Chapter 19
Soil and water movement: combining local ecological knowledge with that of modellers when scaling up from plot to landscape level

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Key questions

1. How do generally held perceptions of the relationship between 'forest' and 'watershed functions' compare with available data and hydrological theory?
2. How, in practical situations, can we compare and combine local ecological knowledge with that of modellers?
3. How can such an analysis be used to reduce conflict and negotiate landscape-level land-use patterns?

19.1. Introduction

Chapter 2 introduced a specific method for documenting, representing and analyzing local ecological knowledge of belowground interactions in agroecosystems. Most of the examples given focused on 'plot-level' soil fertility issues. The succeeding chapters described various aspects of the 'scientific' exploration of the contributing processes, leading to a discussion of management options for farmers in Chapter 17. The management options that farmers actually use, however, depend on the specific constraints that those farmers face (e.g. with regard to labour and capital), and the degree to which the farmers wish to maximize profitability. In Chapter 18, emphasis was placed on landscape-level impacts of local land use, via the lateral flows of water. In this chapter we will 'pick up' the discussion from Chapter 2, and discuss examples of how local ecological knowledge can be contrasted with the ecological knowledge of modellers as well as examples of how the two can be combined to gain a better understanding of the way landscape-level resources can be managed. Both types of knowledge may contrast with the apparent logic underlying existing policies and with the perceptions generally held by people living in urban areas. Almost by definition, the management of resources at this scale involves multiple stakeholders: thus, conflicts can easily emerge. We therefore have a number of reasons to carefully explore local ecological knowledge and perceptions:

- In as far as local ecological knowledge is based largely on site-specific local experience and observations, it provides a rich testing ground for the supposedly generic concepts reflected in current models.
- Local ecological knowledge tends to be 'operational' or 'functional' and linked to the implications of various human interventions, and therefore provides a practical perspective, which is directly relevant to (and thus very useful in) 'system-oriented' science.
- In landscape-level interventions there is little scope for the 'recipe'-type outcomes sometimes associated with traditional agronomic research; so, a blending of 'hard' and 'soft' science that tries to extract and adapt 'rule-based knowledge' is needed.
- Communication with, and the provision of extension services to farmers requires a common 'language'.
- Negotiations between multiple stakeholders are probably easier if they are based on a shared understanding of underlying ecological phenomena.

This chapter will begin by analysing the current confusion surrounding watershed functions in relation to land-use change (specifically deforestation), and discussing an analytical framework that can be used to predict relationships between plot-level interventions and landscape-level effects. Finally, the chapter will consider two case studies, documenting and comparing both local concepts and those of modellers, before addressing associated issues.

19.2. Myths, misunderstandings and analytical frameworks

Usually the general public attributes watershed functions directly to standing trees, the entity that is seen as that promoting and maintaining most forest functions (Calder, 2002). Removal of trees is most usually blamed for events such as floods, landslides and reductions in the baseflow of downstream rivers (which subsequently cause siltation). Media reports claiming calamities due to the loss of trees are accepted as ‘the truth’ by the public at large. As explored by Grove (1995), perceptions of the relationships between deforestation, subsequent changes in rainfall, land degradation and siltation of rivers date back to experiences in the Mediterranean region, with Theophrastus (c. 372–287 BC) being one of the earliest writers to document such perceptions.

Experience gained as a result of European colonial expansion into the tropics, particularly that gained on small islands such as Mauritius (which have a dry, non-forested side and a wet, forested side), strengthened the perception that forests generate rainfall. Yet, hard evidence of a change in documented rainfall as a consequence of deforestation is still lacking. The causal relationship between forests and rainfall (‘rainfall leads to forest’) is generally actually the reverse of what is perceived to be true (‘forest leads to rainfall’). For example, a recent re-analysis of rainfall patterns in Indonesia (Kaimuddin, 2000) indicated shifts in isohyets (zones of equal rainfall) which are not obviously related to local land-cover change: some areas that lost forest cover became wetter whilst others became drier. For Indonesia as a whole, average rainfall did not change, despite a considerable loss of forest cover, though there may have been a change in the overall circulation pattern that affects local rainfall. Although at a local scale real changes in rainfall may have coincided with real changes in forest cover, there is no convincing evidence to support the hypotheses concerning causal relationships. However, the way a landscape ‘processes’ the incoming rainfall depends directly on land cover – the total amount of water in streams, the regularity of the flow and the quality of the stream water can be directly affected by changes in cover (see Box 18.3, this volume, for a debate concerning the link between forests and hydrological functions).

Globally, the ‘community’ practicing soil and water conservation and integrated watershed management is in a state of confusion. On the one hand therefore, multibillion dollar efforts are being made to rehabilitate degraded watersheds based on the ‘scaling up’ of results obtained from erosion plot experiments and the expectation that conserving forest and planting trees are, respectively, the best and next-best methods by which to guarantee dry-season flows of water and secure land productivity. However, on the other hand, there is a remarkable absence of documented evidence regarding the impact of such methods, whilst the rules regarding the ‘scaling up’ of results have been seriously questioned (as the results of reforestation efforts made to restore watershed functions are generally disappointing). On the basis of an e-conference and a search of published literature, Kiersch and Tognetti (2002) could not find any convincing evidence that land use affects the major ‘watershed functions’ related to flow rates and sediment loads for areas larger than 10 x 10 km^2. We should therefore ask is ‘watershed management’ a fiction and a waste of public resources? Or, has research not yet addressed the right questions?

Of course, as Kiersch and Tognetti (2002) state, ‘lack of evidence of effect’ is no ‘evidence for lack of effect’. Those authors discuss a number of reasons why a measurable impact may be lacking – given that rainfall variability occurs in short-term studies and climate change affects extrapolations at larger scales in longer term studies. It should also be remembered that inter-site comparisons are complex, whilst attributing measured changes in water to specific factors requires a full understanding of both internal and external feedbacks in the system. However, evidence given in Table 19.1 (regarding the effects land-use change has on salinity, pesticides and heavy metals) shows that there is no lack of studies at the 10^5 km^2 scale. The fact that ‘sediment delivery ratios’ (the ratio of erosive losses from uplands and the sediment load of streams) tend to decrease continuously with an increase in the size of the area under consideration (van Noordwijk *et al*., 1998d) indicates that landscape-scale sedimentation processes have been overlooked, or underestimated, in most attempts to scale up erosion studies on small plots. Calder (2002) has called attention to the many ‘myths’ surrounding forests, tree planting and water resources, while leading tropical forest hydrologists (Bruijnzeel, 2002) have made valiant attempts to summarize the available empirical data. Their data show that increases occur in total river flow upon the conversion of forest to agriculture, that variable impacts are made over time on the baseflow/peakflow ratio and that there is a marked lack of evidence to indicate the return of baseflow after reforestation.

