Negotiation-support toolkit for learning landscapes

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29 | Generic river flow (GenRiver) at landscape level

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Generic River Flow (GenRiver) is a semi-distributed, process-based model that extends a plot-level water balance to sub-catchment level. It was developed for data-scarce situations and is based on empirical equations. The model can be used to explore the basic changes of river flow characteristics across spatial scales: from patch, sub -catchment to catchment. GenRiver is a simple river flow model that can be used to explore our understanding of historical changes in river flow owing to land-use changes.

Introduction: why model river flow?

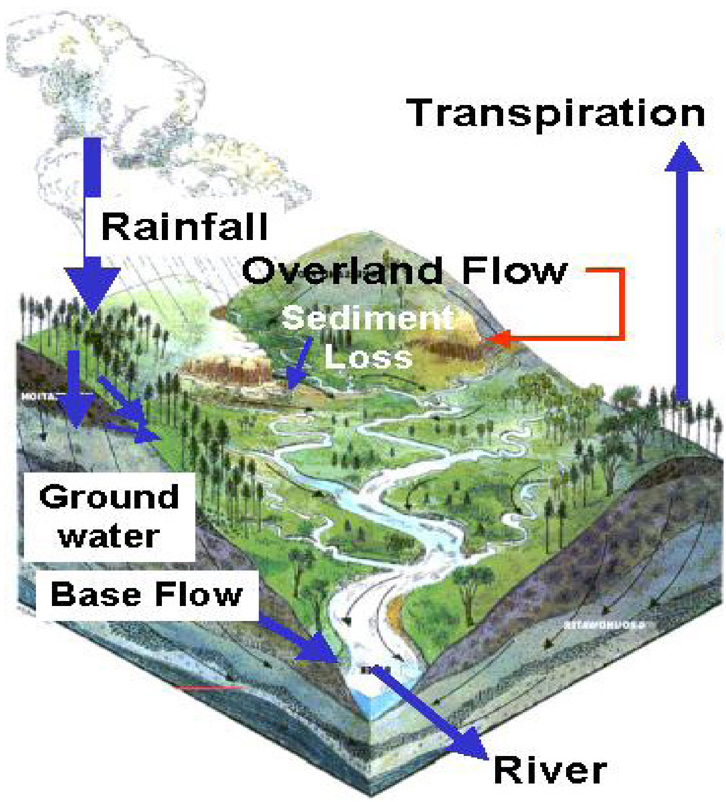

Figure 29.1. Schematic diagram of water flow in a catchment

Changes in land cover can significantly affect watershed functions. For example, they can change the amount of rainfall that reaches the ground and, consequently, the pathways of water flow over and through the soil, as well as affecting the rate of water use by plants. Most of the impacts on river flow can be explained by characteristics of the vegetation and soil. Empirical assessments of the dynamics of water flow as a function of changes to land-cover and soil properties require time and resources and need to take the temporal and spatial variation of rainfall into account. A model based on 'first principles', which integrates changes of land-cover and soil properties as driving factors of changes in river flow, can be used to explore scenarios of land-use change, provided it passes a 'validation' test against observed data.

GenRiver

GenRiver is a generic model for analysing river flow. As is common in hydrology, it starts with the accounting of rainfall or precipitation (P) and traces the subsequent flows and storage in the landscape that can lead to either evapotranspiration (E), river flow (Q) or change in storage (ΔS):

$$P = Q + E + \Delta S \quad \text{.......................................} (1)$$

Hydrological models differ in the relations between the different terms of the balance equation and in the way they account for the 'slow flows'. Slow flows derive from water that infiltrates the soil but that takes a range of pathways (with various residence times) to reach the streams and rivers, depending on landform, geology, and extractions along the way.

The core of the GenRiver model consists of a 'patch'-level representation of daily water balance driven by local rainfall and modified by the land cover, land-cover changes, and soil properties of the patch. The patch can contribute to three types of stream flow: 1) surface quick flow on the day of the rainfall event; 2) soil quick flow on the next day; and 3) base flow via the gradual release of groundwater.

A river is treated as a summation of streams, each originating in a sub-catchment with its own daily rainfall, yearly land-cover fractions, and constant total area and distance to the river outflow (or measurement) point. Interactions between streams as they contribute to the river are considered to be negligible (that is, there is no 'backflow' problem). Spatial patterns in daily rainfall events are translated into average daily rainfall in each sub-catchment. The sub-catchment model represents interception, infiltration into the soil and rapid percolation into the subsoil as well as surface water flow and rapid lateral subsurface flow into streams, with parameters that can vary between classes of land cover.

