A Negotiation Support Tool for Assessment of Land Use Change Impacts on Erosion in a Previously Forested Watershed in Lampung, Sumatra, Indonesia

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Abstract: Land use is changing rapidly in SE-Asia from forest to landscape mosaics with various degrees of tree cover. The relations between impacts at these different scales should recognize a range of 'lateral flow' and 'filter' phenomena. To develop concepts and an appropriate methodology, ICRAF and partner institutions study land use and its change in Sumberjaya, West-Lampung, Sumatra an area of about 730 km2, which encompasses a watershed, that was transformed in the past three decades from a large forest cover to a mosaic of coffee farms with rice paddies in the valleys and which has seen quite some conflict over the past 10 years. For risk assessment of erosion and consequent delineation of protection areas various stakeholders convinced of their own 'rightness' often only use their own mental model, often based only on strong perceptions and beliefs. The (weak) knowledge base used for evaluating these issues for landscape mosaics covering the wide range between pure forests and purely cropped lands is now challenged by the development of different erosion equations and models over the past ten years. In an erosion modeling exercise various scenarios for the USLE, WEPP and GUEST (Rose) equations are compared at different scales. Results are strikingly different. The methodology is inspired by the one developed for 'Sustainable coastal-zone management, a case study for Southwest Sulawesi'. Aim is to test and validate that methodology in a completely different setting and use it as a discussion tool for various stakeholders.

Keywords: Negotiation support model; Erosion; Watershed functions; Land use change

1 INTRODUCTION

The general problem can be defined as the perceived unsustainable use of natural resources (forest conversion) and the negative impacts this has on external stakeholders. The perception may or may not be based on causal relationships and facts. Forest conversion in much of Southeast Asia is not a black-or-white deforestation process, but a gradual loss of 'forest functions' in changing agroforestry landscape mosaics. Existing institutions and policies are largely based on a forest - agricultural land use dichotomy and this may lead to an unnecessary sense of conflict. The issue is of particular relevance where supposed 'watershed protection functions' have been the basis for regulations of access to land.

Key hypothesis in our current research is that some farmer-developed agroforestry mosaics are as effective in watershed protection functions as the original forest cover. Hence conflicts between state forest managers and local population can be resolved to mutual benefit. The problems are clearly represented in the Sumberjaya watershed, an area of about 50.000 ha at the forest fringe with the Bukit Barisan National Park in Lampung, Sumatra, Indonesia and there is no easy solution. Until now the outcome was often sub-optimal - a euphemism for violent eviction of thousands of farmers in the early nineties [Kusworo, 2000]! The Forest department wants to conserve the protection forest, next to the National Park and has evicted farmers in the past. Farmers need a living and come back, often under silent approval of local government that needs income and wants to see economic development … This scenario might be representative of possible future trajectories for many other watersheds all over Sumatra. The underlying causes of conflict are probably even more generic and are related to the lack of insight to what extent does a landscape - and its various elements - function properly in providing certain services to and meet expectations from various users and stakeholders.

2 A NEGOTIATION SUPPORT SYSTEM

2.1 Introduction

Aim of this research is to build a useful toolbox, which can clarify options and be adapted and applied at a wider scale. An iterative stakeholder analysis is in progress to allow articulation of the objectives of stakeholders and questions the negotiation support model should try to answer.

Farmers are interested in a regular and sufficiently high income. *Local government* through taxes is interested in a regular and sufficiently high income. The *electricity company* and the *Ministry of Public Works* are interested in a high and regular water flow as to generate more power and in a low sediment content in the river to increase the production time of the (small) storage lake. The *Department of Forestry* lists the need for erosion control as a main reason to protect forest. To tackle this large amount of issues and stakeholders the following framework for analysis and negotiation support was developed (Fig. 1; [van Noordwijk, et al. 2001].