Watershed management projects have evolved away from the largely technical focus of the past towards one governed by participatory practices and the need for consultation with local stakeholders. However, rigid project frameworks hardly ever allow for a critical questioning of the basic premises of these projects, and the gap between ‘science’ and the ‘community of practice’ may

Table 19.1 Documented impacts of land use change on ‘watershed functions’, by basin size (Kiersch and Tognetti, 2002); x = Measured impact; - = No well-documented impact.

Impact type	Basin size (km^2)						
	0.1	1	10	10^2	10^3	10^4	10^5
Thermal regime	x	x	-	-	-	-	-
Pathogens	x	x	x	-	-	-	-
Average flow	x	x	x	x	-	-	-
Peak flow	x	x	x	x	-	-	-
Base flow	x	x	x	x	-	-	-
Groundwater recharge	x	x	x	x	-	-	-
Organic matter	x	x	x	x	-	-	-
Sediment load	x	x	x	x	-	-	-
Nutrients	x	x	x	x	x	-	-
Salinity	x	x	x	x	x	x	x
Pesticides	x	x	x	x	x	x	x
Heavy metal	x	x	x	x	x	x	x

be widening. In the following sections, we look at local farmers’ mental models of watershed ecosystems and compare them with models developed through a scientific approach. We take two examples – one from Indonesia, the other from Vietnam.

19.3. Case study 1: Sumberjaya, West Lampung, Sumatra (Indonesia)

The island of Sumatra is composed of a chain of (inactive) volcanoes and mountains (running parallel to its west coast) and a vast lowland peneplain with generally acid sedimentary soils on its eastern side (van Noordwijk *et al*., 1998e). The richer soils are found in the mountains and foothills (piedmont). Many of the valleys in the mountains have been used for agriculture for thousands of years, with pottery and other archaeological remains providing evidence of long-term external trade links via the rivers. Sumberjaya is one of these valleys, having an elevation of between 500 and 800 m a.s.l. and rainfall averaging 2614 mm year^{-1} (Agus *et al*., 2002). Until the middle of the 20th century, the valley remained relatively inaccessible by road and was sparsely populated. Population densities have now reached 147 per km^2 (BPS ,1999), as a result of immigrants flowing into the area either from traditional coffee-growing areas to the north, or from the island of Java. Coffee (*Coffea robusta*) is the main component of the majority of gardens. A considerable part of the area has been designated ‘protection forest’, and hundreds of households have been evicted from the area in the name of ‘watershed-protection functions’. Only after the political changes of the late 1990s have farmers resettled the area, and they are currently negotiating tenurial rights in the context of ‘community forest management’ arrangements. Perceptions of watershed functions thus have a direct, political relevance in this area.

Coffee cultivation methods and garden typology vary widely across the district (Verbist *et al*., 2002). Gardens range from young monocultures of coffee, through simple shaded coffee to complex multistrata agroforests. Increasing land scarcity has resulted in the cultivation of steeper land and the conversion of most primary and secondary forest to agriculture, except in the case of some of the steepest slopes and the top of a ridge which formally held the status 'protection forest'. Soil conservation in these erosion-susceptible areas is a priority, in order to sustain coffee yields in the short term and prevent a longer term decline in productivity. Consequently, various soil management strategies and garden typologies have developed to suit different locations. A variety of soil conservation measures are applied in coffee gardens – from physical barriers such as terraces, trenches, ridges and pits, to the choice, positioning and manipulation of the plant components within the garden. These measures are often practiced in conjunction with soil improvement through cultivation, and fertilizer and compost application. The effects of companion tree species in a mixed coffee system are well understood by farmers in Sumberjaya, where trees are classified based on their 'friendliness' to coffee (Box 19.1).

Box 19.1. Grouping of trees in coffee gardens based on their influence on coffee plants (source: farmer interviews in Sumberjaya in 2000/2001; Chapman, 2002).

'Coffee-friendly' trees

Trees considered 'friendly' to coffee demonstrate the following:

- Non-competitive roots variously described as 'cold', 'deep' or 'water holding'
- A light, airy crown with small leaves (allowing penetration by sunlight)
- Regular leaf shedding
- Leaves which decompose readily
- Leaves with a good compost value (e.g. improving soil fertility)
- Leaf retention during dry season.

Examples of such trees are kayu hujan (Gliricidia sepium), lamtoro (Leucaena leucocephala), sengon (Paraserianthes falcataria) and dadap (Erythrina orientalis).

'Coffee-neutral' trees

Trees considered neutral in terms of their interaction with coffee provide some shade and help in soil conservation, although they do compete with coffee to some extent. This category includes fruit and spice trees (grown for household consumption and for sale), which are mostly maintained around homesteads. Examples of such trees are nangka (*Artocarpus heterophyllus*), rambutan (*Nephelium lappaceum*) and jambu air (*Syzigium aqueum*).

'Coffee-harming' trees

Trees considered harmful to coffee are usually productive, being grown for timber, spices or fruit. The economic gains of such trees outweigh the negative effects they have on coffee production. However, the negative effects they have on coffee are acknowledged, and are mitigated by planting position (boundary) and spacing (wide) used. Such trees have:

- Strong, 'hot', expansive root systems
- High nutrient requirements
- Leaves with a poor composting value - such leaves are described as *keras* ('hard', 'difficult to decompose').

It is preferable not to have such trees in one's field, so they are mostly maintained on the garden boundary. Examples of such trees are kemiri (*Aleurites moluccana*), jati (*Tectona grandis*), pohon afrika (*Maesopsis eminii*) and mahogani (*Swietenia macrophylla*).

A study of the local ecological knowledge held by farmers was carried out using the knowledge-based-systems (KBS) approach (Sinclair and Walker, 1999), the same method used in the investigation of local ecological knowledge discussed in Chapter 2. Over 30 farmers were interviewed and asked to articulate their knowledge and understanding of the ecological processes occurring in their fields and in the surrounding landscape.

19.3.1 Erosion and water quality and flow

Farmers in Sumberjaya hold the view that a decline in forest cover affects uniformity of water flow in rivers, resulting in an increase in river flooding in the rainy season and greatly reducing the amount of water in rivers in the dry season. They also believe water turbidity increases with the destruction of forest cover (Fig. 19.1).