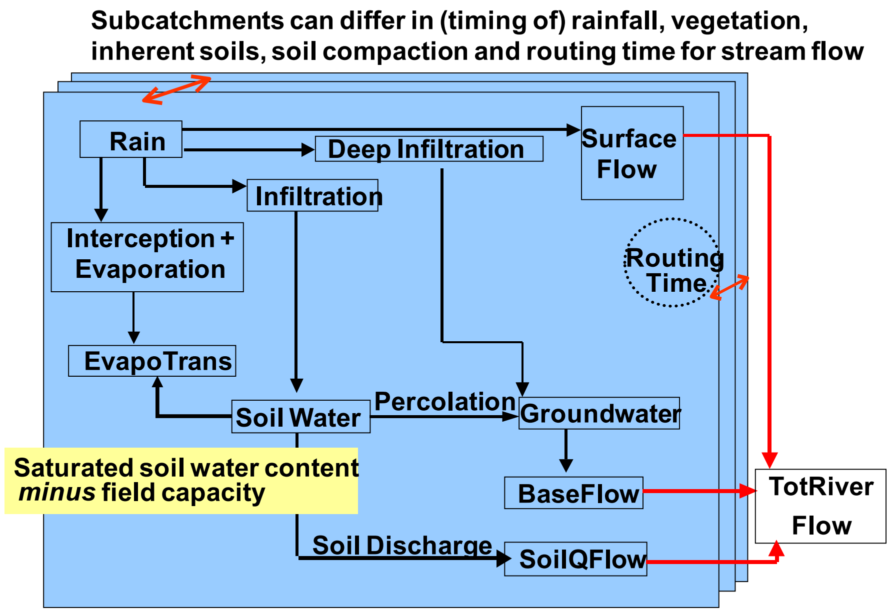

Figure 29.2. Schematic of the model aligned with the basisc plot-level water balance equation

The model has been built on the STELLA platform, with an accompanying Excel file to store input parameters; a NetLogo version of GenRiver is also available.

Objectives

To help to simulate the effects of land-cover and climate changes on the hydrological functions of a watershed.

Steps

Modeling is carried out using the following steps.

1. Data preparation and model parameterization.
2. Model calibration including evaluation on model performance.
3. Assessment of hydrological situation of the watershed.
4. Scenario development.
5. Model simulation based on scenarios developed in Step 4 to understand the impact of land-use changes on water balance and river flow.

Example of application

GenRiver was used to analyze the response of Bialo watershed (11 417 km^2) to land-cover changes. The watershed is situated in Bantaeng and Bulukumba districts, South Sulawesi, Indonesia. Model simulations used rainfall data from 1989 to 2009. Annual rainfall ranged 1142–2668 mm per year.

In general, more than 58% of Bialo watershed area was dominated by agroforests (such as mixed-tree, clove, cocoa and coffee systems). Forests (primary and secondary) and rice covered 22.5% and 11% of the area, respectively. The remaining cover was shrub, grass, cleared land and settlements. The percentage area of each land-cover type in Bialo in 1989, 1999, 2005 and 2009 are presented in Figure 29.3.

