achieve their aim, namely to restore the watershed functions attributed to natural forest cover. In fact, reforestation generally reduces the amount of water available off-site for other purposes, especially when fast-growing tree species with high moisture requirements replace poorly managed crop- or scrubland having a much lower water use. It is important for policy makers to understand which vegetation changes will affect the quantity, quality and regularity of river flow and to be aware of the possible consequences in terms of changes in flooding, erosion and landslide hazards. The last thing policy makers need is a straightjacket woven from misinformation and oversimplification of the watershed issues at hand.

1. Are all forests alike?

Natural forests are ecosystems, not mere collections of trees. Several features of **natural forest landscapes** – their rough surfaces, swamps and temporary water storage sites, make them more able to regulate water flow after rain events than **man-made forests.**

A good cover of old-growth **natural forest** provides good stream flow. This is because the soil below a natural forest landscape serves as a 'sponge', soaking up water during wet periods and releasing it gradually, thereby supporting dry-season stream flows. It also offers maximum soil protection via several green and brown layers of cover, thus controlling erosion and reducing stream sediment loads. Natural forests keep water clean, partly because trees stabilize soil with their roots and partly because the relative absence of human settlements and activities in forested areas means less pollution.

Man-made forests generally reduce the amount of water available downstream, especially when fast-growing evergreen tree species with high moisture requirements in the dry season are planted. There is little evidence that reforestation schemes actually achieve their aim, namely to restore the watershed functions attributed to natural forest cover, at least not within a period of 1 or 2 decades. One reason for the popularity of reforestation as a cure for disturbed watershed functions is that its proponents often 'can't see the forest for the trees.' They forget that forests are complex living systems composed not just of trees but also of soil and a supporting landscape. People don't build forests and soils, nature does – over long periods of time. Large-scale replanting of trees uses a lot of water but does not restore 'forest' and 'soil', in the holistic sense of the term.

Agroforests are a combination of both natural and man-made forests. A typical agroforest consists of land where planted trees and other agricultural plants are cultured among forest trees. When properly designed and managed, such forests can provide many of the watershed functions normally attributed to natural forests. At the same time they allow local people to feed themselves and earn cash from the land (explained further in ASB Policy*brief* no. 9 - Restoring the Functions of Watersheds - Agroforestry Solutions).

Wrong diagnosis, wrong solution

Photo: ASB

During the 1970s, in Lampung Province of Sumatra, the Indonesian Government implemented the Way Rarem Scheme, under which it dammed the Rarem river near Kota Bumi in order to facilitate downstream irrigated rice production. The scheme, however, never met the expectations and only part of the area could in fact be irrigated. The scheme's managers cited deforestation on the slopes above the dam as the cause and proposed reforestation as the solution. But closer inspection revealed that the project's designers had miscalculated the size of the watershed and overestimated the amount of water that could be captured, planning too large an irrigable area as a result. The consequences of these design faults were most severely felt during drought years such as 1997, an El Niño year in which the whole country, not just the Way Rarem watershed, experienced sharply reduced rainfall. Unfortunately, there are implicit incentives for project developers to oversell the likely benefits, and deforestation (and the small farmers doing this) is always available as 'scapegoat'.

2. Does forest produce extra rain?

Interactions between weather and vegetation are complex, involving changes in surface reflectivity (albedo) and surface roughness (air turbulence) in addition to changes in evapotranspiration. Rainfall occurs when cooling of air leads to oversaturation with water vapour, and condensation nuclei are present. Forests can influence local air circulation (cooling), the condensation nuclei and the recycled water vapour, but the net effect is hard to predict.

There is evidence that large-scale (> 1,000 – 10,000 km^2) removal or addition of old-growth forest in humid parts of the world affects rainfall during the transition between rainy and dry season. Effects on annual rainfall are modest (5-10%) but do manifest themselves mostly during this critical time of year. Any increments in rainfall after widespread forestation will often be less than increments in local water interception and use. The effects of partial tree cover are still largely undescribed.

3. Does forest affect annual water yield?

The removal of trees can be followed by a rise in the water table and an increase in dry-season flows. The explanation is that trees are pumps, using their deep rooting systems to access large amounts of groundwater. Replacing trees with less 'thirsty' plants such as grasses and annual crops allows groundwater reserves to recover as long as soil degradation is kept moderate. However, once soil degradation proceeds to a stage where infiltration becomes so impaired that large volumes of overland flow are generated (>15% of rainfall), then dry-season flow is likely to be significantly reduced. This degraded stage is typically reached after prolonged exposure of bare soil, intensive grazing or the use of heavy machinery, frequent use of fire hampering vegetation recovery, and by the introduction of paved surfaces such as roads, settlements, and urban areas.