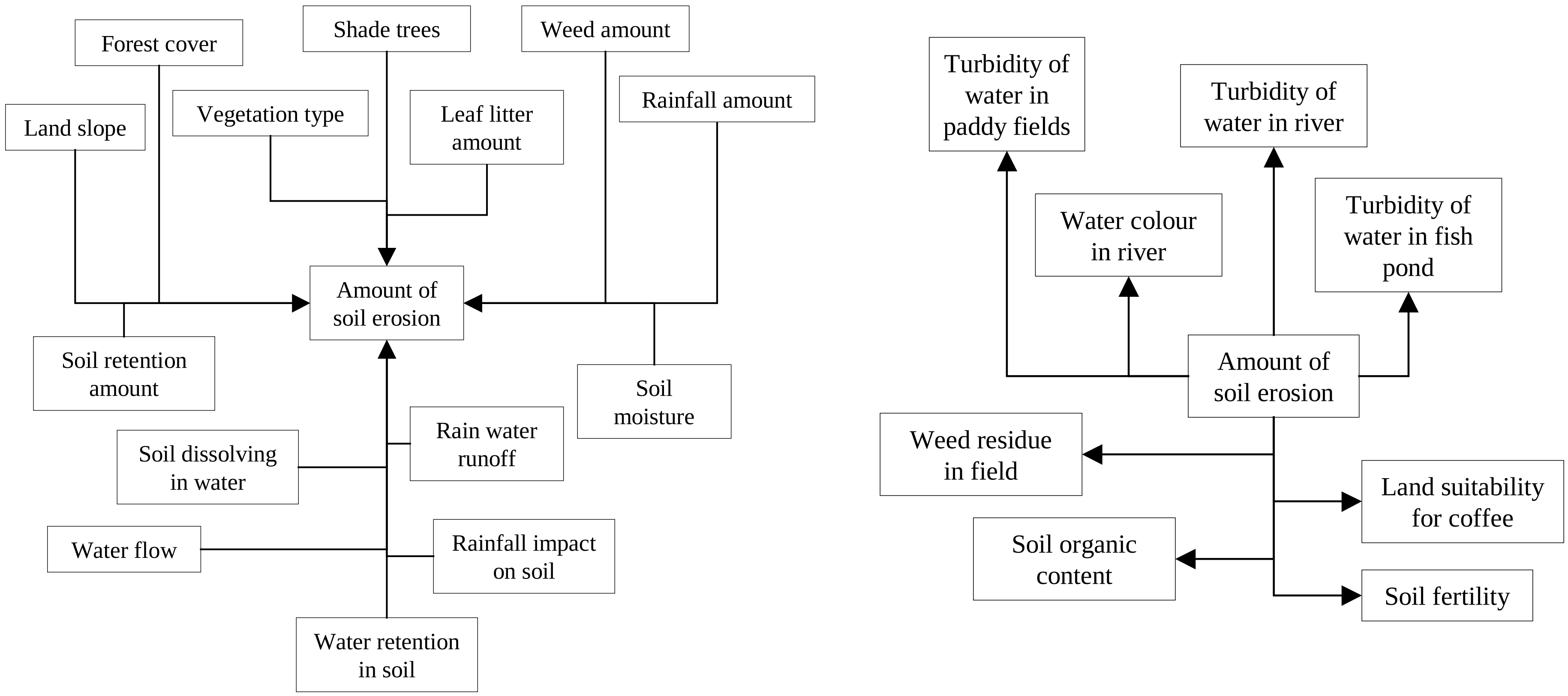

Fig. 19.1. Sumberjaya farmers' understanding of the causes and consequences of soil erosion in coffee gardens and the surrounding landscape. Change in values (such as an increase or decrease) of source nodes determines values in associated target nodes

Cultivation methods strongly influence the efficiency with which coffee gardens maintain watershed functions. Earthen constructions (such as terraces, furrows and composting holes) can help reduce erosion. On the other hand, weeds and weeding techniques also affect soil erosion, as intensive weeding increases erosion whilst the presence of weeds can be used to reduce erosion, as can weed strips, ring weeding and mulching.

19.3.2 Riparian vegetation

Riverside vegetation is believed to be crucial to watershed function at a landscape level, significantly influencing flooding, landslides, bank erosion and changes in the courses of rivers. There was no consistency amongst the farmers with regard to how wide this vegetation should be: estimates ranged from 50 to 500 m. Trees along river banks, even if they occur only in thin strips a few metres wide, are considered to be effective filters by farmers. Additionally, the root systems of vegetation are believed to hold soil, thereby reducing the occurrence of landslides and soil loss. Shrubs and bushes along riverbanks are also believed to have similar functions. Bamboo, which has many fine and intricate roots, is considered a very efficient plant for planting along riverbanks.

Farmers see turbid water flowing down from upslope coffee gardens and forests as something which contributes to soil fertility in paddy fields (represented in the second diagram in Fig. 19.1), even though excessive water flow and sedimentation are physically detrimental to paddy plants. By carefully monitoring and regulating water flow in and out of paddy fields, farmers control both water speed and the duration for which that water remains in paddy fields, and hence the deposition of soil particles. It is common knowledge amongst farmers that, if water flow is properly regulated, such sedimentation leads to a reduction in the turbidity of the water flowing out of the fields. Cultivation practices that disturb soil (installing paddy fields, building terraces, hoeing and even planting rice), however, increase water turbidity.

19.4. Case study 2: Dong Cao catchment, Vietnam

The Dong Cao catchment lies 60 km south of Hanoi (20°57’N, 105°29’E) in the Luong Son district in Hoa Binh province, northern Vietnam. It is inhabited by 40 households, from the Muong and Kinh ethnic groups. The area receives a mean annual rainfall of 1500 mm, which falls mainly between April and September (Fagerström *et al*., 2002). Ferralsols and Acrisols, classified as ‘clay’ and ‘clay loam’ soils, dominate the area. There are patches of secondary forest, mainly at higher altitudes. Cassava, maize, arrowroot and soybean are the major annual crops grown on hill slopes, whilst paddy is the major crop grown at lower altitudes. The gradients of the slopes in the catchment range from 15% to 60% (Toan *et al*., 2001). On the gentle slopes and on the foothills, legume-based cropping systems are common.