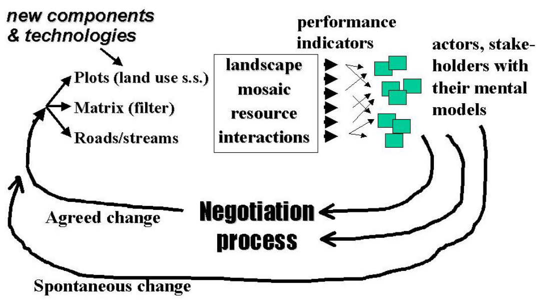

Figure 1. Conceptual framework of a negotiation support system for natural resource management

The negotiation support system that is envisaged relates the predicted impacts of landscape level changes in land use, channels and/or filters to the range of performance indicators that is considered to be relevant by the actors and other stakeholders of this landscape. On the other hand there is the facilitation of a process of negotiation that may lead to changes in the way actors manage various parts of the landscape. The integrated system model serves as a common (qualitative) framework of analysis, but also and perhaps more important for the implementation phase, as a discussion tool. Different scenarios outlined by the various stakeholders and *possible future changes* can be examined and discussed in a qualitative way in a first approach. Disciplinary research can offer the necessary "building blocks" to make quantitative simulations with a certain probability and precision.

2.2 Methodology

In this case study a top-down approach based on a system description is used, which still allows for the incorporation of individual stakeholder's perspectives and mental models. The set-up was inspired by a modelling framework for coastal zone management near Ujung Padang, Sulawesi, Indonesia. The RAMCO-model (Rapid Assessment for Management of COastal zones; [de Kok and Wind 2002] is based on conceptual guidelines provided by Miser and Quade [1985] and Randers [1980] recognizing eight distinct steps for the design and use of integrated models for policy analysis:

1. Problem formulation, which should include at least one problem definition, its boundaries and constraints and the various values and criteria used by respective stakeholders
2. Generation of alternatives
3. Qualitative system design, which involves the development of a causal relationship diagram or system diagram (see Fig. 2)
4. Quantitative modeling
5. Model implementation
6. Model validation (and return to steps 3, 4 or 5, as needed)
7. Ranking of alternatives from various stakeholder perspectives
8. Stakeholder negotiations on the consequences of the various alternatives (return to the step 2, if new ideas arise)

The apparently contradictory objectives of the stakeholders in this conflict can be formulated in terms of the values that are considered relevant for watershed management. On the basis of these values and criteria, a more concrete problem definition, the boundaries, and constraints of various alternatives can be generated, with an initial compilation of the perceived causal relationships. Research to map the "mental models" of all participants in the negotiations, can help to clarify the service that each stakeholder can actually expect from the watershed. The mental model of a model-builder (an example is given in Fig. 2) needs to be completed and verified with the mental models of the various other stakeholders [van Noordwijk et al., 2001]. Different "what if" scenarios, based on stakeholder inputs and feedback, will allow an exploration of various possible options. The main objective of this model building is to put stakeholders on a more equal footing and thus help them in negotiating an agreement over future resource use and access rights. The social process to achieve this objective requires a series of confidence-building experiences, and a political climate of openness that only recently developed in Indonesia.