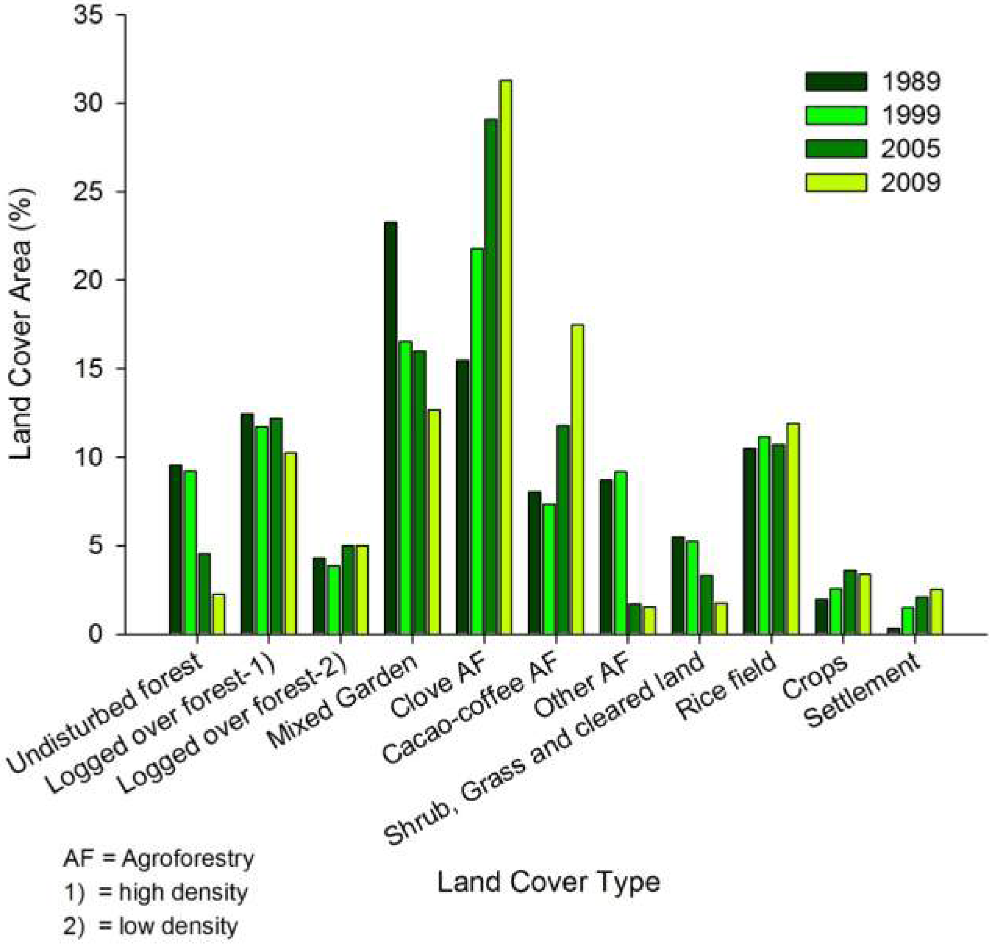

Figure 29.2. Land-cover percentages in Bialo watershed

Calibration and validation was carried out using river flow data from 1994–1995 and 1998–1999. The results showed that the hydrograph from GenRiver captured the patterns of observation data in the Bialo watershed with NSE values 0.55 and 0.63. According to Moriasi (2007), these NSE values are satisfactory criteria and can be used to simulate river flow of the watershed.

