Forests and Watersheds

RESTORING THE FUNCTIONS OF WATERSHEDS

AGROFORESTRY SYSTEMS that are intermediate between natural forests and intensive foodcrop agriculture can restore most if not all watershed functions attributed to natural forests.

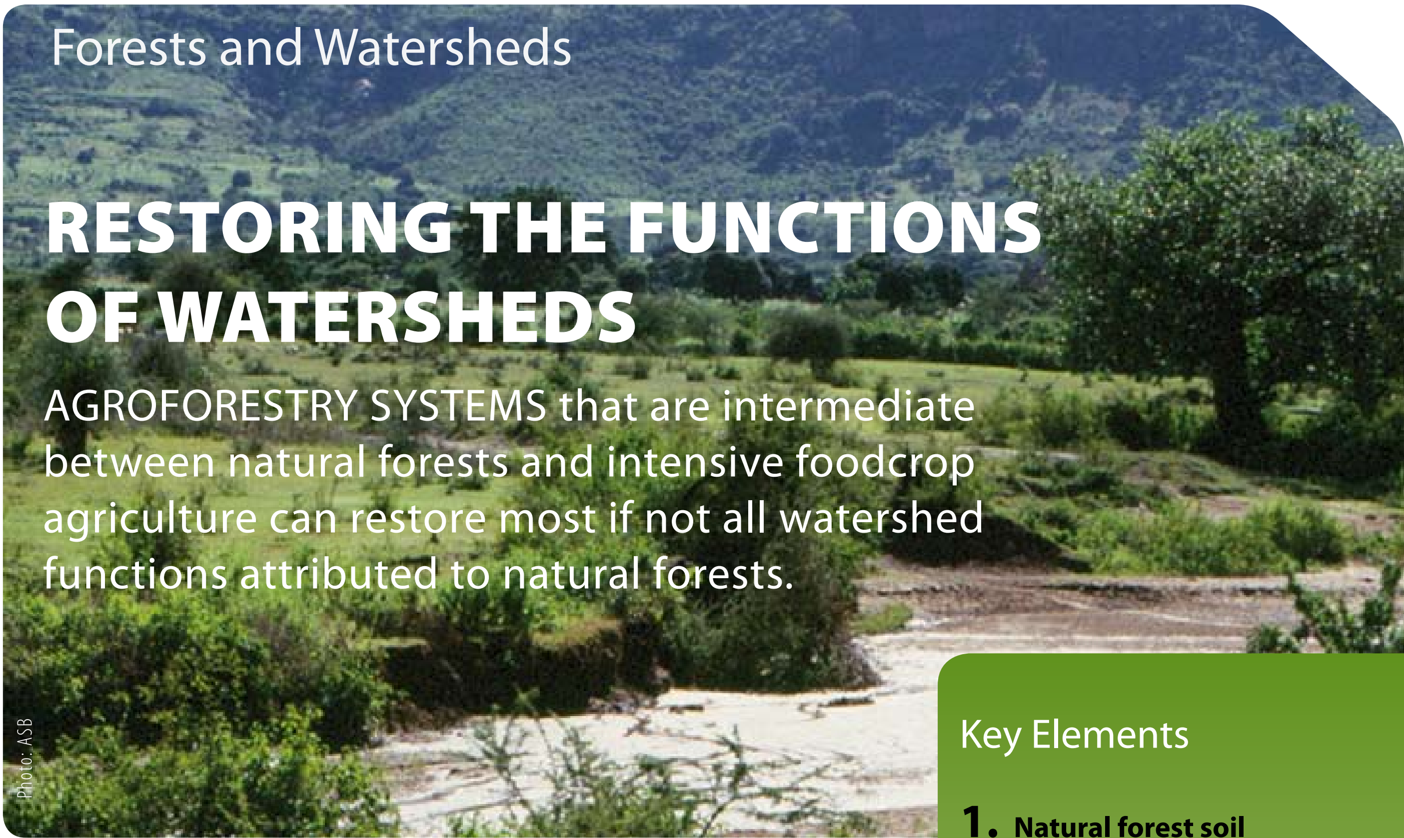


Photo: ASB

Watershed functions are determined by a complex mix of natural factors – quantity and timing of rainfall, lay of the land, geology, soil types, and so on. But is should be equally clear that human interventions on the land can also affect those functions. For example, if water cannot percolate deep into the ground in some areas because the soil has been compacted by livestock or machinery, then stream flow during the dry season may be adversely affected. Or, if too much space is devoted to roads and paths, which serve as rapid drainage channels, then excessive rain run-off may cause flooding during the rainy season or block culverts and irrigation channels with sediments. In addition, the proportion, species mix and distribution of vegetation – whether field crops or trees planted by land users – will also affect water yield and patterns of flow.

1. Natural forest soil

Natural forest soil has a protective litter layer (brown cover), is subject to minimal compaction, contains a wealth of macro and microorganisms that structure the soil, and supports the constant production and decomposition of tree roots. The resulting high porosity of forest soil enables it to absorb and distribute large amounts of water. Some is consumed by trees and other plants, some flows laterally offsite through the soil, and some penetrates to aquifers. The considerable surface roughness, or natural unevenness, of the forest landscape allows for temporary storage of surface water. And the absence of man-made (typically straight) channels prevents rapid delivery of surface runoff to streams. The unique characteristics of natural forest soil can provide a point of reference for restoring watershed functions that are normally attributed to tropical forests.

Key Elements

1. Natural forest soil
