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From Plot to Continent: Reconciling Fine and Coarse Scale Erosion Models

*Mike Kirkby**

INTRODUCTION

I am honored and pleased to have been invited to speak here in one of the leading international centers for soil erosion research. Let me begin by telling you a little about my own research strategy and background, which tells you some of my credentials for speaking to you, and also explains some of my particular point of view on these issues.

Soil erosion is a global problem, as is plainly recognized in the title of this conference. I understand the term "Soil Conservation" in the title of ISCO as the obverse of the term "Desertification" which is essentially about degradation of global soil resources. For the last ten years, I have been primarily involved in the MEDALUS project, on Mediterranean Desertification and Land Use, which has been funded by a series of European Union Research Grants to a partnership involving nine countries and over 30 research groups, and which has been led by John Thornes, of King's College, London (Thornes & Brandt, 1996). My own work is concerned primarily with modeling, but I have benefited enormously from the experience of working with a wide range of colleagues, which includes many laboratory and field scientists working in semi-arid environments

During our research, we have been progressively urged to raise our objectives from the study of detailed processes to more regional perspectives, where there is a greater relevance to policy issues, and to address the questions in the context of current and future global climate and land use changes. This has led us to move on from the detailed studies and models of soil erosion processes on a single event or short-term basis on which our own experience and much of the literature is based. We have been stimulated to look at time scales of 10-100 years, and at areas going up to 100's or 1000's of square kilometers, and then to at least the whole of Europe. The coarse scale drivers include the UN Convention on Combating Desertification (UNCCD), which is being translated into Desertification Action Plans in most Mediterranean countries (among others); and the European Common Agricultural Policy, which is currently leading to widespread re-modeling of landscapes in Spain and Italy to harvest subsidies from unsuitable land, and in some cases destroy more sustainable traditional styles of land use.

Soil degradation is clearly one possible end product of an interacting set of socio-economic and physical drivers (Figure 1). In principle, policy should be driven by an identification of the intended goals, associated with research into how best to influence those goals, but in practice the history of soil conservation world-wide shows that the political process rarely operates in this way, and that even well chosen policies generally have many unintended side-effects.

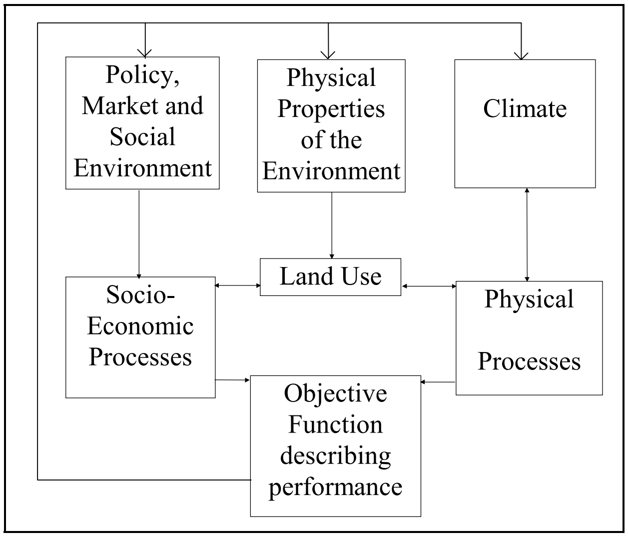

Figure 1. Interaction of socio-economic and physical factors in erosion forecasting.

One aspect of our research on desertification has been a primary concentration on uncultivated areas, although we are now coming back towards work on cultivated areas of various kinds, including both field crops and tree crops such as vines, olives, and almonds. The reason for this focus is that abandoned fields are seen as one important area at increased risk of erosion in southern Europe, but it has also given a distinctive time scale to our work, as changes accumulate over at least several decades. This perspective has parallels in rangeland research, but may explain some of our particular points of view.

Another strand of my recent activity has been involvement in two overlapping international discussion groups devoted to Soil Erosion. The first of these is the Global Change in Terrestrial Ecosystems (GCTE) Soil Erosion group, which has successfully brought together scientists from around the world to compare, and of course expose the shortcomings, of even the best current Soil Erosion models, such as WEPP and EUROWISE. The second is the COST (Co-operation on Science and Technology) group on soil erosion, funded by the European Union from 1998 to promote and synthesize research in soil erosion for five years, initially under three main headings, of which *Scale Issues* is one, and in my view a very important one. In these discussions, one of our initial conclusions is that hydrology is perhaps the most important key to a better understanding of soil erosion, and that we should not expect to forecast or understand sediment loss without getting the runoff right first.

