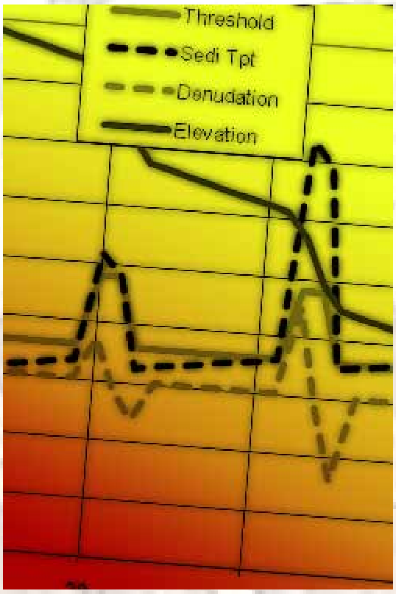
DESIRE REPORT series



Improved process descriptions integrated within the PESERA model in order to be able to evaluate the effects of potential prevention and remediation measures

Authors: Mike Kirkby, Brian Irvine, Jean Poesen, Lorenzo Borselli and Mark Reed

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University of LEEDS, United Kingdom

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DESIRE

DESERTIFICATION MITIGATION AND REMEDIATION OF LAND

A GLOBAL APPROACH FOR LOCAL SOLUTIONS

Deliverable 5.2.1 – due Month 36

Improved process descriptions integrated within the PESERA model in order to be able to evaluate the effects of potential prevention and remediation measures

M.Kirkby, B.Irvine, J.Poesen, L.Borselli and M.Reed

University of Leeds
KU Leuven
CNR
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Contents

Abstract

This report describes changes to the PESERA model within the DESIRE project to incorporate

1: additional relevant processes as proposed in the DoW, namely grazing, wind erosion and fire.

2: the soil and land management strategies that have been proposed for implementation in DESIRE (WB3)

3: proposed conceptual approaches for additional processes represented within PESERA that are linked to fine scale modelling advances

A: Mass movements, based around a fine scale model developed by IRPI

B: Sediment delivery, related to work by KUL on collating reservoir data, and including a report from KUL on their work

1. Introduction

The principal objective of WB5 is to "develop a model for the main bio-physical and socio-economic processes interacting within an agro-ecosystem, building on existing experience in combination with results generated within WBs 1-4". Deliverable 5.1.1 described the principles of a model that is designed to evaluate the likely biophysical and socio-economic effects of applying remediation strategies selected by stakeholders in WB3 at a regional scale, by scaling up results from field trials and secondary data. This model will be applied in all study areas for which there is sufficient data. A more complex additional socio-economic model is also being developed for application in a single study site (the Guadalentin catchment in SE Spain) to further explore factors influencing the adoption of remediation strategies by land managers and the wider effects of adoption on the regional economy.

Increasingly sophisticated models are being used to represent both biophysical and socio-economic processes in relation to land degradation, usually within disciplinary boundaries. More recently there have been an increasing number of attempts to connect these models in mutually relevant ways, and in ways that are increasingly informed by inputs from stakeholders. The importance of participatory modelling, especially in land degradation and rehabilitation, derives from the awareness of the inadequacy of traditional, engineering approaches to dealing with these "complex and ill-structured problems(Giordano *et al.*, 2007). It has become increasingly obvious that traditional modelling approaches have to be combined with inputs from stakeholders, influencing both model design and interpretation of results if the use of models is to feed effectively into policy design and implementation (Prell *et al*., 2007). However, although there are now approaches that can incorporate inputs from stakeholders into model development, many limitations remain. For example, stakeholder knowledge tends to be restricted to local contexts, so input to models with regional or global coverage is difficult; and there are generally competing stakeholder interests. In the DESIRE project we are making one significantly innovative attempt to incorporate stakeholder inputs into an integrated model combining social, economic and environmental systems, with the following features, which are more fully explored in deliverable 5.1.1:

§ The DESIRE project collaborates with stakeholders to define the most important land degradation processes (WB1) and potential solutions to model in WB5. Stakeholder analysis is used to ensure a cross-section of stakeholders with different knowledge are represented and decision support tools are used to negotiate differing stakeholder priorities (WB3);

- Information collected from stakeholders in WB3 provides the basis for assessing the cost-effectiveness of remediation options across environmental and socio-economic gradients;
- Environmental effects of selected remediation options are evaluated using the PESERA model;
- The resulting linked models have the potential to be applied around the world through the case study approach of the DESIRE project, whilst retaining and building on inputs based on local knowledge;
- In one study site, this is expanded by incorporating stakeholder inputs into (Agent Based) models of human behaviour using data from structured questionnaires and combining this with a (Input-Output) regional economic model.

Linking environmental and socio-economic models not only facilitates a spatially explicit evaluation of mitigation strategies, but also gives spatial expression to the pattern of adoption of mitigation strategies by individual land users, based on economic analysis of available alternative options within each model cell. The coupled models can also be used to model the likely impact of both environmental (e.g. climate change) and socio-economic (e.g. policy) scenarios, providing estimates of global impact of land degradation mitigation, built on local realities.