The unique characteristics of uncompacted natural forest soil covered by litter can provide a point of reference for restoring watershed functions.

2. Rapid degradation - slow recovery
It is important to correctly identify what type of degradation prevailing in a given location before formulating solutions and predicting the time frame for potential recovery.

3. Agroforestry solutions
Agroforestry systems combine the use of trees and other elements of the natural forest with areas dedicated to intensive food crop production providing at the same time environmental services and better livelihood opportunities for larger populations than could be supported by natural forests.

4. Modeling tools
ASB partners have developed a set of modeling tools to improve decisions about the adaptation of agroforestry to a range of watershed contexts, at spatial scales from plot to river basin.

2. Rapid degradation - slow recovery

Forest conversion to other land uses typically leads to degradation and problems with watershed functions unless preventive soil conservation measures are applied. Correct identification of the type of degradation is a prerequisite for formulating solutions and predicting the timeframe for potential recovery.

Soil compaction is a rapid degradation process; bulldozers, cars, animal hooves and people can all apply sufficient pressure to compact a soil. The reverse process, however, is slow; it primarily depends on the activities of earthworms and similar 'engineers' and the turnover of woody roots to restore macroporosity. Once a soil is severely compacted, the recovery process may take decades or up to a century.

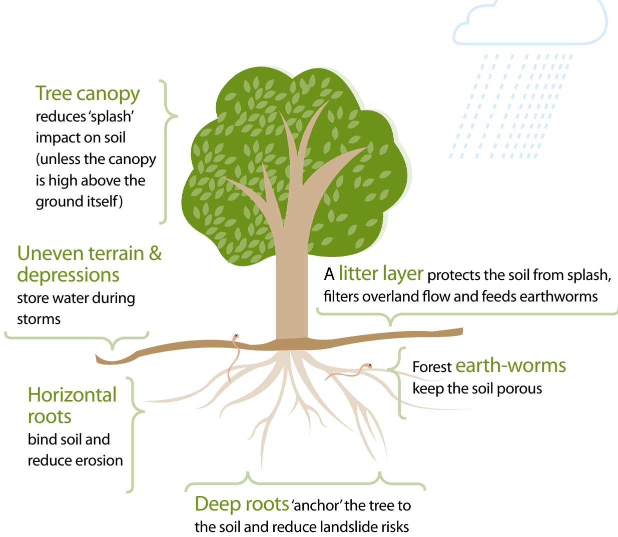
Surface crusting is another degradation phenomenon that can dominate the soil physical degradation process. This type of degradation occurs mostly in relatively dry climates where soil is exposed to direct sunlight. In this case, recovery can be relatively fast and easy to achieve. Using any type of mulch that protects the soil from the direct impact of rain and sunshine and that stimulates soil biological activity may lead to recovery in a timeframe of months.