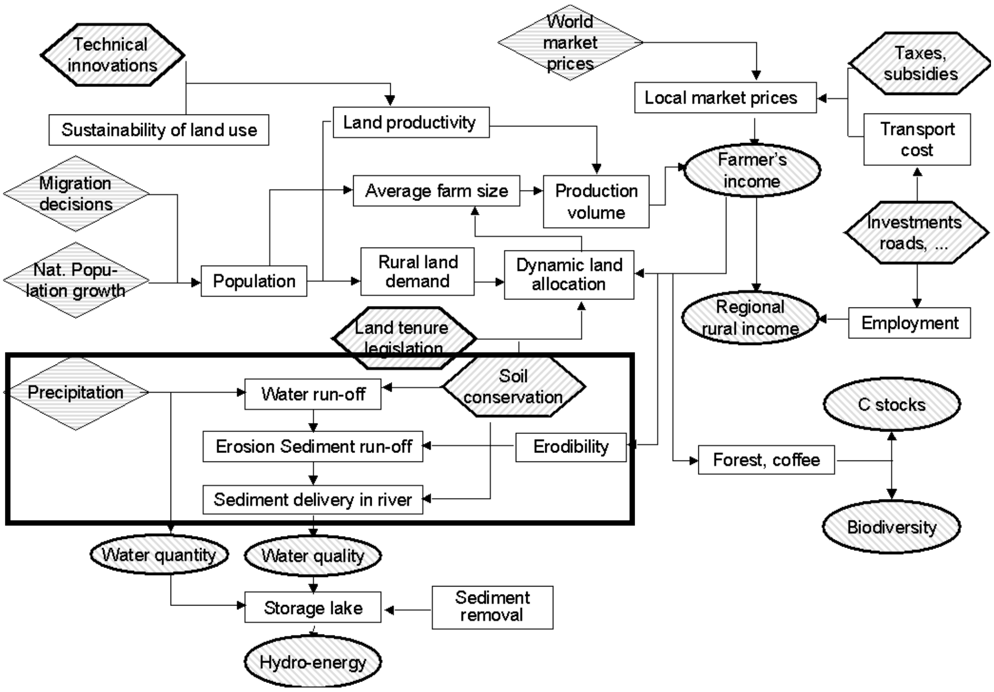

Figure 2. Initial causal relationship diagram for the Sumber Jaya area; shaded diamonds indicate external variables, shaded hexagons indicate management options for some of the stakeholders, shaded ovals represent key impacts. In section 4 we will zoom in on the 'thick' rectangle.

3 PAST LAND USE CHANGE

Forest cover decreased over the past 30 years from 60 % in 1970 to 12 % in 2001 on an area of 730 km^2 [Syam et al., 1997] and [Dinata, 2002].

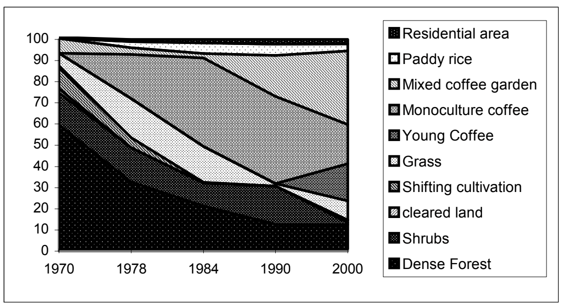

Figure 3. Past land use change in Sumberjaya area

This landscape knew a gradual deforestation and intensification of land use. The various coffee systems increased from a percentage of only 7 % in 1970 to more than 70% in 2000. A detailed land use map of the Bodong site of 787 ha was derived from IKONOS imagery of 2000 and used as an input in the erosion modeling at catchment level.

4 PREDICTING EROSION

4.1 Introduction

Quantifying erosion and especially the scaling up is tricky. Like in many other countries also in Indonesia, the empirical USLE *(Universal Soil Loss Equation)* is most commonly used to quantify erosion. The USLE is based on mostly American research at plot level for moderate slopes. Its application to quantify erosion at the watershed level generally overestimates erosion and gives notoriously high errors (up to 2000 %) [Van der Poel and Subagyono, 1998]! Scaling up from plot to slope or (sub)-catchment level using the empirical Sediment Delivery Ratio (SDR) does not take into account the spatial distribution of various land-use types and thus the effects of filters. This methodology on estimating erosion is an underlying principle for current Indonesian legislation (e.g. decree n^0 683 of 1980 of the Ministry of Agriculture with criteria on rainfall, slope and soil type) to classify forests to protect watersheds. This is used by the Department of Forestry to justify the delineation of large areas in watersheds as protection forest. At this point in time the *mental model* of the Department of Forestry is the most explicit of all stakeholders (and reflected in current legislation) and we'll contrast it in this modelling exercise with a set of different erosion equations and models, which were developed over the past 10 years. The more physical 'GUEST' (Griffith University Erosion System Template) gives a better description of the underlying physical processes of erosion than the USLE [Coughlan and Rose, 1997]. This equation is unfortunately more complex and more 'data hungry'. Another model, which is calibrated for small-scale areas in the tropics, is WEPP (Water Erosion Prediction Project). It is a distributed parameter, continuous erosion simulation prediction model [Flanagan and Livingston, 1995].