An investigation of soil–plant interactions in the Dong Cao catchment was carried out using a suite of methods that included a Participatory Landscape Analysis (PaLA) survey, and biophysical data gathering, as well as the use of Participatory Rural Appraisal tools. The KBS methodology (Sinclair and Walker, 1999) was adopted to explore farmers’ ecological knowledge, with 10 purposively selected farmers being interviewed in order to gain an insight into their knowledge and understanding. Farmers in both the upper and lower parts of the catchment were consulted and an electronic knowledge base developed and tested, as recommended by Dixon *et al*. (2001). Farmer knowledge was analysed in terms of the farmers’ understanding of erosion and filter functions in the landscape. Particular attention was focused on the filter efficiency of species such as *Acacia mangium*, *Vernicia montana* and bamboos. Farmer knowledge was then compared with scientific knowledge, as represented in the WaNuLCAS (Water, Nutrient and Light Capture in Agroforestry Systems) model (van Noordwijk and Lusiana, 1999).

19.4.1 Trees, soil and water

In the interviews, farmers articulated their knowledge about and perceptions of soil movement and the processes of terrace formation, and also the influences that earthworms and organic and inorganic fertilizers have on soil fertility. Using examples of *Acacia mangium* and *Vernicia montana*, the two most common tree species in the catchment, farmers explained the mechanisms by which, according to their understanding, both the leaves (in terms of size, colour and density) and the rooting behaviour of different plants influence soil erosion and soil fertility (Fig. 19.2). Furthermore, they also stated that tree roots can hold soil and absorb and retain moisture when it rains and that this moisture is later slowly released into the surrounding soil. The farmers also stated their belief that trees retain water during the day and so resist heat from the sun.

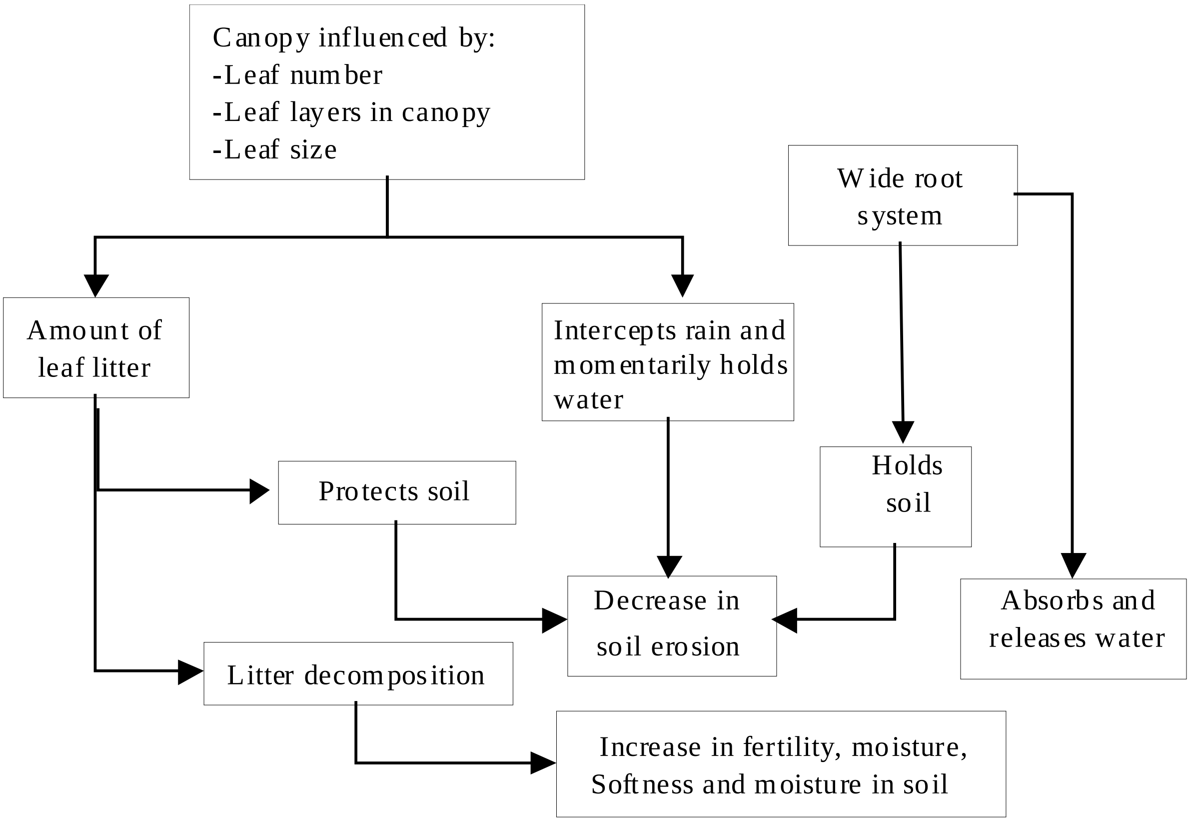

Fig. 19.2. Dong Cao farmers' understanding of tree–soil interactions. Change in values (such as an increase or decrease) of source nodes determines values in associated target nodes.

Farmers in the Dong Cao catchment identified factors, due to physical processes, plant growth and human activities, that they believed influence soil erosion. Rainfall intensity and duration, slope of land, weeding, soil cultivation and tillage all increase soil erosion in fields. Farmers said that short duration rainfall (<20 minutes) merely translocates soil within a field (from the upper slope to lower down the slope); long duration rainfall (>1 hour) can permanently wash away soil from the field. Conversely, the presence of bamboo hedgerows slows down the downward movement of soil, as its fine, widespread roots hold soil and prevent it being washed away. By the same token, leaf litter covers the soil and also absorbs rainwater, whilst tree crowns reduce splash erosion by intercepting raindrops before they hit the soil. Farmers also stated that ditches on the lower slopes also accumulate soil, preventing it from being permanently lost. The overall impact of soil erosion means that good soil is gradually lost from the field, whilst the water in the streams becomes turbid. Some of the soil lost may also be deposited in paddy fields below. Where live fences (hedgerows) exist along lower borders of a field, good soil can be retained.

The Dong Cao farmers believed that tree roots release water into the soil, leading to a higher and continuous water flow in the streams. Farmers also believed that the more trees there are in the catchment, the higher the uniformity of water flow and the higher the volume of water in the streams.

Farmers regard bamboo as a very good hedgerow plant for use along field boundaries. In addition to preventing animals moving into the field, bamboos trap and retain soil because they grow in dense clumps (locally called *boi*) and have far-reaching, dense roots. Bamboo stems also reduce water runoff. However, farmers said that the extensive, fine roots of bamboo also absorb or 'eat' soil fertility, significantly affecting annual crops in their vicinity. Similar observations are reported by hill farmers in Nepal, who only maintain bamboo along a field's boundary, and never in the middle of a field (Thapa *et al*., 1995).