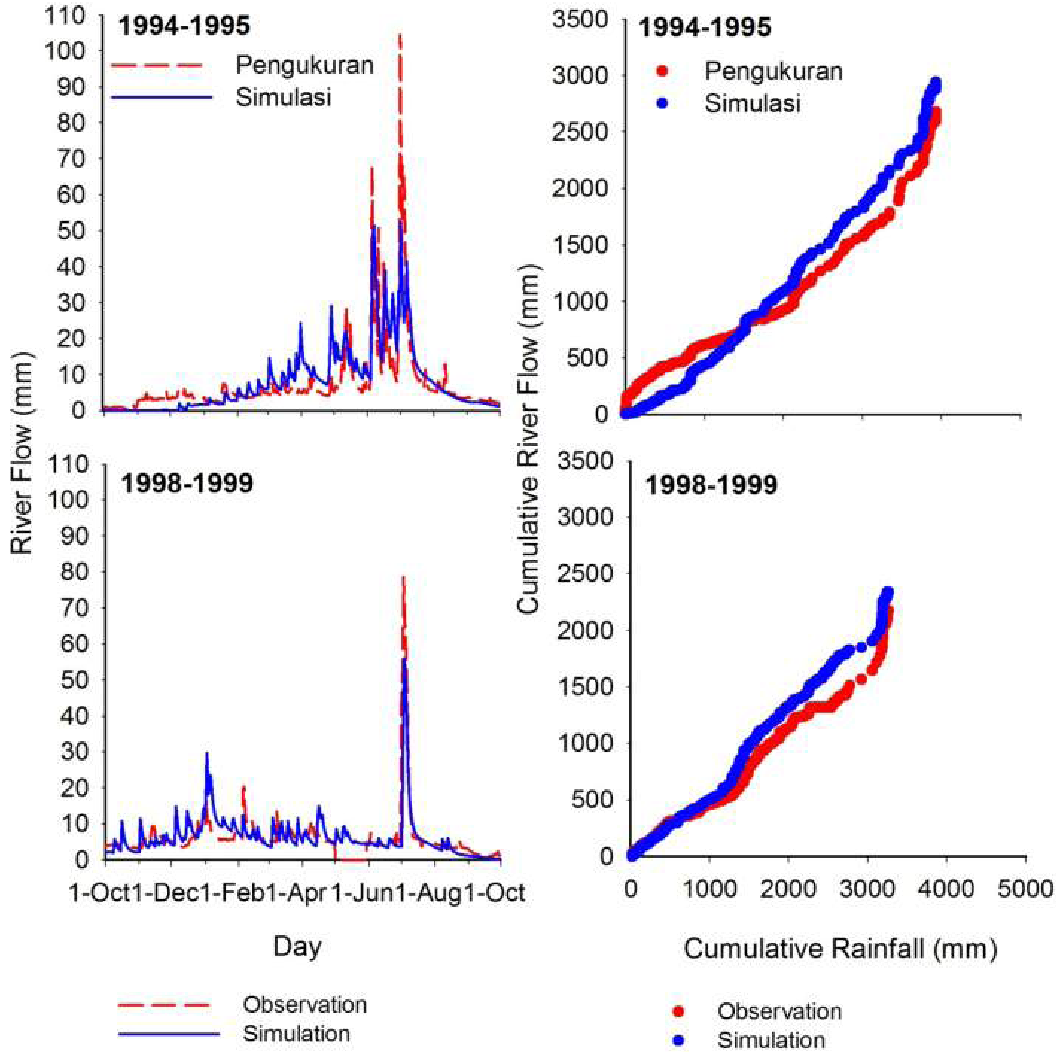

Figure 29.3. River flow simulations by GenRiver with actual observation

The results of the simulation of the impacts of land-cover changes on the water balance in Bialo watershed, using GenRiver, can be divided into three transition periods: 1) 1989–1999; 2) 2000–2005; 3) 2006–2009.

The first period (1989–1999) enjoyed annual rainfall ranging 1142–2668 mm and land-cover changes, such as the deforestation of 39 hectares, a decrease in mixed-tree gardens from 23.3% to 16.5%, a decrease in coffee and cocoa agroforestry from 8% to 7.3% and an increase of 6.3% and 0.5% of clove and other agroforestry, respectively. This led to an increase in evapotranspiration of 12.16% per year and a decrease in river discharge of 12.13% annually. The decrease was caused by the decline in surface flow (12.14% per year) and base flow (0.1% per year).

The second (2000–2005) and third (2006–2009) periods had annual rainfall ranging 1392–2194 mm and 1184–2365 mm, respectively. The main land-cover transition that occurred in these periods was in forests and clove agroforests. Forests decreased from 9.25 to 4.5% and then from 4.5% to 2.3%. Clove agroforests increased from 21.8 to 29.1% and then from 21.9 to 31.3%. This led to increased evapotranspiration of 0.53% per year and a decrease in river discharge of 0.43% annually. This change of river discharge featured increasing baseflow and decreasing surface flow.