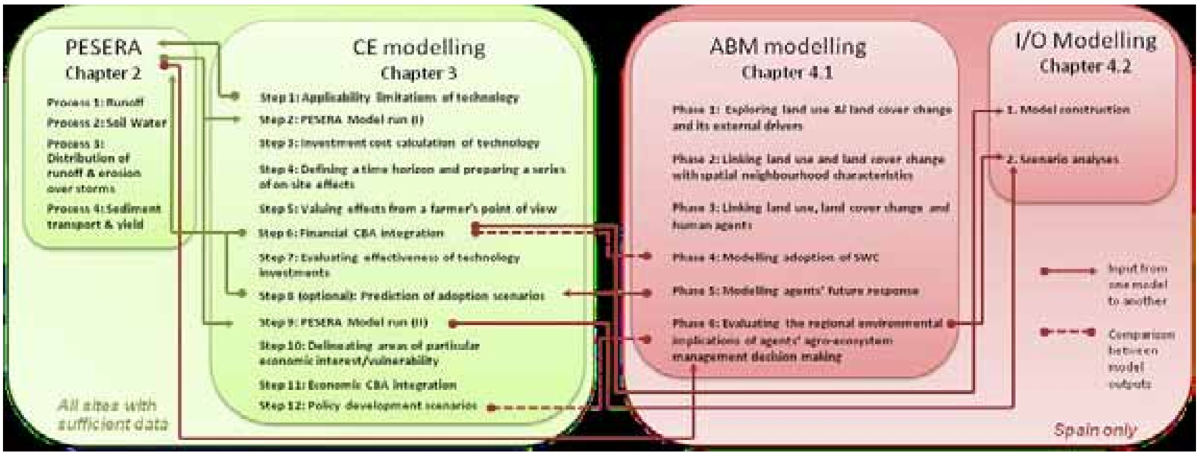

Figure 1.1: *Schematic overview of model interrelations within WB5*

Figure 1.1 gives an overview of the inter-relationships within WB5. Deliverable 5.1.1 has described how the biophysical model proposed for the DESIRE project builds on and extends the PESERA model (Kirkby *et al.*, 2008), originally developed for Pan-European Soil Erosion Risk Assessment within a dedicated EU (FP5) project. The original PESERA model is being extended to capture the role of grazing, fire and wind erosion more effectively, and enhance pedotransfer functions on the basis of dialogue and data within each study area. Current work on these components is reported in Section 2 below. The model is being adapted to each study area to reflect indicators and land degradation drivers identified in WBs 1 & 2 as closely as possible. The modified model will look at the biophysical effects of different remediation options that we have trialled in study areas at a regional or perhaps national scale. These results will be integrated with field trial results in all study areas, and will form the basis of a final stakeholder workshop, in which we will discuss recommendations for policy-makers and extension services. Locally calibrated application of the PESERA model will then be used to expand the results of pilot area studies to a larger hinterland, in order to evaluate the impact of recommended conservation measures for the surrounding area. The extent of this wider hinterland will be constrained by broad similarities of environment (guided by WB 2) and the availability of coarse (1km) resolution data, although reference data is already available at this scale for much of Europe.

In this report we expand the developments in the PESERA model, first describing general developments that have been shared between the DeSurvey and DESIRE projects, second taking each of the mitigation strategies that have been proposed by our study area partners and showing how these are incorporated into the model code, and third discussing the incorporation of coarse and fine modelling approaches developed by other partners and how far these can be effectively incorporated into the PESERA framework. This third component is still ongoing, awaiting full details from partners that are also due in month 36.

The mitigation strategies that have been proposed for application have already been listed in D5.1.1 and are summarised in Table 1 below (Table 2.2 from D 5.1.1).

Remedial Measures	**Examples from the WOCAT database on technologies (from Del. 3.2.1)**	**Model manipulation**	**Details**
Mulching and/or maintaining ground cover vegetation within tree crops (vines, nuts, olives...) Crop or fallowing rotation Changes of land use (e.g. tree addition/ removal) Zero or reduced tillage	SPA03 (Spain); MOR14 (Morocco) MOR11, MOR12 (Morocco); TUR04 (Turkey) CPV03 (Cape Verde); MOR013 (Morocco) CHL01 (Chile); GRE01, GRE03 (Greece);	Change of month-by-month ground cover. Section 2.4.1	Reduces surface crusting and therefore runoff and erosion. Better water retention favours vegetation growth etc.
Retention of crop residues as litter layer at harvesting of arable and other crops Zero or reduced tillage	CHL01 (Chile); GRE01, GRE03 (Greece);	Modifies biomass balances and cover Section 2.4.2	Affects surface properties as above and feeding slowly into soil organic matter that further enhances water retention etc.
Irrigation	GRE02 (Greece); GRE05 (Greece); RUS01 (Russia); TUR03 (Turkey)	Added water for greater growth of crops Section 2.4.3	Expressed as a proportion of irrigation demand met after using rainfall to the full. Output as total water required as well as improved crop yields etc
Water harvesting	BOT04 (Botswana); CPV01 (Cape Verde); SPA04 (Spain); TUN09, TUN12, TUN13 (Tunisia)	Added water for greater growth of crops. Reduced area available for crop growth. Requires suitably compact collecting areas or diversion from ephemeral streams. Cisterns/ storage	Expressed as a multiplier representing ratio of collecting area to irrigation area, allowing for efficiency of collection (i.e. measures to enhance runoff from collecting area). Upper thresholds set by

		reservoirs allow displacement of irrigation over time Section 2.4.3.	spillway design and associated erosion risks.
Changing intensity of grazing Changes in fuel wood harvesting Removal of unpalatable species Game ranching	ITA01 (Italy); TUN11 (Tunisia); TUR01 (Turkey) BOT05, BOT06 (Botswana) BOT07 (Botswana)	Expressed as fraction of available biomass growth removed by animals or people. Section 2.1	Grazing intensity needs to recognise contribution of supplementary fodder. Relevant for biogas or solar cookers
Terracing with vegetated, earth or stone strips/banks Strip cropping Contour .v. downslope cultivations Novel cultivation patterns	CHN51, CHN52, CHN53 (China), CPV02, CPV04 (Cape Verde), GRE04 (Greece), SPA02 (Spain); TUN10 (Tunisia) CPV05, CPV06 (Cape Verde), POR01 (Portugal) SPA01 (Spain) SPA05 (Spain)	Sub-grid modelling (Finer scale model to parameterise impacts of treatments that have a finer texture than the 100m or 1 km cell) Section 2.4.5	Details vary with treatment. Sub-model resolution 1-10m. Output as a correction factor for main PESERA model (hopefully with appropriate scale dependence)
Use of nitrogen fixing crops in rotations	MOR11, MOR12 (Morocco); TUR04 (Turkey)	Enable nitrogen and carbon budget components of PESERA Section 2.4.6	Show effect of fertilisation in enhanced crop yields etc.
Plastic sheeting/ greenhouses		Manage irrigated water use and increase winter temperatures. Suppress weeds.	May require increased pesticide use, and replacement of topsoil. Increased yield, especially of winter crops.

Table 1*: Parameters and methods from PESERA that can be adapted to represent the impact of different SLM technologies proposed in DESIRE (Table 2.2 from D 5.1.1)*

To meet the needs of the integrated models that are being developed, the PESERA model needs first to be run to equilibrium, in order to establish average values of runoff, erosion and productivity under current conditions and to establish initial conditions for runs with explicit time series drawn as realisations of future climatic conditions. Using the same time series for climate in each site, the model can then be run again, applying alternative proposed technologies either as a step-change or through gradual adoption over time. These runs are then used to assess the expected responses of land managers to the changing performance and its economic consequences. In order to do this, PESERA has been developed to ensure that model output responds appropriately to the remedial SLM technologies that are being proposed within the project through WB3. The impacts of relevant SLM approaches will then be incorporated in the cost-effectiveness modelling and agent-based modelling. In the sections below we expand on the approach followed for each relevant activity or treatment. As can be seen below, we have been developing methods that represent all but the last technique listed in Table 1 (plastic sheeting/ greenhouses).