19.5 Science-based models of watershed functions

The behaviour of rivers and the relation of such behaviour to land use and land cover can be studied using either a 'spatial pattern' approach (a common starting point in geographical studies) or a 'process' perspective (an approach commonly used in physical hydrology). When the two approaches are applied to one particular situation (e.g. the evergreen forests found at higher elevations in northern Thailand), apparently contradictory statements may arise (Table19.2).

Table 19.2 Some characteristics of two 'modelling approaches' applied to the relationships between land cover and watershed functions.

Starting point	Spatial patterns	Hydrologic (water balance, processes)
General characteristics	• Approach starts with existing land cover and river flow properties, as they vary across space • Correlations are analysed and used for extrapolation • Models can be based on data obtained at different scales, and can apply to various map resolutions	• Approach starts with rainfall and traces water, through various pathways, to evapotranspiration or delivery to oceans • Land-use change is taken into account, as it can affect interception, infiltration and evapotranspiration (seasonality) • Models can be strongly spatially disaggregated, 'lumped' or 'parsimonious'
Typical statement	'Evergreen forest is associated with highest water yields….'	'Evergreen forest uses more water and allows less rainfall to reach associated streams than other land-use types....'

The contradiction apparent between the two statements given in Table 19.2 can be resolved by realizing that, as in Thailand, evergreen forest tends to occur in locations where rainfall is highest. The real question, then, is whether this higher level of rainfall is the cause or the effect of the presence of evergreen forest. If either model is used to predict the impacts of land-use change on watershed functions, uncertainty with regard to the causes and effects of rainfall plays a key role.

Remnants of the 'spatial pattern' approach still exist in public perceptions; however, the theory of river flow that dominates current scientific thinking is based on our understanding of 'hydrological processes'. The validity of many of the hydrological-process models appears to be constrained, however, by incomplete data on rainfall, due to spatially inadequate sampling schemes resulting from, for example, too few rainfall gauges and a bias towards easily accessible locations.

Relevant to the construction of science-based models of watershed functions, are the four types of controls (see Fig. 19.3) which can normally be distinguished in the infiltration process. Of these, the following three can be influenced by land cover:

- the rate of water use between rainfall events (relative to the potentialevapotranspiration dominated by the energy balance);
- soil surface structure and macroporosity (which influence the potential rate of infiltration);
- the difference between field capacity and saturated soil water content.

Nearly all models, even those applied at a global or river-basin scale (Vörösmarty *et al*., 2000), include the first control listed above in their predictions of the impact land-use change will have on river behaviour. The effects of land use on the second and third controls listed above are only included in models such as DHSVM (**http://www.hydro.washington.edu/Lettenmaier/Models/DHSVM/index.htm**; Wigmosta *et al*., 1994) and WaNuLCAS (van Noordwijk and Lusiana, 1999), which were developed for high-resolution applications.

We will now look more closely at the WaNuLCAS model, which has been used to compare modellers' understanding of the erosion process with that of farmers. The WaNuLCAS model was developed to simulate a range of tree–soil–crop interactions in agroforestry systems, for a wide range

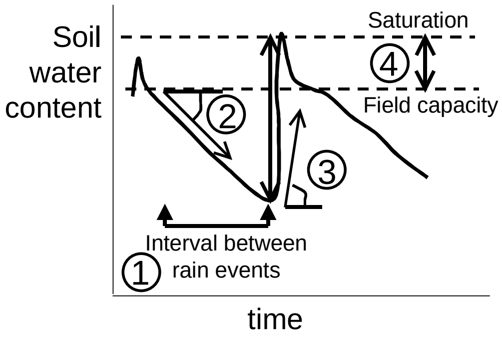

Fig. 19.3. Schematic time course of soil water content and soil physical understanding of the determinants of the infiltration process: (1) time interval between rainfall events, (2) rate of soil water depletion between rainfall events, creating soil storage space, (3) potential rate of infiltration into the soil, in relation to the intensity of rainfall and (slope-dependent) opportunities for temporary water storage at the soil surface, and (4) difference between 'field capacity' (= soil water content 24 hours after a heavy fall of rain, when the rate of water seepage to deeper layers tends to reach a small value) and 'saturated' soil water content, when all soil pores are water-filled.

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of soil, climate and slope conditions (see also Chapter 10). Basic ecological principles and processes, as understood from a scientific perspective, are incorporated into the model using modules such as climate, soil erosion, sedimentation, water and nutrient balance, tree growth and uptake, competition for water and nutrients, root growth, and soil organic matter and light capture (Fig. 19.4; Khasanah *et al*., 2002).