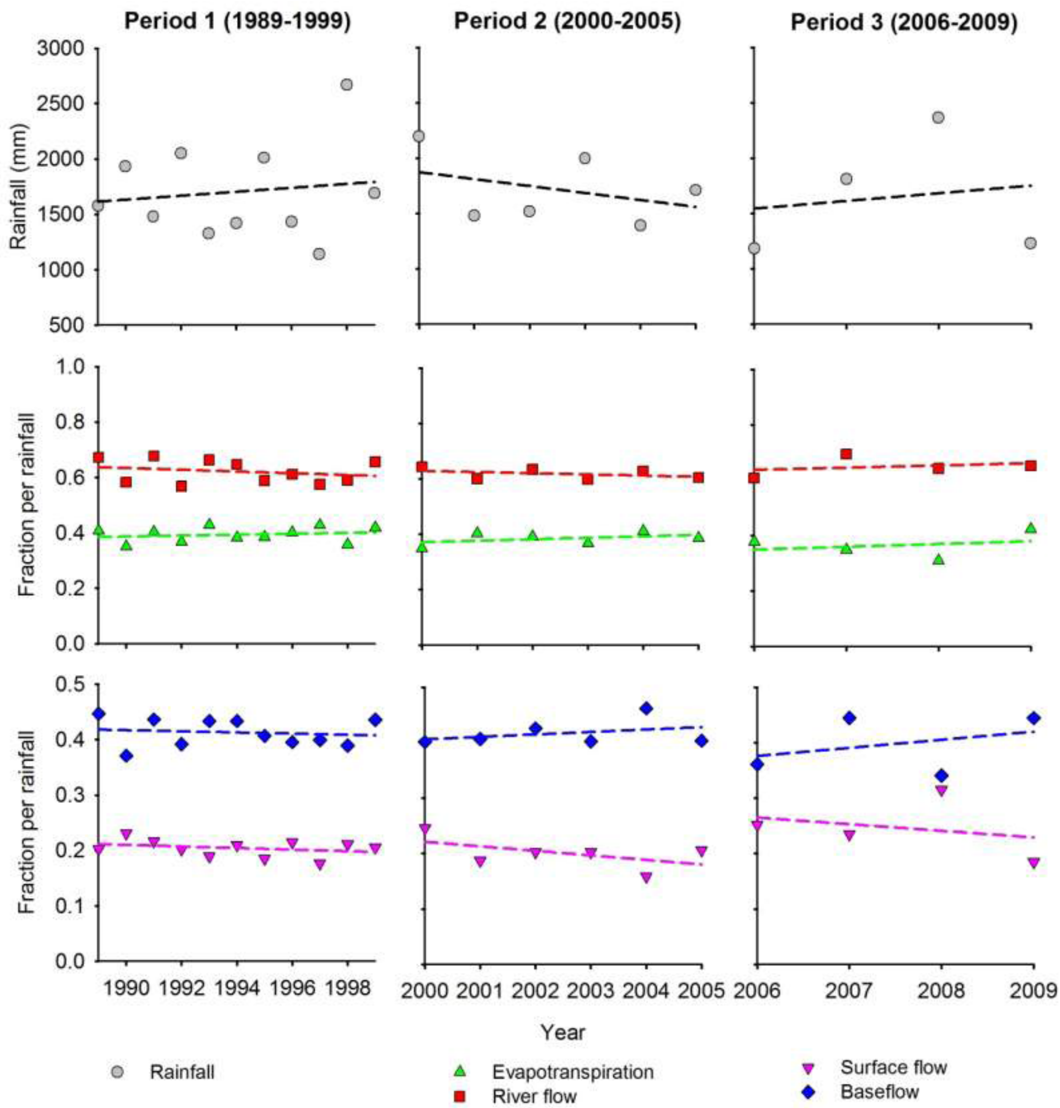

Figure 29.4. Simulation result of water balance in Bialo watershed using GenRiver model for each transition period

The assessment of the hydrological situation of a watershed is determined by the criteria and indicators of water transmission (total water yield per unit rainfall), buffering capacity (relationship of peak river flow and peak rainfall, linked to flooding risk) and gradual release of groundwater in the dry season, based on recharge in the rainy season (Table 29.1). These indicators all relate the flows of water to preceding rainfall and by doing so allow the analysis of relatively small land-use effects, superimposed on substantial year-to-year variation in rainfall.

To capture the impact of land-use changes, the indicators were scattered over the 21-year simulation period (Figure 29.1). The main effect of the changes seems to have been an increase in evapotranspiration and a decrease in total water yield as a fraction of total rainfall. The buffering capacity (buffering indicator, buffering relative, and buffering peak events) tended to be stable until 2009. The buffering indicator and relative buffering indicator had a negative correlation to the discharge fraction (fraction of river flow per rainfall) over the year (Figure 29.1).