4.2 Equations

The USLE is generally known as

$$A = R * K * LS * C * P \quad (1)$$

[Wischmeier, 1971 in Morgan, 1986]

A = soil loss in Mgha^{-1}year^{-1}; R = rainfall factor; K = soil erodibility factor; LS = slope length factor and slope gradient factor; C = crop-management factor; P = erosion control practice factor

The GUEST – equation is described in Coughlan and Rose [1997]:

$$C_t = k^{\beta} * Q^{0.4\beta} * Q_t * \exp^{(-Ks*Cs)} \quad (2)$$

Where C_t is the estimated soil loss, β is the erodibility, Q the total run-off amount per event (m^3), Q_t is the runoff rate per unit area (m^3 s^{-1}), Ks is a non-dimensional crop factor, Cs is the fraction of surface contact cover and where

$$k = \frac{F\sigma SL^{2/5}}{(\sigma/\rho - 1)\varphi} * (\frac{\sqrt{S}}{n})^{3/5} \quad (3)$$

The parameter k depends on the slope S, Manning's roughness coefficient n, slope length L, depositability φ, wet sediment density σ (= 2600 kg m^{-3}), water density ρ (= 1000 kg m^{-3}) and the fraction of the stream power F.

4.3 Methodology

Various land use scenarios were created to be able to compare the methods and the land-use types at each level of scale: plot (20m x 20m), slope (20m x 500m) and catchment (2.4 km x 3.3 km). USLE and GUEST were applied using PCRaster, a grid based dyna-mic modelling package, developed at the Faculty of Geographical Sciences, University of Utrecht, the Netherlands (www.pcraster.nl). Grid size was 20 m x 20 m. The WEPP model was applied using its own interface. Most data were derived from literature and preliminary field data. For this exploration a rainfall year consisted of 94 big rainfall events, measured in a nearby weather station and each event was then a time step.

Plot level analysis

Scenarios were compared for a constant slope 15 % and same soil type or K-value (0.15) [Schmitz and Tameling, 2000]. The USLE seems to syste-matically overestimate the erosion (in Mg ha^{-1} yr^{-1}) for all discriminated land uses (fig. 4). The WEPP results are relatively close to results of the GUEST equation, except for bare soil (where WEPP overestimates the erosion, because the clayey soils in Sumberjaya are more stable than the ones the WEPP model is calibrated for). The low sediment yield measured in the field can be attributed to the limited amount of rainfall during observations.

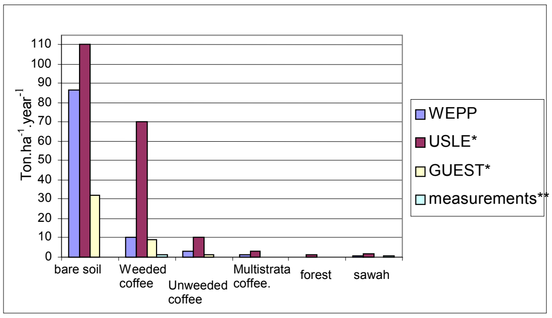

Figure 4. Comparing sediment yield predicted by erosion models and field measurements in Sumberjaya [*Schmitz and Tameling, 2000]; ** [Sinukaban et al., 2000].

Slope level analysis

Each time a slope of 500 m long and 20 m wide was used in a downhill sequence of 25 grid cells of 20 m x 20 m. The list below represents only 3 of a whole series of different slope-level analysis scenarios. One scenario consists of a combination of land use-types formulated above. Combinations are given from the top of the slope to the valley bottom:

1. Natural forest (80 m)/ bare soil (180 m) / clean weeded coffee (200 m)/ irrigated rice (40 m)
2. Natural forest (80 m)/ multi strata coffee (380 m)/ irrigated rice (40 m)
3. Natural forest (80 m)/ unweeded coffee (380 m) / irrigated rice (40 m)

WEPP did estimate 29%, 68% and 79% less sediment for each scenario presented (fig. 5).