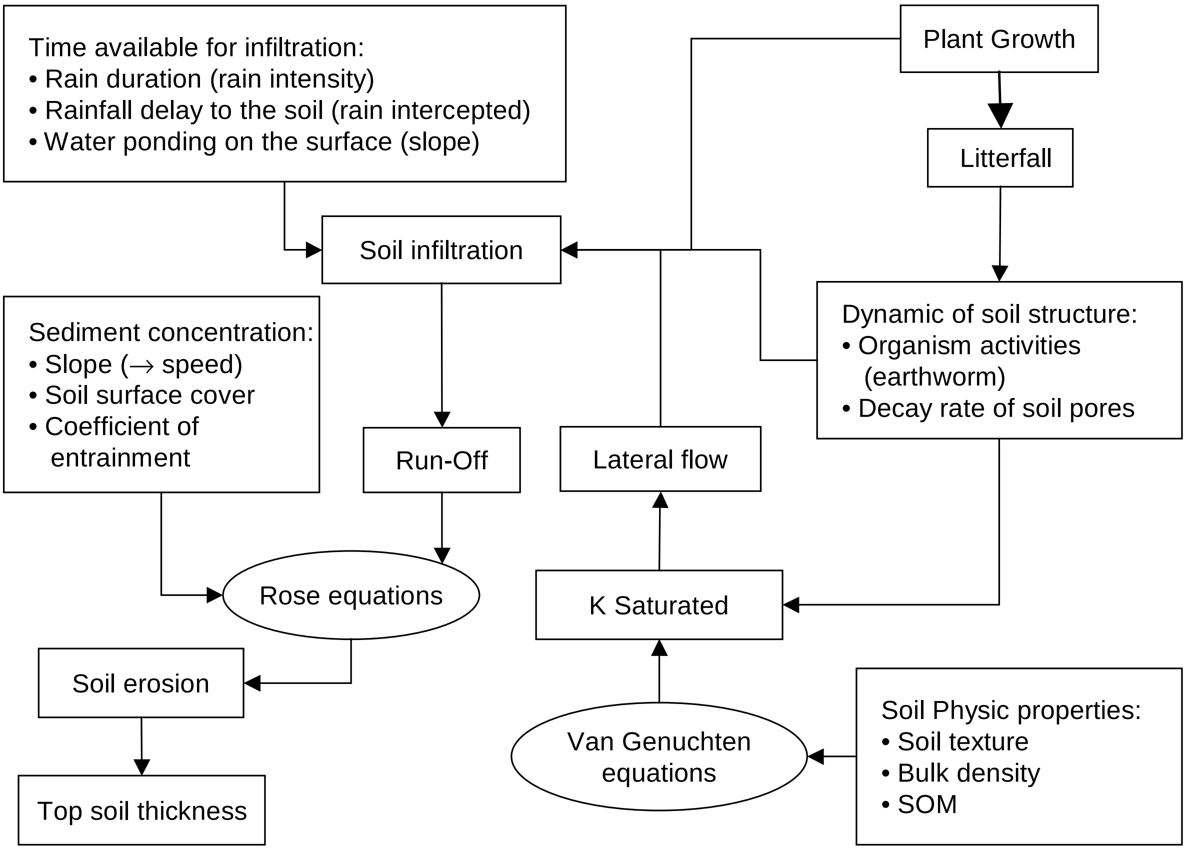

Fig. 19.4. Key factors in the soil erosion component of the WaNuLCAS model, which include such well-established process descriptions as the 'van Genuchten' functions for soil water conductivity under saturated (K_{sat}) and unsaturated conditions, and the 'Rose equations' for overland flow of soil particles (see also Chapter 18. Source: Khasanah *et al*., 2002.

In WaNuLCAS, physical soil properties (i.e. texture, bulk density and organic matter content) and soil structure dynamics (i.e. biological activity, dependent upon nutrition provided by plants through litterfall and root decay) determine saturated hydraulic conductivity (K_{sat}), and condition the processes of lateral flow and vertical infiltration. Rain intensity, plant growth (through the interception of rain) and lateral flow (over the surface and as sub-surface flows) influence infiltration, which determines the amount of runoff water. Soil erosion is influenced by the amount of runoff water, the flow velocity (which determines the maximum transport capacity for particulate matter) and the actual concentrations of sediment (which depends on the particles' 'entrainment' or 'propensity to join the flow'). Actual sediment concentrations in overland flow thus depend on the steepness of the slope (determining the runoff velocity), the soil's surface cover (canopy of trees, shrubs, weeds, and litter: all of which reduce flow velocity at the surface and thus cause the sedimentation of particulate matter) and the coefficient of entrainment (which mainly depends on aggregate stability at the soil's surface).

19.6. Soil erosion – farmer perception versus simulation modelling

In this section we will compare farmers' mental models of surface runoff and erosion with the way such processes are represented in current scientific simulation models. The overall concept of a water balance, in which all losses and gains can be accounted for (in = out ± change in storage), appears to be absent from farmers' perceptions and interpretations of events. This is probably because water use by plants (evapotranspiration) is invisible, whilst rainfall, stream flow and changes in soil water content are observable. However, with regard to the phenomena of overland flow and erosion, the observational basis of local ecological knowledge differs little from the basis of 'scientific' models, and agreement is stronger with regard to the underlying concepts.

The major components of farmers' understanding of the erosion process include:

1. Rain – duration and intensity
2. Standing trees, bamboos and shrubs – crown morphology and root system
3. Ground cover – leaf litter and live ground vegetation
4. Soil – e.g. physical properties and nutrient content.

A generalized representation of the process of soil erosion as understood by farmers is shown in Fig. 19.5. Farmers believe that rain intensity and duration play an important role in determining the intensity of soil erosion. Farmers also believe that trees and other tall vegetation have multiple functions: their crowns intercept raindrops, and so reduce splash erosion, and also cause shading (a positive or negative effect depending on density and crop type); their roots (depending on the spread and type) hold soil in place; their stems (especially in the case of clumps of bamboo) slow water runoff, whilst the leaf litter they produce prevents soil being washed away by rain and also reduces excessive evaporation in dry periods. Decayed leaf litter is also an important source of the organic matter and plant nutrients soil contains. The presence of earthworms is considered to be an indicator of a good soil, as they are known to contribute to increasing soil fertility.

Farmers' conception of soil compactness, and the influence it has on surface runoff, is similar to the representation given in WaNuLCAS (Fig. 19.4), which represents it as the coefficient of entrainment, determined by aggregate stability. Farmers understand well that loose soil will erode more quickly, and that soil compaction can therefore increase overland flow of water and reduce soil movement.

In the WaNuLCAS model, soil structure dynamics are caused by biological activity in the soil (mainly represented by earthworm activity) which results from inputs of plant material such as leaf litter, prunings and decaying roots. Farmers relate the presence of leaf litter and roots directly to infiltration; thus, both their understanding and that of researchers are comparable in this matter. They also see and value the role earthworms play in improving soil fertility. Farmers directly link soil physical properties, usually linked to organic content (loose and sandy versus compact and clayey soils) and soil structure dynamics (biological activity: leaf litter and roots) to infiltration. Although they do not allude to the processes which appear in the model (such as saturated hydraulic conductivity or lateral flow), both farmers' and researchers' conclusions are similar. Farmers, however, do not mention macropores or microbial-related aspects of the soil.

On the other hand, farmers do emphasize the important role trees and their leaf litter play in breaking the fall of the raindrops, thereby reducing the strength of their impact on the soil and so decreasing soil erosion. Interception was incorporated into the WaNuLCAS model as a factor that