Table 29.1. Average of indicators of watershed function

	Observed			Simulated		
	Min.	Average	Max.	Min.	Average	Max.
Total discharge fraction	0.32	0.57	0.77	0.57	0.63	0.69
Buffering indicator	0.58	0.74	0.90	0.58	0.68	0.76
Relative buffering indicator	0.17	0.54	0.75	0.35	0.50	0.61
Buffering peak event	-0.68	0.51	0.91	0.72	0.84	0.91
Highest monthly discharge relative to mean rainfall	1.36	2.30	3.61	1.62	2.38	3.18
Overland flow fraction				0.16	0.21	0.32
Soil quick flow fraction				0.00	0.00	0.00
Slow flow fraction				0.33	0.41	0.47
Lowest month fraction				0.01	0.18	0.44

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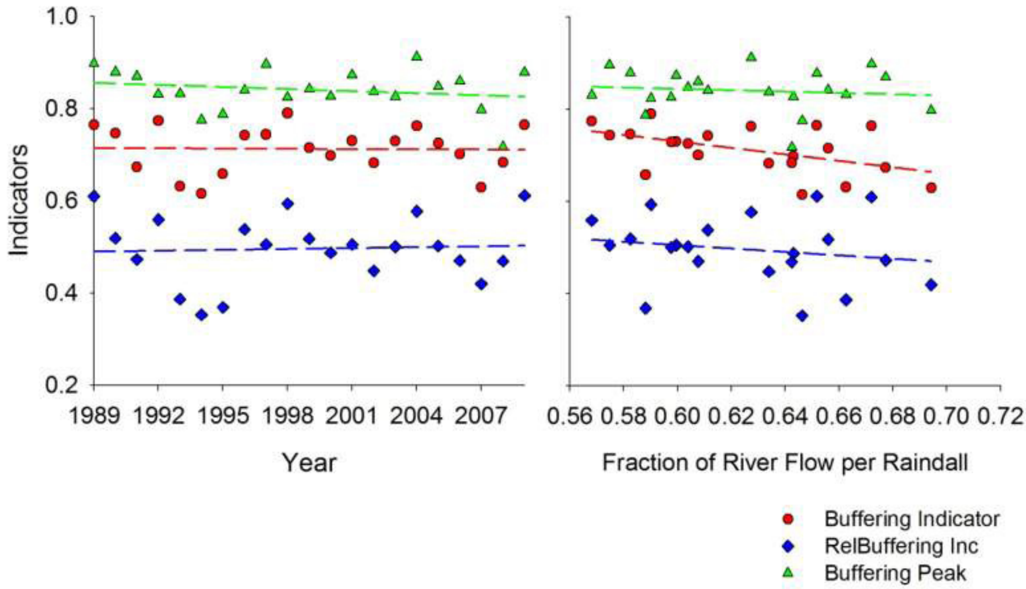

Figure 29.5. Trend of buffering capacity indicator over 21 years (1989–2009) and to discharge fraction

Key references

Van Noordwijk M, Widodo RH, Farida A, Suyamto DA, Lusiana B, Tanika L, Khasanah N. 2011. G*eneric River and Flow Persistence models. User Manual Version 2.0*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. http://www.worldagroforestry.org/sea/publication?do=view_pub_detail&pub_no=MN0048-11.

Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL. 2001. *Model evaluation guidelines for systematic quantification of accuracy in watershed simulations*. American Society of Agricultural and Biological Engineers 20(3):885–900.

The landscape scale is a meeting point for bottom–up local initiatives to secure and improve livelihoods from agriculture, agroforestry and forest management, and top–down concerns and incentives related to planetary boundaries to human resource use.

Sustainable development goals require a substantial change of direction from the past when economic growth was usually accompanied by environmental degradation, with the increase of atmospheric greenhouse gasses as a symptom, but also as an issue that needs to be managed as such.

In landscapes around the world, active learning takes place with experiments that involve changes in technology, farming systems, value chains, livelihoods' strategies and institutions. An overarching hypothesis that is being tested is:

> Investment in institutionalising rewards for the environmental services that are provided by multifunctional landscapes with trees is a cost-effective and fair way to reduce vulnerability of rural livelihoods to climate change and to avoid larger costs of specific 'adaptation' while enhancing carbon stocks in the landscape.

Such changes can't come overnight. A complex process of negotiations among stakeholders is usually needed. The divergence of knowledge and claims to knowledge is a major hurdle in the negotiation process.

The collection of tools—methods, approaches and computer models—presented here was shaped by over a decade of involvement in supporting such negotiations in landscapes where a lot is at stake. The tools are meant to support further learning and effectively sharing experience towards smarter landscape management.

World Agroforestry Centre
ASB Partnership for the Tropical Forest Margins
AARD
Federal Ministry for Economic Cooperation and Development
Norad
IFAD Enabling poor rural people to overcome poverty
CGIAR Research Program on Forests, Trees, and Agroforestry