Deforestation typically leads to a decline in dry season stream flow when the removal of trees, and the use of land that follows this, reduces infiltration more than it affects transpiration. In other words, it is the combined effect of changes in infiltration plus vegetation water use that determines the outcome for dry season flows. Plantations of fast-growing evergreen species can quickly draw significant quantities of water from below-ground. Tree species with water requirements that exceed available rainfall during certain times of the year start to mine soil water reserves, thereby producing negative trade-offs for local and downstream water users.

4. Does forest reduce flooding?

Local flooding in upland watersheds may be linked to deforestation. However, these links are often associative rather than strictly causal. Many of the processes that accompany or follow forest conversion compact the soil, reducing infiltration and so increasing runoff. These processes include the use of heavy machinery for land clearance and logging, the building of tracks and roads, and overgrazing by livestock.

Even where soils are not disturbed much, forest removal will increase stormflows during rainfall across the flow spectrum. However, for the biggest events the relative effect will be small.

Flooding (bank overflow) also depends on local topography as well as on the size of storage areas upstream (e.g. wetlands); allowing bank overflow upstream reduces the risk of flooding downstream and vice versa.

Reforestation is unlikely to reduce flooding risk to the same degree as the former old-growth forest because recovery of degraded soils often takes several decades and the impacts of drainage infrastructure (roads, housing) are not undone by tree planting alone.

Pointing the finger

Seasonal floods occur regularly in Jakarta, Indonesia's capital city. Deforestation upstream, by smallholders and recreational villas in the Puncak region, is widely held to be the cause. But Jakarta is in fact built on a floodplain at the mouth of a major river, where flooding occurs naturally, particularly after heavy rain during the monsoon. The city has grown rapidly over the past decades and many new areas, including ponds that once took overflow, now have paved roads, concrete yards and tiled roofs from which rainwater runs off. Added to all that is the inadequate carrying capacity of the city's canals and drains, which are frequently blocked with rubbish. These factors are at least as important as upstream landuse to the cause of flooding in Jakarta during heavy rains.

5. Does forest reduce erosion, landslides and stream sedimentation?

Soil erosion after forest conversion to annual cropping without proper soil conservation measures typically increases hillslope soil erosion by 10-20 times due to direct exposure of the soil to rainfall, gradual decreases in soil organic matter content, and associated deterioration of soil infiltration capacity and aggregate stability.

Shallow landsliding (1-1.5 m depth) after extreme rainfall on potentially unstable slopes increases significantly after forest conversion to pasture or cropping once the original root system has decayed (after 3-5 years); soil compaction and reduced infiltration during post-forest use will, in the long run, reduce the frequency of soil saturation and associated risk of landslides, but (as stated previously) will increase surface runoff and flooding risk downstream.

Stream sedimentation after forest conversion to cropping typically increases by a factor of 2-10 as a result of increases in both hillside sediment production and transport capacity of stormflows.

Planting trees or restoring natural vegetation on eroding land usually fixes surface erosion and stream sedimentation within a decade primarily through the establishment of a permanent litter layer and enhanced infiltration, unless deep natural landsliding is the chief source of the stream sediment (see ASB Policy*brief* no. 9 - Restoring the Functions of Watersheds).

Long, winding road to erosion

Researchers in the Pang Khum experimental watershed in northern Thailand's mountainous Chiang Mai Province found that unpaved roads were just as important as surrounding agricultural land in contributing water and sediment to streams, despite occupying a fraction of the total surface area.

The compacted surface of the roads generated a faster and greater flow of water, while drainage infrastructure ensured that this flow, with its sediment load, passed straight into the stream system. Erosion of the road surface was particularly rapid where the gradient was steep and the descent long. Road maintenance activities, the passage of vehicles, exposed banks, the trekking of cattle and the movement of people all renewed the presence of surface sediment, which was easily transported downhill whenever it rained.

The ASB Partnership for the Tropical Forest Margins is working to raise productivity and income of rural households in the humid tropics without increasing deforestation or undermining essential environmental services. ASB is a consortium of over 80 international and national-level partners with an ecoregional focus on the forest-agriculture margins in the humid tropics, with benchmark sites in the western Amazon basin of Brazil and Peru, the Congo Basin forest in Cameroon, southern Philippines, northern Thailand, and the island of Sumatra in Indonesia.

This document is based on nearly a decade of research on watershed management and policy by ASB, ICRAF and its partners. The ASB Policybriefs series aims to deliver relevant, concise reading to key people whose decisions will make a difference to poverty reduction and environmental protection in the humid tropics.