2. General extensions to the PESERA model to represent mitigation and remediation measures

2.1: Grazing

Grazing animals consume vegetation, removing a significant fraction of the primary production. Although a fraction of this consumption (c 10%) is returned locally as solid or liquid excretion, there is a net loss of biomass (including carbon and nitrogen) from the system, much of it returned to the atmosphere as CO_2 or CH_4 (methane) and about 10% converted to body tissue and finally transferred to market. Under equilibrium conditions there is thus a fairly constant ratio between biomass consumed and the carrying capacity of the land, with transitional states where there is a change in grazing intensity,

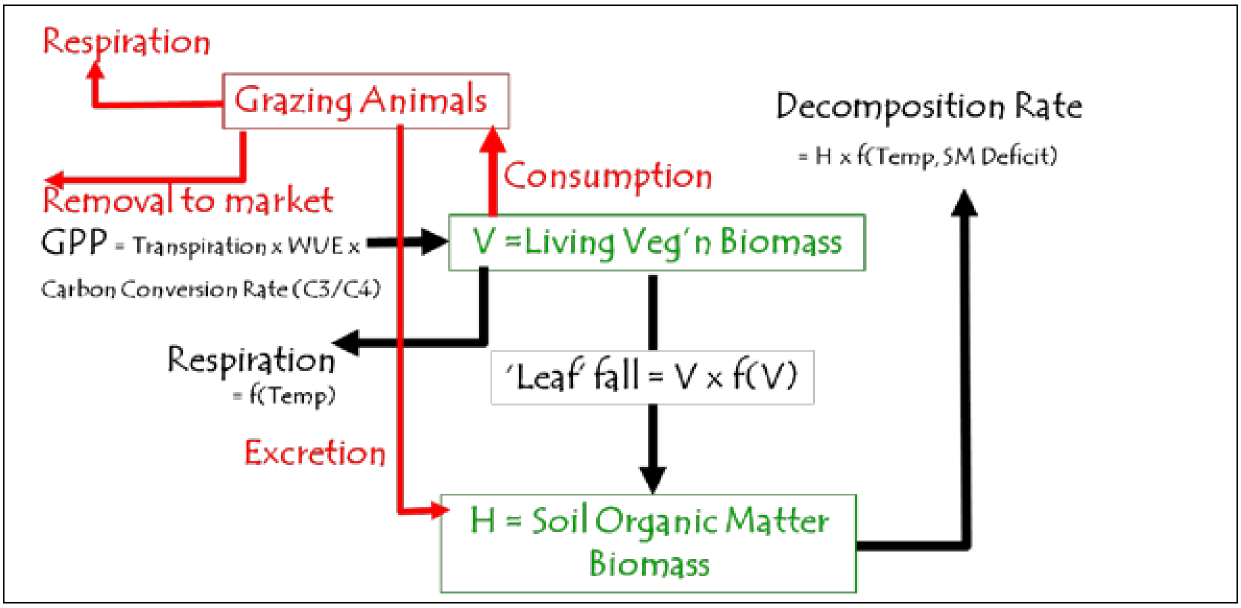

Figure 2.1. Inclusion of grazing animals within the carbon cycling scheme in PESERA

The approach adopted in PESERA has been to specify the fraction of the plant biomass that is consumed each month, which can range from 0 to 100%. This has been preferred to setting the number of grazing animals, as it prevents the possibility of consuming more biomass than is present at any time. As a result the carrying capacity changes through the year, and this can be interpreted in at least three ways; first by considering that the carrying capacity is set by the minimum month, second as a basis for estimating supplementary fodder requirements for the leaner months and thirdly through transhumance, so that grazing only takes place when material is available.

When this approach is implemented in PESERA, we see an interesting relationship between grazing intensity and carrying capacity, illustrated for Senegal (Ferlo) in figure 2.2. At low grazing pressures, increased consumption allows higher carrying capacities but, beyond an optimum, the increased grazing reduces the biomass so much that carrying capacity falls, setting a clear point beyond which the area can be described as 'over-grazed'.

The work described here has been performed to serve both the DeSurvey and DESIRE projects. Corresponding to the resources available and the timig of the projects, the majority of this work on grazing (70%) has been supported by DeSurvey, but have been taken further to provide for the management needs identified in DESIRE.

Changing intensity of grazing and changes in fuel wood harvesting are listed above as one of the mitigation strategies to be adopted. Since fuel wood harvesting can also be seen as a removal of a fraction of the biomass, these two strategies can both be modelled through the approach outlined above, modifying the code to recognise that a part of the biomass removed is assigned to animal grazing and another part to fuel wood collection. The intensities of removal may be linked to location – access to water for grazing and proximity to cities and roads for fuel wood collection. Game ranching can also be treated in this way, assigning the carrying capacity to the game herd instead of to domestic animals, and there may again be a need to recognise trans-humance behaviour, seeking high seasonal carrying capacities along an annual migratory track.

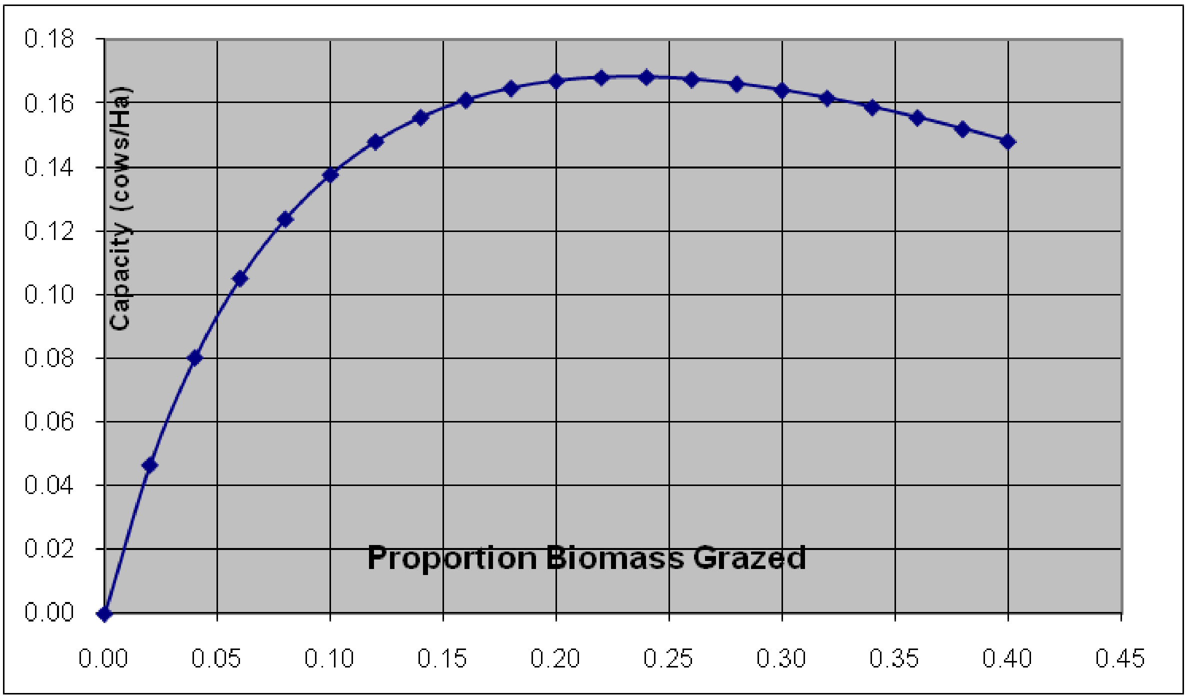

Figure 2.2*. Relationship between proportion of biomass grazed and carrying capacity (cattle equivalents per hectare: 1 cow ~ 3 sheep/goats)*