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The third relevant aspect of my background is a long-term involvement with Hillslope Hydrology, and the development of physically based models for partitioning subsurface and overland flow. This work was initially based in temperate climates, where a number of people in America and Europe became convinced that much overland flow, most strikingly in forested areas, is generated by rain falling on small parts of the catchment where shallow subsurface flow has saturated the soil. What we are now beginning to realize, in a partial reversal of our previous roles, is that Hortonian overland flow and Saturation overland flow often co-exist, or dominate alternately, especially in areas with strongly seasonal rainfall regimes (Fig. 2).

Hortonian Overland Flow (HOF) and Saturation Overland Flow (SOF) can each generate water erosion, but are accompanied by very different distributions of erosive activity and by different associated processes (Figure 3). Water erosion is most commonly associated with HOF where rainfall intensity exceeds the infiltration capacity, and leads to overland flow discharge which increases linearly, or less than linearly downslope. In humid areas, however, SOF dominates in some areas, leading to a pronounced concentration of flow and discharge at the base of hillslopes. The hydrological process regime can therefore lead to a great contrast in the topographic distribution of sediment loss within fields and on rangeland slopes.

Techniques for scaling up and down

Putting together these points of view, you will realize why I believe that one of the central issues of erosion research is to research the best ways of moving between time and space scales, as far as possible within a shared knowledge of the relevant physical processes. This will, I hope, lead us towards a consistent basis of understanding what is happening; from one extreme for erosion plots in a single storm and at the other for the distribution of long term erosion rates over the whole of North America or Africa. In both cases, a proper physical basis should begin to provide an insight, and preferably a forecast, of expected changes under different tillage systems, different land uses and changing climate under greenhouse warming. Finally, you will not be surprised to hear me insist that the physical basis should always be rooted very firmly in an understanding of the soil, hillslope and catchment hydrology.

Most of our process knowledge is based on plot-scale studies and it is now sometimes possible to make reliable forecasts at this scale for a year or two, provided that there is sufficient data to parameterize the best models. Many policy-related issues must be addressed at catchment, regional and national scales, and for periods of decades, where fine-scale models cannot be properly applied due to lack of parameter data, computing power and finance. In scaling up, it is essential to simplify the complex set of process interactions. At the same time, complex system theory warns us that new interactions are likely to emerge as we study larger areas and longer time spans, so that coarse and fine scale models may well be based on different dominant processes. For example, it is argued that surface characteristics, including roughness at all scales, and heterogeneity of properties (such as rainfall intensity and infiltration) over space and time become still more important at coarser scales.

From the perspective of policy, the scaling problem is one of scaling down, of zooming in on problem areas, which require analysis that is more detailed and research (figure 4). From this perspective, it is essential to begin with coarse scale models, which for soil erosion, are needed to extend direct analyses of remotely sensed data, since the operational detection of degradation is still at a very early stage of research. These models need to give a generalized and objective survey of the distribution of severity for a particular problem, which can focus detailed research on smaller areas, at greater intensity and a finer scale. Nesting is therefore seen as an appropriate strategy for supporting the implementation of policy. Coarse scale models identify sensitive areas for more detailed study, and this process may be repeated with models and field studies at each appropriate scale down to the level of the hillside or field at which conservation measures are finally applied. The coarse scale RDI and MEDRUSH models described below can be combined with the MEDALUS model (Kirkby et al, 1997), or other widely used plot or catena models, such as KINEROS (Woolhiser and Smith, 1990), WEPP (Lane and Nearing, 1989) or EUROSEM (Morgan et al, 1992), to carry the nesting from continental scales, through catchments to individual fields or erosion plots. What is still needed, however, is to develop a greater consistency of approach and forecasts across the full range of scales.