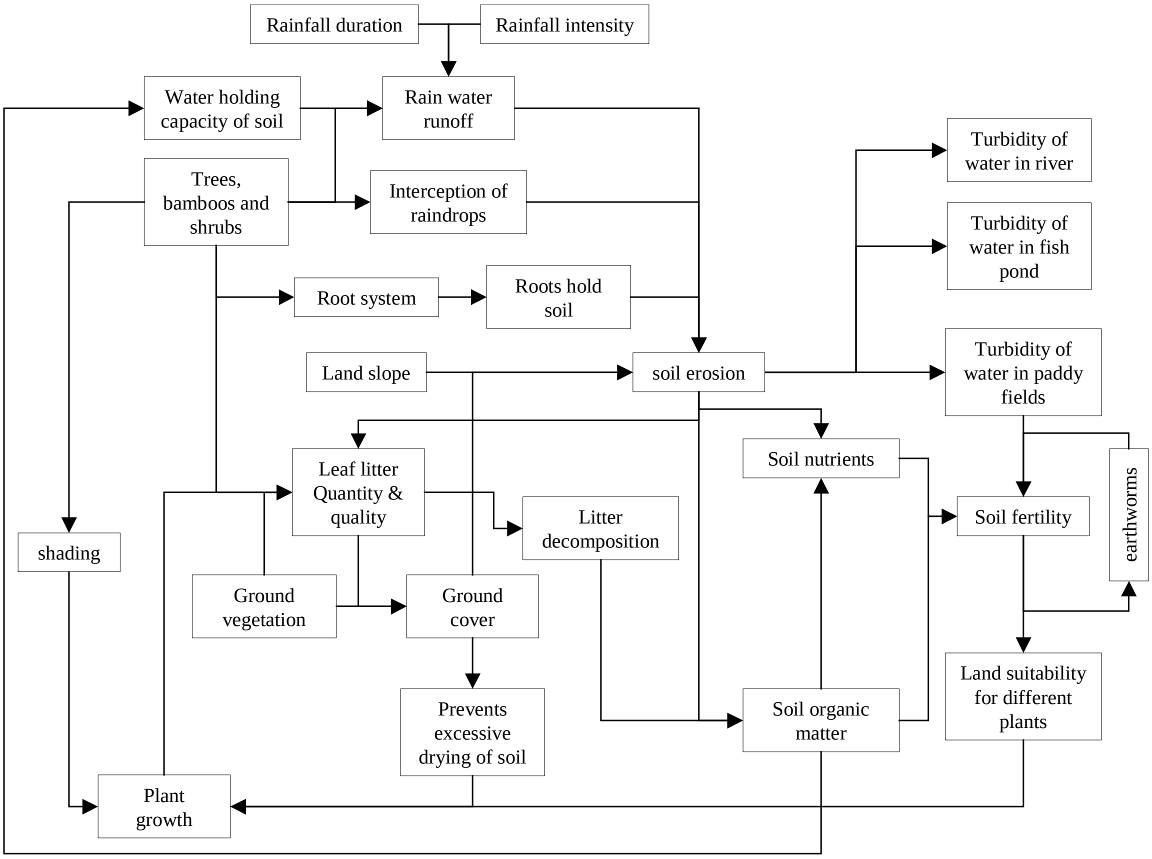

Fig. 19.5. Main components of farmers' understanding of the soil erosion process, combining studies in Indonesia, Vietnam and Nepal. Arrows show cause–effect relationship between linked 'nodes'.

diminishes the amount of rainfall reaching the ground. However, the impact rainfall has in terms of directly increasing erosion, caused by splash erosion, has not been incorporated in WaNuLCAS (although it is indirectly represented in the effect soil cover has on entrainment).

Some differences do exist between local and scientific understandings of soil processes – e.g., in the way information is represented (qualitative in the case of the former and quantitative in the case of the latter). As with most simulation models, WaNuLCAS uses a mathematical approach. By contrast, farmers' understanding is largely qualitative in nature and simple cause–effect relations are a norm in farmers' mental models. So, while WaNuLCAS can predict a final output quantitatively, farmers' models reflect the direction of change in the form of an increase or decrease. Furthermore, due to the site-specific nature of local knowledge, the ranges that occur in terms of local variation will condition farmer knowledge. Simulation models, on the other hand, are supposed to be more generic and able to cover a wider range of situations, thus requiring more parameters to specify components' behaviour on any given site.

Both farmer knowledge and science-based models allow for a much more nuanced approach to soil conservation than that implied by the simple 'forest' versus 'non-forest' dichotomy that dominates public discussions on soil conservation and land classification systems. By considering the underlying processes of soil and water movement the category 'forest' can be split, so making clear the dominant role played by the surface litter layer. Within the 'non-forest' category we are able to see the presence or absence of a litter layer emerge as a distinguishing element in predicted soil and water movement. We may note that a surface litter layer is both an 'indicator' of the absence of surface flows with enough energy to move the litter particles and a link in the causal chain to soil biological activity, which maintains soil structure and increases infiltration rates. Wiersum's (1984) observation of the occurrence of high erosion rates under tropical plantation forests with uniformly high canopies (and thus with high-energy drips falling from such canopies) and an absence of surface litter (due to farmers harvesting it) is easy to understand using both local and scientific paradigms.

19.7. The gap between knowledge and practice

Knowledge is conceptually different from practice or action, as discussed in Chapter 2. What farmers know may not always be reflected by what they do and vice versa. Farmers cultivating cassava in the Dong Cao catchment (Vietnam) are well aware of the heightened soil erosion problem that results when cassava is interplanted with *Acacia* in its establishment phase. They know that cassava cultivation can significantly affect *Acacia* growth in its early stages. They also know that if the *Acacia* or *Vernicia* being grown are taller than the cassava (a state normally reached after two years) the cassava will be severely affected. WaNuLCAS simulations of an *Acacia* and cassava intercropping system have also shown that erosion is a major problem during the first year of the cycle. Despite this knowledge, farmers still continue to cultivate cassava with *Acacia* and *Vernicia,* because doing so provides them with much-needed food and income and also reduces animal damage to trees and crops, due to the presence of people in the field (PaLA survey).

In Sumberjaya (Indonesia) all farmers interviewed were aware of deforestation, erosion and water problems: their knowledge was detailed and commonly shared. Farmers also know about the processes and reasons behind these problems and possess a substantial range of possible technical solutions. However, in reality, not all farmers practice soil and water conservation measures when cultivating steep slopes. What constrains farmers from translating this sophisticated knowledge into practice? In the Indonesian case study of farmer knowledge and practice in Sumberjaya, Schalenbourg (2002) identified the following common constraints as being those which make it difficult for farmers to translate their knowledge into practice:

1. Lack of capital investment (money, labour and time). Most soil conservation practices require time, money and labour, and often involve construction work and maintenance. Farmers, particularly the poorer members of the community, simply do not have the resources necessary to invest in soil conservation innovations.
2. Lack of enthusiasm (‘laziness’) or lack of the necessary incentives. Many farmers reported that they are too *malas* or ‘lazy’ (note that the Indonesian word does not have the same negative connotations as the English word ‘lazy’). The farmers probably meant to imply that soil conservation is not their priority or that implementing soil conservation practices does not yield sufficient benefits to make it worthwhile.
3. Uncertain land tenure. Many farmers cultivate coffee on government designated ‘forest land’, and the region has seen numerous evictions (by the government). Land tenure largely remains uncertain, and this has been an important factor with regard to influencing farmers’ decisions not to spend their resources on long-term soil conservation methods.
4. Low returns to labour, or a low price for coffee, result in emphasis being placed on short-term cash gains (including alternative annual cash crops) rather than on long-term productivity and sustainability. Like that of many commodity crops, the price of coffee has ‘nose-dived’ in recent years. Many farmers have converted their fields to the production of other cash crops, and thus are involved in vegetable production and fish farming. Again, farmers are not prepared to invest in any soil conservation activity that requires additional resources, especially if that activity only facilitates long-term coffee production.
5. Isolated efforts with regard to soil conservation are ineffective. Only a concerted effort can yield tangible results, which perhaps to a great extent explains why farmers do not practice soil conservation practices. On-going land disputes (both between settlers and the government and settlers who arrived in the area at different times) mean that there is little possibility that farmers’ groups will be organized.

Bio-physical, social, economic and market environments are likely to vary between sites. Therefore, methodological guidelines need to be developed both in order to provide a more holistic view of the constraints farmers face and to develop strategies to address them.

19.8. Discussion

Numerous studies concerning local ecological knowledge (including the two reported in this chapter and those reported in Chapter 2) provide convincing evidence that farmers have detailed plot-level knowledge which they may use when managing their resources. Farmers’ knowledge at the landscape level seems (1) to consist of logical explanations for various natural processes and (2) to be based on their plot-level knowledge. In comparison with plot-level processes, farmers have a less intimate knowledge of landscape-level interactions, which perhaps explains why landscape-level local ecological knowledge is less developed at the 'process' or 'explanatory' level. There is, of course, a fairly detailed understanding of the variations that occur in topography, vegetation and microclimate at the landscape scale: the language spoken by farmers contains many words to describe such variation. In the Indonesia case study at least, although plot-level knowledge varied to some degree between farming communities (Chapman, 2002) landscape-level knowledge varied less between farmers and between farming communities (Schalenbourg, 2002).

It would be unrealistic to think that we can 'quantify' farmers' models as simulation models. However, it may be possible to gather data in order to quantify certain key components in farmers' models (such as the fact that live and dead vegetation reduce splash erosion and that plant roots have the ability to 'hold' soil). Likewise, the reasoning that farmers apply when 'running' their models can be tested and represented in scientific models. The understanding that farmers have developed can complement scientific understanding, thereby enriching scientific models. At the same time farmers will be better able to comprehend, accept and benefit from such synthesized models if their knowledge is represented. A combined model will, therefore, be richer than either the stand-alone 'local' or the scientific model. Better understanding, appreciation and representation of local knowledge, terminology, and perceptions can likewise contribute towards improved communication and negotiation between farmers, professionals and decision makers.

From the perspective of translating knowledge into practice, there is increasing evidence (the Sumberjaya study, for example) that farmers do not only rely on their ecological knowledge to make management decisions about their resources, but also take into consideration available resources (land, labour, capital), markets, and social relationships. An additional factor that is becoming clearer from our work (particularly that undertaken in Indonesia) is the important role social capital plays when scaling up plot-level actions to the landscape-level management of natural resources. In other words, no individual effort will accrue benefits on a landscape scale in those cases where neighbours' practices are detrimental to soil conservation. Under such circumstances, no farmer will expend personal resources to seriously practice soil conservation measures. The need for collective action in soil conservation is obvious. In the case of the study made in Sumberjaya, perhaps the main limitation to control erosion is not a lack of knowledge of conservation practices, but the constraints associated with farmers functioning as an effective unit and the fact that they do not have secure land tenure. The 'scientific understanding' that we discussed so far answers only one of the five issues in any natural resource management issue (Box 19.2).

Box 19.2. Knowledge and natural resource management

Improved natural resource management, for example watershed management, may not be limited by a lack-of-scientific-understanding of the issue. There are five important issues that are for 'problem solving', answering different question in natural resource management:

1. Emotional links: The first question we should ask, if put bluntly, is 'why should I (or anybody) care?'
2. Scientific understanding: 'how does the system work?' Which elements, patterns, processes and system dynamics are associated with the natural resource in question.
3. The current problem: 'what or who is causing the current problem or perceived problem?', 'what are the consequences', 'what are possible remedies?'
4. Stakeholders: 'who benefits from causing the problem?', 'who suffers the consequences', 'who will pay for remedies and solutions?'
5. Governance opportunities: 'how can a working solution be achieved?', 'is it better to spatially segregate activities or go for an 'integrated' multi-functionality solution?', 'how can the different stakeholders and actors negotiate solutions that meet their various sets of objectives?'

As we have seen, local and science-based perceptions of landscape-level watershed issues contrast with public perceptions of the same issues. This is a matter that requires some form of 'negotiation support' if landscape-level watershed issues are to be resolved (van Noordwijk *et al.*, 2001; Verbist *et al.*, 2002). Such support should involve a shared vision of the likely consequences of various land-use alternatives in combination with a social process of stakeholder negotiation, whilst retaining respect for the various positions held by the stakeholders involved.

Conclusions

1. Farmers' knowledge of water and soil movement at the landscape level provides logical explanations for several 'observable' phenomena and is closely linked to farmers' plot-level knowledge. However, their landscape-level knowledge may be less clearly articulated.
2. Farmers generally have a fairly detailed understanding of the variations that occur in topography, vegetation and microclimate at the landscape scale.
3. Because of the constraints imposed by the observational capacity of farmers, less visible processes (such as evapotranspiration) are not included in the farmers' mental models and, hence, for them 'water balance' is a qualitative, rather than a quantitative concept.
4. Farmer knowledge, like scientific knowledge, is cumulative; it evolves as farmers adopt, adapt and formulate new ideas and innovations, try them out in different settings, evaluate and assess the results and make decisions about their potential value for continuously improving their farming methods.
5. Collective action and social capital are important with regard to the scaling-up of plot-level actions to the landscape-level management of natural resources.

Future research needs

1. There is a need to further explore the obvious contrast between the 'process-based' conceptual models held by farmers and researchers and the 'black-or-white' public perceptions of the landscape-level watershed issues (which underlie current policies and regulatory frameworks).
2. Research should be conducted to find replicable ways to provide 'negotiation support', by combining a shared vision of the likely consequences of various land-use alternatives with a social process that involves stakeholder negotiation and respect for the various positions.