2.2 Fire

We have implemented a simplified fire model within PESERA, using simplified versions of algorithms developed and tested independently (Venevsky et al, 2002) for Portugal. A fire danger index (FDI) is calculated as:

$$FDI = 1 - \frac{1}{\alpha N}[1 - \exp(-\alpha N)] \text{ where } \alpha = 0.00037$$

and $N = \overline{T}(T_R / 2 + 4).D_{>3}$

where $\overline{T}, T_R$ are respectively the mean monthly temperature and temperature range, and $D_{>3}$ is the number of days in the month with more than 3 mm of rain.

The number of wild fire start-ups depends on two factors, the number of lightning strikes (0.1 to 10 per km^2 per year) and the number of visitors. The former is the dominant factor in the Sahel and the latter in southern Europe. The probability of a fire is then calculated as the number of start-ups multiplied by the Fire Danger Index. Once started, the area of a wild fire is calculated from the rate of spread, which decreases with the fuel load (dry vegetation biomass) and increases with the wind speed. Within the PESERA model the fire area cannot exceed one complete grid cell (normally 1 km^2), which is adequate for all but the most catastrophic fires, which will commonly be represented by fire start-ups in many adjacent cells.

In establishing the equilibrium state, fire is ignored. However, for a time series, there are options to include random fires (drawn at random with the calculated fire probability) and managed fires (regularly applied in a selected month of the year). These fires are assumed to destroy a fixed fraction of the vegetation biomass over the fire area, reducing the biomass in the grid cell, with knock-on effects to runoff and erosion in subsequent years. We propose to further calibrate this model in association with the Swansea and Aveiro partners working in Portugal, and extend these methods for managed fire behaviour. Fire should also affect soil properties, and there may be scope to do this through pedo-transfer functions, but there is no experimental data to support parameterisation for this at present.

This work was begun for the DeSurvey project (20%) but has largely been brought to fruition within DESIRE, where it is ongoing, involving collaboration with Portuguese partners, particularly to improve parameterisation with respect to intensity of fires and soil responses.

2.3 Wind Erosion

There is a fundamental difference between wind and water erosion, in that material eroded by water is travelling exclusively downslope and downstream towards the sea, whereas material entrained by the wind can travel in all directions. In practice, most coarse material detached by the wind is re-deposited locally, perhaps blocking local drainage lines and drifting along fence lines etc, while fine material (silt/clay) and organic dust is lifted into the atmosphere, where it may travel a long way, and generally diffuses down-wind from eroded areas to surrounding vegetated areas. This dust is observed to cross the Atlantic from the Sahara, so that the material is essentially lost to the source area. Of course there are massive sand accumulations in dunes, but in most of the study sites of DESIRE, this is not the main issue of wind erosion.

Our approach has been to simulate the mechanics of disturbance of the soil surface, estimating the frequency of disturbance as an index of the frequency of removal of the fine materials and organics that provide most of the fertility of fragile semi-arid soils that are prone to wind erosion (Visser and Sterk, 2007). To do this, we first estimate the critical velocity, v_{cs} for disturbance at the level of the soil surface roughness (10mm) as a function of monthly soil saturation deficit and soil surface grain size.

$$v_{cs} \sim \exp(5/D)d$$

where D is the soil saturation deficit (mm) and d is the soil grain size (mm).

This expression shows a strong increase in the critical velocity for soils as they approach saturation, and is highly sensitive to grain size.

The wind speed profile empirically extends the normal logarithmic profile down through the vegetation to the surface roughness height (figure 2.3) , even though this procedure is thought to underestimate the importance of periodic velocity bursts in a sparse canopy (King et al 2008: Kenney et al, 2008). The wind speed at instrument height (v_{cl} at say 2m), corresponding to this critical near-surface velocity is then calculated as:

$$v_{cl} = v_{cs} \frac{\ln\left[1 + \left(\frac{2000}{z_0}\right)^{2.5}\right]}{\ln\left[1 + \left(\frac{10}{z_0}\right)^{2.5}\right]}$$

Where z_0 is the roughness height, derived from the vegetation cover. The frequency of wind speeds exceeding this value is estimated by fitting a gamma distribution to the wind velocity distribution. Where there is not adequate information on wind velocity distribution, values are transferred from neighbouring sites. In this approach, there is no attempt to estimate the volume of material removed by the wind, but to estimate the frequency with which surface fines are mobilised, relating this frequency linearly to the loss of fertility of the soil.

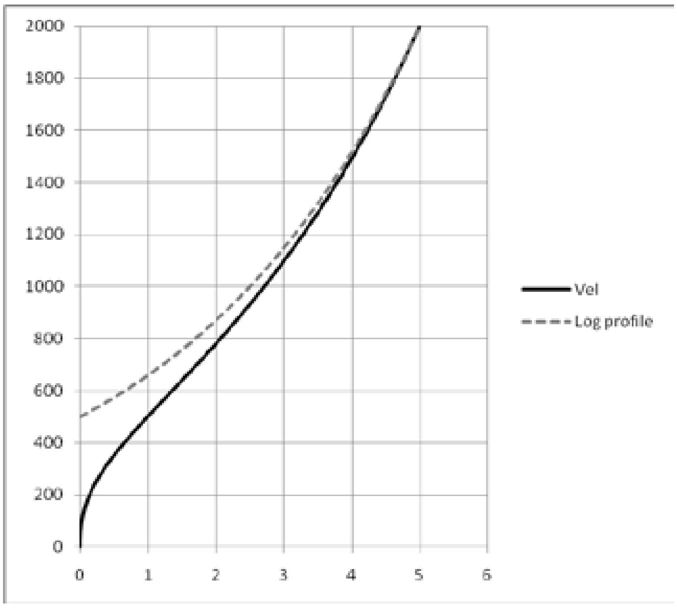

Figure 2.3. Comparison between interpolated velocity profile and log velocity profile, for roughness height of 500mm.

Although the theoretical principles of this work on wind erosion were proposed in the context of the DeSurvey project (15%), it has been brought to a concrete conclusion within the DESIRE project, and has not been reported in full previously.