Creation of local infiltration sites is often the first step required to break out from a soil degradation–surface runoff erosion cycle. Such sites will both reduce negative impacts on downhill neighbouring zones and allow for a positive feedback loop of vegetation that stimulates formation of soil structure, increasing infiltration and acting as a further stimulus to plant growth.

However, the best solution to avoid soil degradation is prevention through the protection of forest soils when this is still feasible. This can simply be done by reducing the drivers of degradation and will be more effective than efforts to rehabilitate degraded locations.

The WaNuLCAS model (van Noordwijk et al. 2004), a simulation tool developed to analyse tree-soil-crop interactions suggests that the most important parts of a forest from a perspective of soil and water flows is likely to be in the litter and root turnover effects, and that in turn supports soil biota to maintain soil structure (figure 1). Half-open (agroforestry) land-use systems with trees can approach the same functionality while providing better livelihood opportunities and income for larger populations than could be supported by natural forests.

Figure 1. Summary of tree and forest effects on soil



Modeling tools

WaNuLCAS — a modeling tool

The WaNuLCAS (**Wa**ter, **Nu**trient and **L**ight **C**apture in **A**groforestry **S**ystems) model was developed to represent tree-soil-crop interactions in a wide range of agroforestry systems where trees and crops overlap in space and/or time. The model can be used for exploring positive and negative interactions for different combinations of trees, crops, soil, climate and management by the farmer. There are two parts to the WaNuLCAS modeling system:

i) WaNuLCAS Excel where most data is entered including climate, soil data crop and tree parameters; and,
ii) WaNuLCAS.stm file/STELLA the modeling environment where simulations are made, including the tree and crop growth, water use and other aspects of the system.

The power of modeling lies in providing scientists with a means of integrating information from many different observational studies in order to arrive at rational predictions for new scenarios. Combining WaNuLCAS with sap flow measurements, taken using a low-cost technology developed by ICRAF, can help to illustrate the impact of tree water use at the landscape-level.

SExI-FS • Spatially Explicit Individual-Based Forest Simulator

The SExI Forest Simulator focuses on tree-tree interactions in a mixed multi-species agroforest, using an object-oriented approach where each tree is represented by an instance of a generic class of tree. The simulated object trees, mimicking real trees, interact through modifying their neighbors' environment. These modifications are mediated through two major resources: space and light. A 3D representation of a one-hectare plot of forest serves as the grounds for the simulation of this competition. Recently root architecture was added to the model.

3. Agroforestry solutions

Modern and traditional agroforestry systems represent a continuum of land uses between two extremes: full forest cover and blanket use of land for food and forage crops. ASB research indicates that such tree-and-crop systems, when properly designed, can restore many of the watershed functions normally attributed to natural forests. As such, they can, under the right conditions, help reduce the threat of local hazards such as water shortages, landslides and floods. At the same time they allow local people to feed themselves and earn cash from the land.

This is not to say that agroforestry systems automatically provide an easy or quick fix. Landscape conditions, climate, economic realities (especially market demand for farm products) need to be taken into account in the design of workable systems.

Some watershed services will be more important to local people than others. For example, if nearby downstream residents do not have a natural reservoir at their disposal, they may be keen to see upstream farmers maintain good dry-season river flow. This may involve agroforestry practices that maximize water infiltration rates. On the other hand, if the downstream community builds a reservoir, public attention will probably shift to total annual water yield and to the possibility of sediments shortening the reservoir's operational lifespan. Soil erosion in upstream fields could become a contentious issue.

Agroforestry systems vary in many respects, including their water use and impacts on watershed functions. Tree species choice is an important determinant of water use as it affects stream flow. Trees that shed their leaves periodically use less water during periods of shedding and can actually mitigate dry-season water shortages. In contrast, fast-growing evergreen species with high water requirements can easily exacerbate water shortages.

Photo: ASB

The location of trees within watersheds is equally important. Trees contribute to the stability of soils, helping to decrease the risk of shallow landslides, bank erosion, and soil loss during peak rainfall events. Trees with deep root systems anchor the tree and topsoil to deeper layers and reduce the risk of shallow landslides. On the other hand, trees with superficial or horizontal root systems bind the soil and reduce erosion by protecting the topsoil.