Our research on these topics is supported by the Australian Centre for International Agricultural Research (ACIAR), the World Bank – Netherlands Partnership Program (BNPP) and the UK's Department for International Development (DFID). Preparation and publication of this brief have been supported by the World Bank. Views expressed remain the authors' responsibility. We especially acknowledge the contributions of Kenneth Chomitz, Ellen Douglas, Jeffrey Richey, Kate Sebastian, David Thomas, Thomas P. Tomich, Sandra Velarde, Charles Vörösmarty, and Stanley Wood.

Contact us at:
ASB Partnership for the Tropical Forest Margins
P.O. Box 30677-00100 Nairobi, Kenya
Tel. +254 20 7224000
Email: b.swallow@cgiar.org
http://www.asb.cgiar.org

References

Agus, F., Farida and van Noordwijk, M. eds. 2004. Hydrological Impacts of Forest, Agroforestry and Upland Cropping as a Basis for Rewarding Environmental Service Providers in Indonesia. Proceedings of a workshop in Padang/ Singkarak, West Sumatra, Indonesia. 25-28 February 2004. ICRAF-SEA, Bogor, Indonesia.

Bruijnzeel, L.A. 2004. Hydrological functions of tropical forests: not seeing the soil for the trees? Agriculture, Ecosystems & Environment Volume 104, Issue 1, September 2004, Pages 185-228. doi:10.1016/j.agee.2004.01.015

Douglas, E., Wood, S., Sebastian, K., Vörösmarty, C., Chomitz, K., Tomich, T. (2007) Policy Implications of a Pan-tropic Assessment of the Simultaneous Hydrological and Biodiversity Impacts of Deforestation. Water Resources Management, 21(1): 211-232.

Douglas, E., Sebastian, K., Vörösmarty, C., Wood, S., Chomitz, K. (2005). The role of tropical forests in supporting biodiversity and hydrologic integrity. World Bank Policy Research Working Paper No. 3635, Social Science Research Network, Washington, DC., 2005, available on-line at http://econ.worldbank.org.

Thanapakpawin, P., Richey, J., Thomas, D.E., Rodda S, Campbell, B. and Logsdon, M. 2007. Effects of landuse change on the hydrologic regime of the Mae Chaem river basin, NW Thailand. Journal of Hydrology. 334(1-2):P. 215-230. doi:10.1016/j.jhydrol.2006.10.012

Tomich, T.P., van Noordwijk, M., and Thomas, D.E. eds. 2004. Environmental Services and Land Use Change: Bridging the Gap between Policy and Research in Southeast Asia. A special issue of Agriculture, Ecosystems and Environment, Vol. 104/1 (2004).

van Noordwijk, M., Richey J. and Thomas, D. 2003. Landscape and (sub)Catchment Scale Modeling of Effects of Forest Conversion on Watershed Functions and Biodiversity in Southeast Asia. Alternatives to Slash and Burn, BNPP Activity 2 Technical Report, available on-line at http://www.asb.cgiar.org/BNPP/phase2/sea/techreport/ FVOBAct2_all_2.pdf

van Noordwijk, M., Poulsen, J.G. and Ericksen, P.J. 2004. Quantifying off-site effects of land use change: Filters, flows and fallacies. Agriculture, Ecosystems and Environment. 104(1):P. 19-34. doi:10.1016/j.agee.2004.01.004

van Noordwijk, M., Agus, F., Verbist, B., Hairiah, K. and Tomich, T.P. 2007. Managing Watershed Services in Ecoagriculture Landscapes. In: Sara J. Scherr and Jeffrey A. McNeely (eds.). Farming with Nature: The Science and Practice of Ecoagriculture. Island Press, Washington DC. pp 191 - 212.

Ziegler, A.D., Giambelluca, T.W., Sutherland, R.A., Nullet, M.A., Yarnasarn, S., Pinthong, J., Preechapanya, P., Jaiarree, S. 2004. Toward Understanding the Cumulative Impacts of Roads in Agricultural Watersheds of Montane Mainland Southeast Asia. Agriculture, Ecosystems, and Environment 104: 14 5–158. doi:10.1016/j.agee.2004.01.012

Credits:
Contributors: Meine van Noordwijk and Sampurno Bruijnzeel
Editors: Sampurno Bruijnzeel, Meine van Noordwijk, Brent Swallow & Kris Galoppin-Vanhoutte

ASB
PARTNERSHIP FOR THE TROPICAL FOREST MARGINS

World Agroforestry Centre
TRANSFORMING LIVES AND LANDSCAPES

VU University Amsterdam