3. Particular extensions to the PESERA model to represent mitigation and remediation measures proposed as management strategies

Here we provide additional detail on how we represent the soil and land management (SLM) techniques selected for study sites in the DESIRE project as modifications of the PESERA model. These are summarised in Table 1 above, taken from Deliverable 5.1.1

3.1: Mulching and/or maintaining ground cover vegetation within tree crops

It is common practice to clean-till between tree crops after every significant rain, and this method is applied to olives, almonds and vines. This practice increases depression storage and breaks up surface crusting, so maintaining good infiltration characteristics. It also removes competition for water from competing growth by eliminating herbs and grasses. One alternative strategy consists of allowing some herb growth between trees, and controlling this growth through cutting or herbicide application. This may be associated with reduced or zero tillage. Another strategy is to mulch the surface with plant residues which may be pruned material from the trees or imported material. In PESERA tree crops are generally represented by a look-up table which specifies cover in each month of the year. Mulching can then be represented by editing this table to increase the cover in this table. There has already been one pre-determined type for inter-sown or mulched tree crops, and this is edited in response to the chosen density of mulching.

3.2: Retention of crop residues as litter layer at harvesting of arable and other crops

Vegetation biomass is set to zero and crop residues are normally assumed to be removed at every tillage, including at harvest. To represent the impact of leaving crop residues, the model will be adapted to transfer a proportion of the vegetation to the litter layer. The proportion removed must be at least the fraction of the crop taken to market. For grain crops this is normally in the range 30-50%, while for horticultural crops it may be much higher, up to 80% for green vegetables (i.e. all of the above-ground biomass). If additional mulch is brought in from outside, then the fraction returned to the organic soil may be larger. Since the crops grow according to the available soil moisture, the mulch fraction will also respond to the weather from year to year. In highly variable environments, it may be appropriate to set a target biomass (or implicitly yield), below which the crop is abandoned, and the entire biomass is ploughed in as a mulch layer.

Minimum and zero tillage is being represented in two ways. First, PESERA increases the rate of soil organic matter (SOM) decomposition by a factor of 5 in the month of tillage, representing the increased aeration of the soil that occurs. For minimum or zero tillage this ratio should be reduced or held to 1.0 (i.e. no increase in rate). Second, normal tillage events are assumed to reset to zero the vegetation biomass. Instead, tillage events around crop planting should have no effect on any pre-existing vegetation; and tillage associated with harvesting should remove the crop, and optionally the residues, but leave the small fraction (c5%) of the biomass that represents the surviving non-crop plants.

3.3 Irrigation and water harvesting for croplands

The difference between irrigation and water harvesting lies in the level of control over the supply of water in relation to crop demands. An ideal irrigation system makes good the deficit between the water demand of the crop and the available precipitation. The simplest water harvesting system catches runoff from an area adjacent to the cropped field, and channels it to the cropped area, effectively increasing the water available to the crop during rainfall events and shortly afterwards. The difference between these extremes lies in the degree of buffering that allows collected water to be distributed according to crop demand rather than immediately during and after rainfall events. For pure irrigation, with unlimited supply, either from groundwater or reservoirs, the irrigation requirement on any day can be described by meeting a specified fraction of the crop demand, H:

$$H = k(PE.WUE - r)$$

where PE is the potential evapotranspiration, WUE is the water use efficiency of the crop at its current growth stage, r is the daily rainfall and *k* is the 'irrigation fraction' (0<=k<=1).

For pure water harvesting from local sources, the water added to a cropped area can be described by the ratio, β, of bare (crusted) collecting area with a storage capacity h_b to a cropped area with averaged storage capacity h_c. The total runoff , *j*, spread over the cropped area, from a rainfall event of *r* can then be estimated as :

$$j = b(r - h_b) + (r - h_c)$$

For intermediate systems, where water harvesting is used to fill a storage reservoir, the reservoir filling rate is given by the term $b(r - h_b)$. Summing this over time, we must solve to determine the maximum irrigation fraction that can be supplied over the growing season:

$$k = \frac{\sum [b(r - h_b)]}{\sum (PE.WUE - r)}$$

The cumulative difference between storage tank filling and use for irrigation determines the size of reservoir required and its reliability over a series of variable years.

3.4. Invasion and clearance of unpalatable species

There is clear evidence of invasion of grazing lands by unpalatable species in southern Africa, significantly reducing carrying capacities while apparently maintaining a relatively high biomass. In the American south-west there has been a historical replacement of grass in semi-arid rangelands by unpalatable shrubs, associated with a decrease in vegetative cover (though less decrease in biomass) and increased erosion. In both cases overgrazing of fragile ecosystems has been a possible cause, although there is also some debate about the role of subtle climate changes. For a given average fraction of biomass α that is consumed, we here provisionally partition the calculated biomass between a proportion, p_U of unpalatable species and a proportion ($1-p_U$) of palatable species. The unpalatable proportion is then estimated as $p_U = \alpha/\alpha_0$ for a parameter (to be determined) α_0 (necessarily >1) , and the palatable portion is then consumed at the increased rate $\alpha/(1-\alpha/\alpha_0)$. This expression is valid for values of $\alpha < \alpha_0/(1+\alpha_0)$. This change reflects immediately on the carrying capacity of the land, although clearly an increase in unpalatable species tends, other things being equal, to provide some protection from erosion by both eater and wind, by increasing the land cover.

This procedure allows the proportion of unpalatable shrubs to be estimated, but the process is not normally reversible, and unpalatable shrubs generally need to be removed by hand or machinery, sometimes repeatedly over a number of years.

3.5: Terracing and strip cropping

It is possible to represent patterns of terracing and strip cropping with a sub-grid model, explicitly representing the morphology and management patterns at a finer resolution within a single (1 km) grid cell. Here we illustrate this approach for strip cropping and terracing across a uniform 100 m slope with 15 m elevation. In Figure 2.4, the area has been separated into equal strips with different land covers, represented here by different runoff thresholds of 30mm and 90mm respectively. Curves show the calculated sediment transport (in red) and the denudation (averaged from the top of the slope to the point in question) for every point on the slope, for an average year of storms, with a mean rain per rain-day of 10mm, falling on 50 days in the year. It can be seen that the denudation varies between limits of +2.4mm to -3.6mm. However the average (0.51mm) is very similar to that estimated for a uniformly covered slope with the average runoff threshold for the two types of strip (60mm), which gives an average denudation of 0.48mm. We are therefore modelling such strip-cropped areas with a runoff threshold that is the areally weighted average of the land cover types within the cell.