From the perspective of scientific knowledge of erosion, we need to work in the opposite direction, which is to build up from the small areas where we have our best understanding to the larger areas where we wish and need to apply our expertise. Formally, this path can be followed

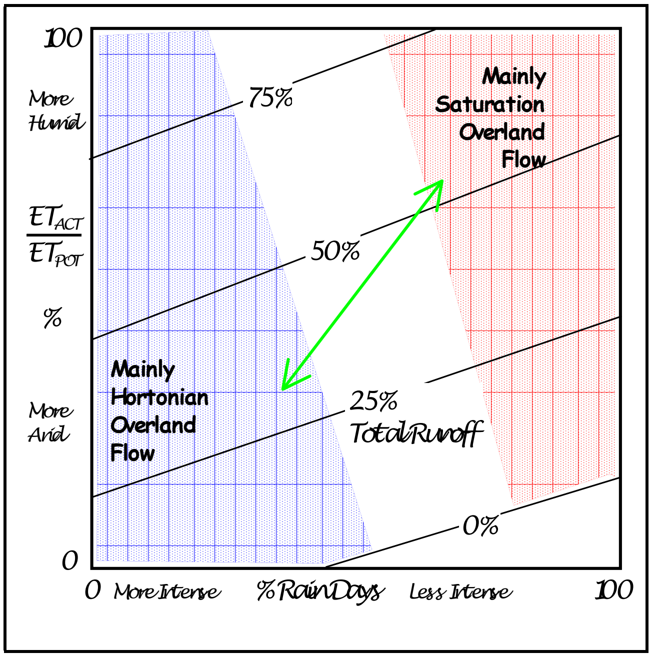

Figure 2. Generalized dependence of runoff coefficient and style of overland flow on arid-humid scale and on storm rainfall intensities. Arrow indicates seasonal or storm period fluctuation.

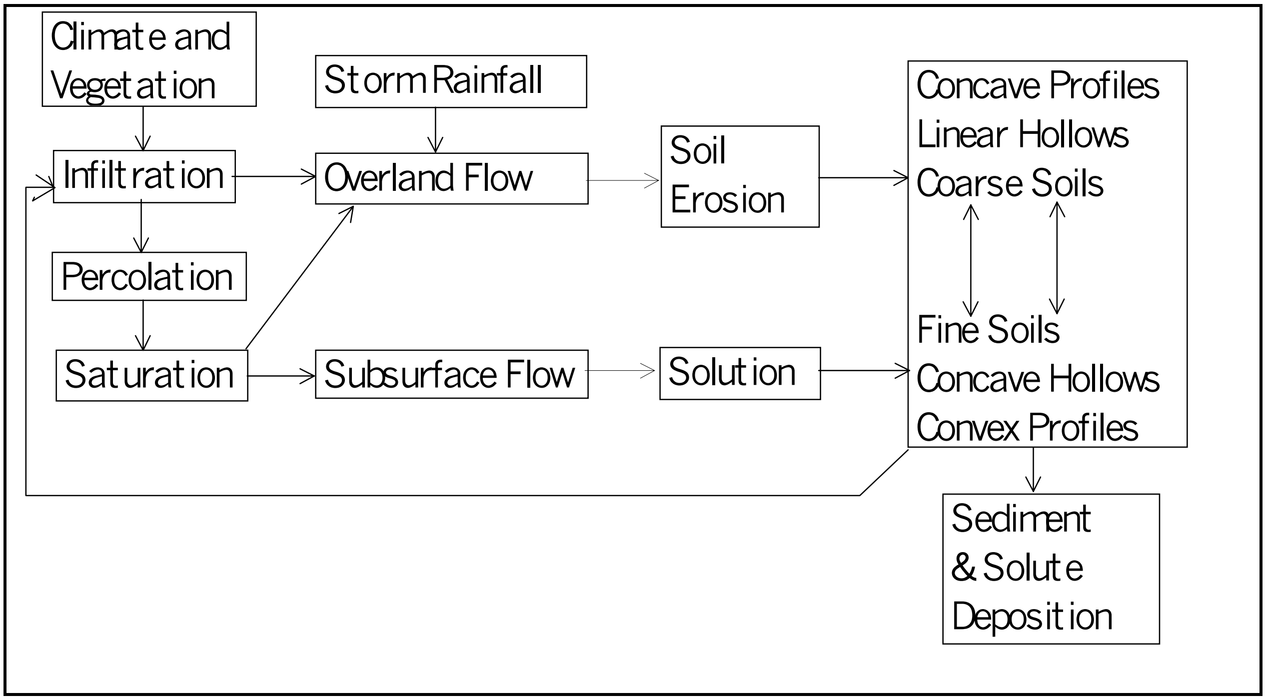

Figure 3. Style of hillslope hydrology and its effects.