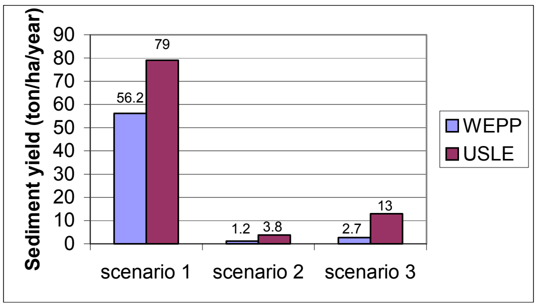

Figure 5. Sediment yield at the bottom of a slope using the WEPP and USLE

For the same slope the GUEST equation always gave an (almost incredible) low erosion yield: almost 0 Mg/ha. This was mainly due to the large sedimentation capacity of the last two irrigated rice plots at the end of the almost flat slope. Hardly any sediment would 'leak' through these 'filter' plots. Especially the gentle slope of less than 15 % in the last 2 grid cells seemed to play a crucial role. The USLE does not account for this effect, because the result is based on an average erosion value the area would give. Consequently, it would not make a difference, if filter elements would be down the slope or on top of the hill!

Catchment level analysis

The Bodong area (787 ha) consisted of a grid of 120 x 164 cells of 20 m x 20 m each. The digital elevation model was derived from aerial photographs, scale 1/25.000 using PCI 's Ortho-engine software (http://www.pcigeomatics.com/). *Pit cells* were defined as the cells were sediment and water would accumulate at the edge of the map or just before flowing into the river. Following scenarios were modelled:

1. Current land use (derived from IKONOS-image)
2. Current land use, but with a 40 m strip of forest along the river (approximating legislation, whereby a strip of 50 m on both sides of the river should be under vegetative cover)
3. Current land use with forest on slopes steeper than 45%, which is one of the criteria in decree n^0 683 of 1980 of the Ministry of Agriculture
4. Current land use with all coffee and bare soil converted into multistrata coffee

Hereby bare soil and very young coffee are land use types, which are very much prone to erosion, while monoculture coffee is often only slightly better. Multistrata coffee, forest, grass stimulate deposition of sediment and thus have 'filtering' capacities. The WEPP equation was not used at this scale, as its catchment module is still under development. In table 1 and fig. 6 results for the 5 'pit cells' or 'hot spots' with the highest sediment yield (SY) are compared for the USLE and the GUEST equation for scenario 1. The interval between minimum and maximum sediment yields is large because of the current uncertainty of parameters. Nevertheless it is striking that the USLE consistently points to two erosion 'hot spots' (U2 and U4), where according to the GUEST equation there is no erosion problem at all (Fig. 6)! Erosion control measures in the subcatchments draining to 'hot spots' U2 and U4 would probably be futile, as results obtained with the GUEST equation show that in these specific areas there is no serious erosion problem. On the other hand the areas draining to G2 and G5 would not be listed as problem areas using the USLE. Sediment yields obtained with the GUEST equation are more directly related to the local variations in topography, while the USLE would still give large sediment yields for large catchment areas, even when they are almost flat.

Table 1. Sediment yields (SY) for USLE and GUEST equation at catchment level

	U1	**U2**	**U3**	**U4**	**U5**	**Total 5 pit cells**	**Bodong catchment**
SY (Gg/yr)	**24**	**22**	**11**	**9**	**8**	**73**	**115**
SYmin (Gg/yr)	8	6	3	3	3	24	37
SYmax (Gg/yr)	29	28	13	11	10	90	143
Subcatchment size (ha)	137	158	39	34	33	401	787
SY($Mgha^{-1}yr^{-1}$)	**173**	**137**	**275**	**252**	**254**	**182**	**146**
SYmin ($Mgha^{-1}yr^{-1}$)	59	41	85	78	97	59	47
SYmax ($Mgha^{-1}yr^{-1}$)	212	177	331	313	300	225	182
	G1	**G2**	**G3**	**G4**	**G5**		
SY (Gg/yr)	**8**	**8**	**4**	**3**	**1**	**24**	**32**
SY (Gg/yr) min	1	1	1	0	0	4	6
SY (Gg/yr) max	53	68	4	21	10	154	194
Subcatchment size (ha)	137	80	33	39	23	312	787
SY ($Mgha^{-1}yr^{-1}$)	**60**	**94**	**106**	**73**	**61**	**75**	**40**
SYmin ($Mgha^{-1}yr^{-1}$)	8	9	42	9	9	12	8
SYmax ($Mgha^{-1}yr^{-1}$)	384	845	106	537	420	494	246