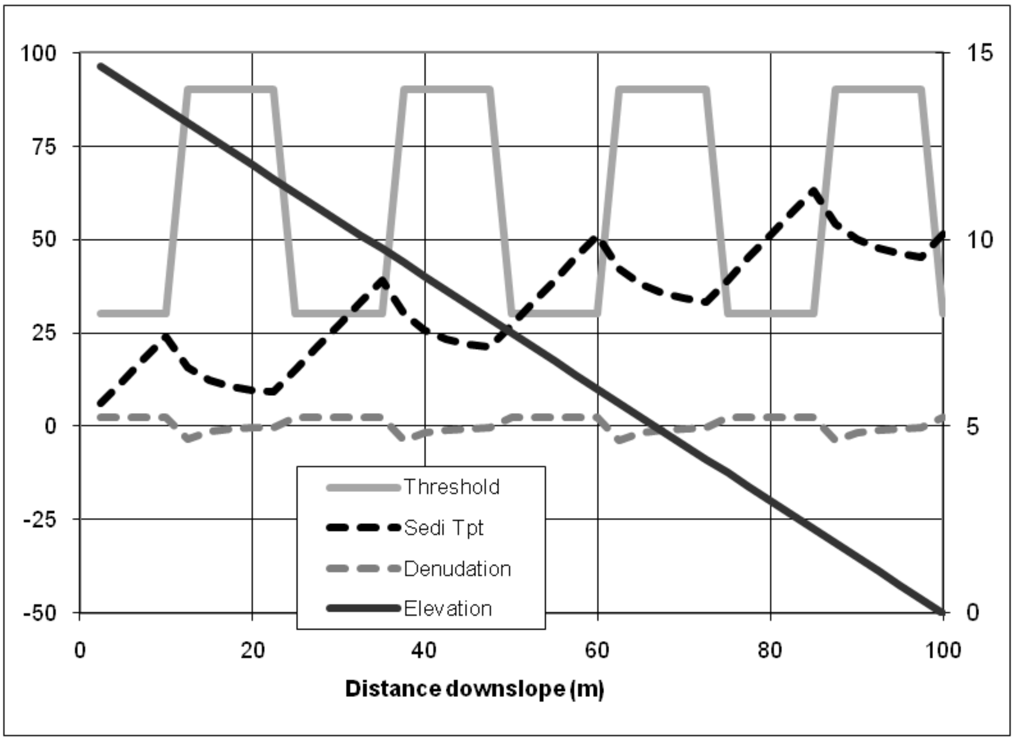

Figure 2.4. Sub-grid model for strip cropping on a 15% uniform slope.

Similarly terracing has been simulated at the sub-grid scale, with both 'soft' terraces in which the riser is not protected in any way and 'hard' terraces in which the riser is protected with stones or vegetation to increase its infiltration and reduce its erodibility. Figure 2.5 shows example output from such a model. It can be seen that the terrace risers produce local peaks in erosion, but that the overall effect is almost identical to the erosion from a uniform slope, at the gradient of the terrace step, but with the weighted average runoff threshold (across read and riser). This then provides the simple modelling rule that is used at the coarser grid scale of PESERA. It can also be seen that local erosion is concentrated on the tops of each riser, which should be reinforced and perhaps protected by diverting any pooled runoff away from the edge.

The effects on the effective modelled relief are more ambiguous for terracing. The lower gradients improve water retention in the lower part of the terrace treads, and this is accentuated by the re-deposition of any material eroded from above. However, in semi-arid climates, most rainfall is evaporated so that this effect is thought to be quite slight. However experiments suggest that the effective relief used in the grid cell should be reduced in the same proportion as the ratio of terrace tread gradient to overall average gradient.

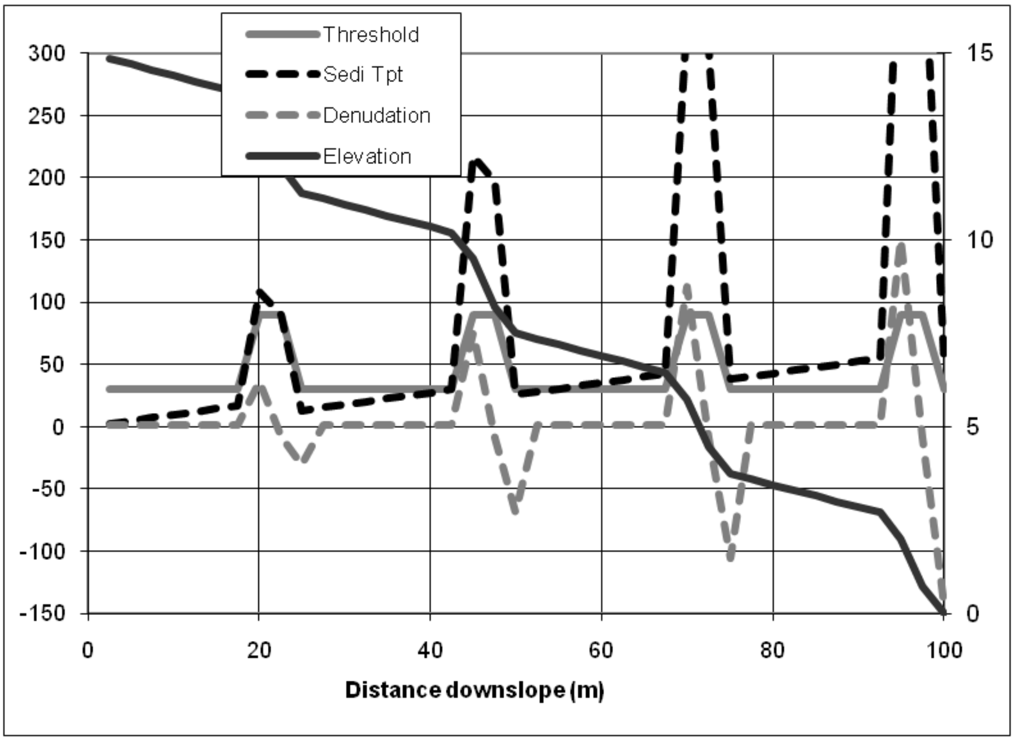

Figure 2.5. Sub-grid model of 'hard' terraces, with 6% treads on an average 15% slope.

3.6 Nitrogen budgeting and rotations

The PESERA model already has a nitrogen cycling component, that was added for work on fertiliser application for upland UK environments. For simplicity, a single soil nitrogen store is simulated in the model. Nitrogen is added to the soil from litter-fall, fertiliser application, animal excretion and a small amount in precipitation; and lost in runoff and to plants. Plants take up nitrogen from this store, and by direct atmospheric fixation, returning it to the soil store and being removed to market. This component of the PESERA model then provides the response in biomass and yield to fertiliser application and nitrogen fixing crop rotations.