From the above, it is clear that the architecture and management of an agroforestry system is crucial if it is to provide environmental and development services and maintain healthy watershed functions all at the same time. A number of tools have been developed to assist with this task.

4. Modeling tools

ASB partners have developed a set of modeling tools to improve decisions about the adaptation of agroforestry to a range of watershed contexts, at spatial scales from plot to river basin (www.worldagroforestry.org/sea/products/AFmodels). These models can be used to address a number of policy-relevant questions: What are the

Download the models at: www.worldagroforestry.org/sea/products/AFmodels

GenRiver

GenRiver • Generic river flow model

GenRiver is a generic model of river flow in response to spatially explicit rainfall and a plot-level water balance that responds to changes in vegetation and soil.

The model can predict streamflow (hydrographs) and relate soil compaction to modified pathways of water into the streams. It also accounts for seasonal patterns of water use by different types of vegetation.

[SpatRain]

SpatRain

The SpatRain model was constructed to generate time series of rainfall that are fully compatible with existing station-level records of daily rainfall, but yet can represent substantially different degrees of spatial correlation. The model can derive daily amounts of rainfall for a grid of observation points by considering the possibility of multiple storm events per day, but not exceeding the long-term maximum of observed station-level rainfall. Options exist for including elevational effects on rainfall amount.

FALLOW

FALLOW • Forest, Agroforest, Low-value Landscape Or Wasteland?

FALLOW is a landscape-dynamics model, that can be used for impact assessment and scenario studies, assisting the negotiation process between stakeholders in a changing landscape by visualizing possible/likely consequences of factors such as changes in commodity prices, population density and human migration, availability of new technology, spatial zoning of land use, pest and disease pressure or climate.

impacts of different configurations of trees in a watershed on sedimentation? What is the potential for modifying upstream land use for achieving downstream benefits in terms of reduced sedimentation or reduced flood risk? When combined with other information about agroforestry, such as farmer returns and market opportunities, the outputs from these models can support good decisions about agroforestry and the management of other tree resources within multi-use landscapes. A smart research approach — called Rapid Hydrologic Assessment (RHA) — has been developed for assessing the potential for providing rewards to upland residents for land uses consistent with desirable watershed functions.

Future implications

Research by ASB partners has shown that intermediate land uses such as agroforestry systems can store significant quantities of carbon, maintain flows of ecosystem services, generate good economic return and reduce pressure on remaining forest resources. However, if agroforestry is to achieve its aims, actions targeting the technical aspects at farm-management scale will have to be embedded in a structure of rules and incentives that relate both the downstream users of landscapes and the stakeholders in maintenance of watershed functions to the decisions made on-farm. The past focus of watershed managers on forest cover per se may now give way to a more subtle view in which agroforestry systems get the recognition that they are due (see ASB Policy*brief* no. 8 for more information on the deforestation/watershed debate).


Photo: ICRAF

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 Chin Ong, jeffrey Richey, Thomas P. Tomich and Bruno Verbist..

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.

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., J. Richey and D. Thomas 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. [http://www.worldagroforestrycentre.org/sea/upload/meine/FVOBAct2_all_2.pdf]

van Noordwijk, M., Lusiana, B. and Khasanah, N. 2004. WaNuLCAS 3.01, Background on a model of water nutrient and light capture in agroforestry systems. International Centre for Research in Agroforestry (ICRAF), Bogor, Indonesia.

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., Farida, Pornwilai S., Agus F, Hairiah K,, Suprayogo D. and Verbist, B. 2006. Watershed functions in productive agricultural landscapes with trees. Pp. 103-112, In: Garrity, D., A. Okono, M. Grayson and S. Parrott, eds. 2006. World Agroforestry into the Future. Nairobi: World Agroforestry Centre.

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.

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

ASB
PARTNERSHIP FOR THE TROPICAL FOREST MARGINS

World Agroforestry Centre
TRANSFORMING LIVES AND LANDSCAPES

Credits:
Contributors: Brent Swallow & Meine van Noordwijk
Editor: Kris Galoppin-Vanhoutte