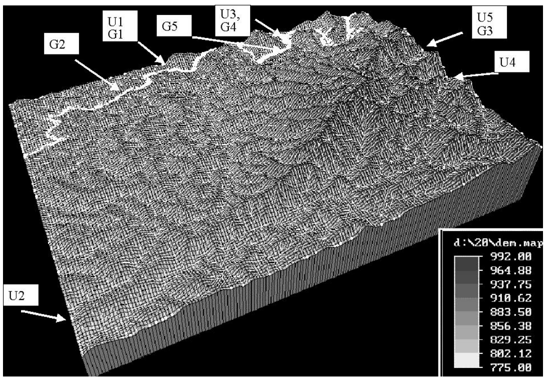

Figure 6. Digital elevation model (DEM) of the Bodong site with erosion 'hot spots' for USLE (U) and GUEST (G) for scenario 1

Total sediment yield (SY) in scenario 2 was only little different from scenario 1 according to the USLE: 111 Gg yr^{-1} for the catchment instead of 115 Gg yr^{-1}. For the GUEST equation it made little difference for most points except for the point with the largest erosion (G1), whereby bare soil was converted into forest and the sediment yield decreased from 8.3 to 4.7 Gg yr^{-1}. For the whole catchment erosion decreased with 15 % to 27 Gg yr^{-1}, while only 6% of the area was converted. Reforesting only the bare soil plots close by the rivers gave similar results. Similar results were obtained in WEPP simulations for hill slope scale, were 50% of hill slope coverage near to the river was responsible for trapping almost 100% of the sediments. Scenario 3 would indeed give a dramatic decrease of erosion of 34% according to the USLE (SY= 76 Gg yr^{-1}). However according to the GUEST equation there would only be a decrease of 2% (SY = 30 Gg yr^{-1}). The USLE is sensitive for the decrease of erosion on steep slopes, while the GUEST equation also records the deposition of sediment in the landscape before it would reach the river, which is more close to reality. Scenario 4 has a relatively dense vegetation cover and is also productive for farmers. It gives the largest decrease in sediment yield for both equations: 58% for the USLE (SY = 48 Gg yr^{-1}) and 25 % for the GUEST (SY= 24 Gg yr^{-1}). Results of these 4 scenarios clearly indicate that it is not so important how much filter elements (or forest) there are in a landscape, but far more important is where they are spatially located, which support the hypotheses brought forward by [van Noordwijk et al., 1998]! It seems crucial that filter elements are close to the inflow points to the river rather on the ridges of steep hills.

5 CONCLUSIONS

The models presented still contain quite some data and model uncertainty and need to be calibrated and validated. However some trends are clear. The USLE gives systematically much higher sediment yields at all levels of scale (plot, slope and catchment). The difference in underlying principles of up scaling is largely responsible for the inconsistency of the results for the 3 equations at the various levels of scale. It is clear that current criteria used to classify erosion risk areas, and consecutively used as a basis to delineate 'protection forest' do a poor job. Some areas don't need to be protected, while on the other hand the current methodology (and legislation) is 'blind' for some erosion 'hot spot' areas. Better criteria need to be developed, preferably in discussion with the various stakeholders! Delineation of protection areas can then be revised accordingly. This modelling example is a first step to clarify perceived cause-effect relationships and to help exploring alternatives. In small informal meetings these results came across as an eye opener and a stimulus for further discussion. A formal workshop with the various stakeholders to present these (and other) results will be held at a later point in time.

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