4. Other extensions to the PESERA model in response to model development by other partners

4.1 Mass movements

A detailed model for mass movements is being developed within the PESERA model by CNR-IRPI in WB 5.2. Because of the finer scale of this application, it has been necessary to simplify the conceptual principles for partial inclusion within the coarse scale PESERA model.   Mass movements are driven by rupture within the soil or rock along a defined surface within the soil. Here we represent only shallow slides with a shallow slide surface sub-parallel to the ground surface. Slides occur when the downslope component of the weight of overlying soil overcomes the resistance to movement, or the 'shear strength' of the material. This resistance is made up of two components; friction and cohesion. The cohesive strength is a constant force per unit area, highest in intact consolidated clays but generally very small for materials weathered near the surface, and here ignored. The frictional strength is proportional to the normal stress (pressure or force per unit area) across the slide surface, with a constant of proportionality that is the 'coefficient of friction', commonly expressed as the tangent of the 'angle of friction'. In a pile of sand or gravel, this angle is equal to the maximum stable angle for the pile. Archimedes' principle states that the upthrust is equal to the weight of water displaced: applying this to a sloping soil mass, the normal stress due to the weight of overlying soil is reduced as the soil becomes saturated. Since soil has a density of approximately twice that of water, a fully saturated soil applies only about half of the normal stress compared to a dry soil, so that the frictional strength is proportionally reduced, and failures in a wettable soil generally occur when it is saturated, and at a gradient that is about half of the angle of friction.

Applying this simplified model as an extension of PESERA, we need to forecast the spatial frequency of susceptible slopes (at or close to half the angle of friction) and the temporal frequency of saturated conditions. Some approximation is needed for both at a coarse scale, so that we recognise the need for calibration and evaluation of the results, preferably against both the CNR-IRPI fine scale model and against observed events.

Gradient can be estimated from DEM data, but needs to be analysed at the finest scale available. Previous work has suggested that a resolution of 10m or better is desirable, whereas PESERA currently relies mainly on the 90m SRTM data set. Gradient measured at these coarser scales generally underestimates the steepest slopes, so that the critical slope value should be made to respond to the DEM resolution, calibrating against progressive degradation of a fine scale data set. For each grid cell, the DEM will provide a frequency distribution of gradients (120 values per km^2 for the SRTM; more with a finer resolution DEM). This distribution, *f(g)* is then compared with a stable angle, g_o, (half the angle of friction) estimated from the soil texture, interpreted from soil and/or geological maps.

Average deficit can also be simulated from the modelled monthly deficit, multiplied by the frequency of rainfall events in the month, each offsetting the average deficit. We obtain a gradient-dependent expression for the probability *p(D,g)* of a given deficit, *D*. Combining these two distributions, we try to fit an expression of the form:

$$p(slide) = \iint f(g)\frac{g}{g_o}p(D,g).dD.dg$$

This expression convolutes the two distributions to provide a probability of landslide occurrence in any grid cell for each month. As with wind erosion this is used primarily to estimate the frequency of crop destruction rather than a sediment transport volume. However, by combining this frequency with an average slide volume, this can be used to estimate volumes removed, which are required to reconcile PESERA model estimates with reservoir data.

The input and output of the fine scale model has been prepared in a way that is compatible with PESERA, and can be treated as an addendum to the basic PESERA model, although final coupling between the models has not yet been completed. The prototype fine scale model has been tested against data for the Rendina catchment and the final version of the model should be ready in May 2010.

Priority has been given to the modelling of mass movements. Other aspects of fine scale modelling will benefit, particularly from the frequency distributions of gradients developed for the landslide model, as a basis for representing details of topography at sub-grid scales. This methodology is being particularly applied to modelling of tillage erosion and land levelling.

4.2 Data collection calibration of PESERA against reservoir data

Whereas a lot of attention in DESIRE is given to the effects of protection and restoration measures, land use and management practices on soil erosion at the scale of farmers' plots or hill slopes, several studies have indicated that the extrapolation of soil erosion rates at the plot scale to sediment export rates at catchment scale is not straightforward (e.g. Walling, 1983; Poesen & Hooke, 1997; de Vente & Poesen, 2005; de Vente et al., 2007). Nevertheless, insight in the total sediment export at catchment scale is needed to evaluate the effects of mitigation strategies and management practices at larger spatial units but also to address off site consequences of runoff and soil erosion such as reservoir sedimentation and flooding.

To help solving this scaling problem, K.U. Leuven (partner 2) developed a database with sediment export rates from river catchments in Europe, the Mediterranean World and the regions of the DESIRE hotspot areas outside Europe. The general objective of this sediment yield (SY) database in WB 5 is to allow the calibration and validation of the (adapted) PESERA model and provide a framework to evaluate mitigation strategies at the catchment scale, considering their effects on the total sediment export.

The SY database was constructed, based on a database on published reservoir siltation rates (Verstraeten et al., 2006), data from publications, reports, PhD. and MSc. thesis's, and data from other DESIRE partners. Although the SY database continues to expand, a first version of the database contains sediment export data, measured at 1630 different locations in Europe, representing at least 26 202 catchment years of measured data. 506 of the sediment export data were derived from reservoir surveys (R), while 1124 of the sediment export data were measured at gauging stations (GS). The database covers catchment areas ranging from 0.01 km² to > 100 000 km². A detailed description of the dataset will be provided in Vanmaercke et al. (in prep.).

The compilation of the SY database is directly related to the compilation of a second database containing soil loss data from runoff plots. In this database, plot-scale runoff and soil loss data are collected through a detailed literature review of journal papers, books, PhD theses, internal project reports and through correspondence with researchers collecting runoff and soil loss data from plots. This database will also be used for model calibration and validation. However, a first analysis of the available sediment export data, confronted with the soil loss data on the plot scales, revealed some noticeable trends.

The European SY data was classified in different climatic zones, based on the LANMAP 2 classification (Mücher et al., 2006; Metzger et al., 2005). An analysis of the cumulative distribution of area-specific sediment yields (SSY, ton/km²/yr) revealed that sediment yields in the Mediterranean climatic zone are significantly (a factor 2 to 10) higher then in other climatic zones.

This draws attention to the Mediterranean region as a sediment yield hotspot. Several authors have already indicated that sediment fluxes in semi-arid regions, and more specific in the Mediterranean basin, are generally higher and more sensitive to (human) disturbances (e.g. Walling & Kleo, 1979; Woodward, 1995). The compiled database offers, however, a first way to quantify and analyse differences in a detailed way, based on a sufficient amount of measured data.

A comparison of the measured sediment export data with the soil loss rates at plot scale for the different climatic region further indicates that extrapolation of erosion rates from the plot scale to sediment export rates at the catchment scale poses difficulties, especially in the Mediterranean region. In most climatic zones, soil loss rates at the plot scale are generally higher then sediment yields at the catchment scale.

This agrees with the traditional expectation that sediment yields generally decrease with increasing catchment areas, as the probability that eroded sediments are deposited again increases with increasing catchment area. In this context, the sediment delivery ratio (SDR, %, the total sediment export, divided by the total gross erosion) is mostly expected to be lower then 100 % (e.g. Walling, 1983). However, for the Mediterranean region it was found that median sediment yields at the catchment scale are a factor ten higher then soil loss rates at the plot scale. Whereas the soil loss rates at the plot scale is generally lower then in many other climatic regions, sediment yields are generally higher.

Soil loss rates at the plot scale mostly take only soil erosion due to rill and interrill erosion into account. The confrontation with sediment export data clearly illustrates that often other sediment sources (e.g. gullies, bank erosion, and landslides) are most probably a more important source of soil erosion and sedimentation problems. Extrapolation from the plot scale to the catchment scale should therefore take this other sediment sources into account.

Many of the DESIRE study areas are included in the Mediterranean region, according to this used LANMAP2 classification (i.e. Guadalentin Basin, Mação, Rendina Basin, Crete, Nestos Basin and Eskisehir), while most other study sites outside Europe would be classified within a similar climatic region. These results therefore illustrate the importance of also focussing on the effects of land degradation and soil erosion at the catchment scale. Especially reservoir siltation might be an important off-site impact, since it has a direct link with water availability. Moreover, other studies have indicated that reservoirs in semi-arid regions are often more susceptible to siltation problems, due to their general higher sediment trapping efficiency (Vörösmarty et al., 2003).

The established sediment export database will allow comparison of erosion rates, predicted by the PESERA model, with actual sediment export rates. This comparison will serve as a basis indication where eventual other sediment sources are important and where additional attention needs to be given to the PESERA model.

This reservoir data collated by KU Leuven as part of WP 5.3, is being used to make comparisons with PESERA estimates. To do this, the PESERA model needs to be extended to route sediment from eroded areas to specific points downstream. There may be considerable de-coupling between hillslope and channel sediment transport, so that exceptional rates of hillslope erosion commonly produces massive valley sedimentation for many decades before the river system responds to balance the inputs. Here we assume that this process is occurring, in the short term, by associating sediment eroded from the land with a characteristic sediment transport distance related to the grain size of the source material. The travel distance from each cell is estimated from the soil type, interpreted as texture, and material is exponentially distributed downstream according to its travel distance. Additional material is assumed to accumulate on flood plains, so that reservoir sedimentation is strongly weighted towards proximate areas with high erosion rates, often associated with gullied river bank areas. The details of this method are still under discussion.

5. Conclusions

It can be seen that we are effectively modifying the PESERA model to meet the needs of the DESIRE project. In almost all cases, we believe that this can be done in a simple way that requires a minimum of parameterisation, and so can readily be extended to a wider area around the individual study sites.

References

de Vente, J. & Poesen, J., 2005. Predicting soil erosion and sediment yield at the basin scale: Scale issues and semi-quantitative models. Earth-Science Reviews (71), pp 95-125.

de Vente, J., Poesen, J., Arabkhedri, M. & Verstraeten, G., 2007. The sediment delivery problem revisited. Progress in Physical Geography (31), pp 155-178.

Kenney, P.M., Keith, T.G., Ng, T.T. & Linn, R.R., 2008. In-field determination of drag through grasss for a forest fire simulation model. Modelling, monitoring and management of forest fires, **119**, 23-29.

King, J., Nickling, W.G., and Gillies, J.A., 2008. Investigations of the law of the wall over sparse roughness elements. J. Geophysical Research –Earth Surface, **113**, Article F02S07.

Metzger, M.J., Bunce, R.G.H, Jongman, R.H.G, Mücher, C.A. & Watkins, J.W., 2005. A climatic stratification of the environment of Europe. Global Ecology and Biogeography 14: 549-563.

Mücher, C.A., Wascher, D.M., Klijn, J.A., Koomen, A.J.M., Jongman, R.H.G., 2006. A new European Landscape Map as an integrative framework for landscape character assessment. In: Landscape Ecology in the Mediterranean: inside and outside approaches, R.G.H. Bunceand R.H.G. Jongman (Eds) 2006. Proceedings of the European IALE Conference 29 March – 2 April 2005 Faro, Portugal. IALE Publication Series 3, pp. 233-243.

Poesen, J.W.A. and Hooke, J.M. 1997. Erosion, flooding and channel management in Mediterranean Environments of southern Europe. Progress in Physical Geography 21 (2):157-199.

Prell C, Hubacek K, Reed MS, Burt, TP, Holden J, Jin N, Quinn C, Sendzimir J, Termansen M (2007) If you have a hammer everything looks like a nail: ‘traditional’ versus participatory model building. *Interdisciplinary Science Reviews* 32: 1-20

Vanmaercke, M., Poesen, J., Verstraeten, G., Maetens, W., de Vente, J. Sediment yield in Europe: spatial patterns, scale dependency and comparison with soil erosion rates (in preparation: will be submitted with Earth Science Reviews).

Venevsky, S., Thonicke, K., Sitch, S. & Kramer, W., 2002. Simulating fire regimes in human-dominated ecosystems: Iberian case study. Global Change Biology **8**, 984-998.

Verstraeten, G., Bazzoffi, P., Lajczak, A., Radoane, M., Rey, F., Poesen, J. & de Vente, J., 2006. Reservoir and Pond Sedimentation in Europe. In: Boardman, J. & Poesen, J. (ed.), Soil Erosion in Europe, Wiley, pp 878.

Visser, S.M. and Sterk, G., 2007. Nutrient dynamics –wind and water erosion at the village level in the Sahel. Lnad degradation and development, **18**, 578-588.

Vörösmarty, C.; Meybeck, M.; Fekete, B. Sharma, K.; Green, P. & Syvitski, J. P. M., 2003. Anthropogenic sediment retention: major global impact from registered impoundments. Global and Planetary Change (39), pp 169-190.

Walling, D., 1983. The sediment delivery problem. Journal of Hydrology (65), pp 209-237.

Walling, D. & Kleo, A., 1979.Sediment yields of rivers in areas of low precipitation : a global view. Hydrology of Areas of Low Precipitation (Proceedings of a symposium held during the XVII Assembly of the International Union of Geodesy and Geophysics at Canberra, December 1979), pp 479-493.

Woodward, J. C., 1995. Patterns of Erosion and Suspended Sediment Yield in Mediterranean River Basins. In: Foster, I., Gurnell, A. & Webb, B. (ed.). Sediment and Water Quality in River Catchments, John Wiley & Sons Ltd., pp 365-389.