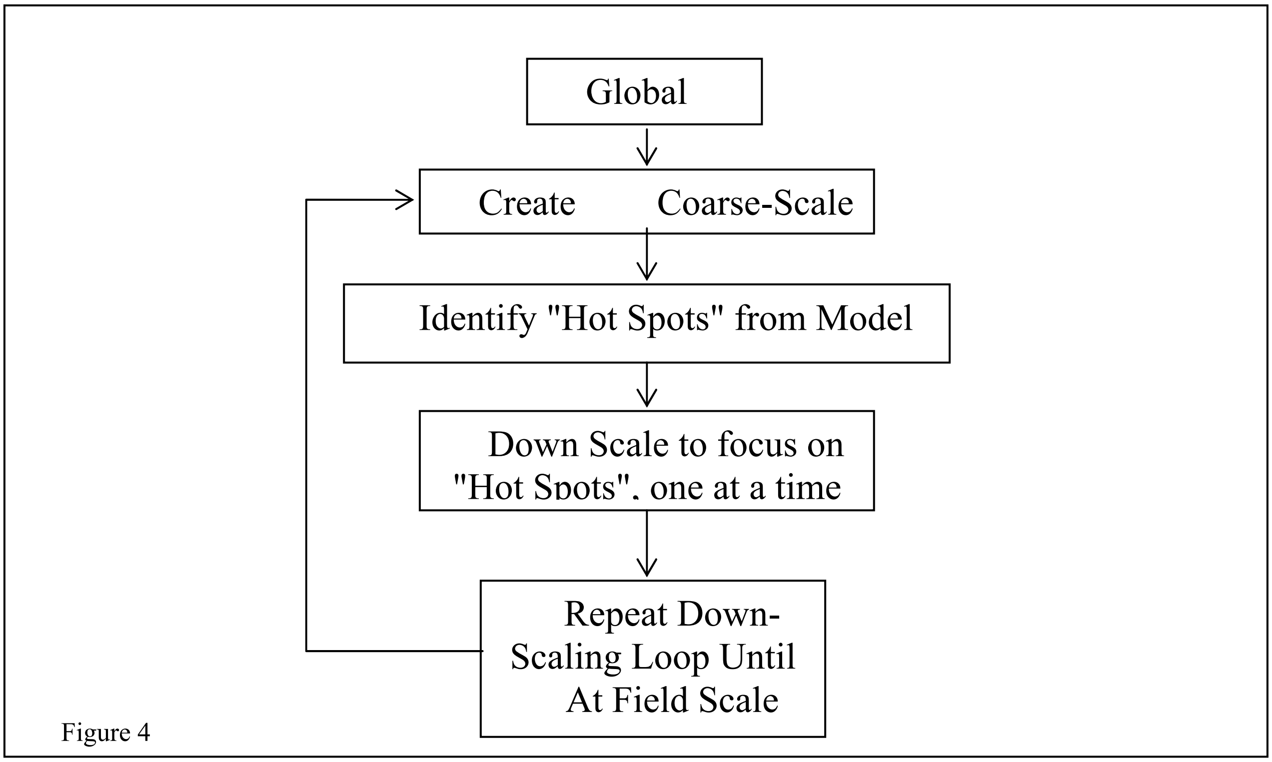

Figure 4. A Nested Research Strategy for Modeling at global to field scales.

through summation or integration over the space and time distributions of the fine-scale process. Over space for example, we may integrate the cumulative effect of infiltration along all possible overland flow paths to convert at-a-point measures of infiltration and runoff to the discharge from larger areas, in the knowledge that runoff coefficients generally decrease strongly with catchment area in moving from erosion plots to whole fields and small catchments. Over time, dynamical effects may similarly be summed through the course of a single storm, and then integrated over the frequency distribution of storm rainfalls to obtain the longer term annual average rate. Where the frequency distributions are well defined, for example as normal or gamma distributions, these up-scaling integrations can be performed analytically or using routine numerical methods. When this is done, the moments of the distribution appear as explicit parameters of the coarser scale model. Thus, integration over turbulent flow fluctuations introduces Reynolds' shear stresses related to the intensity of turbulence; integration of sediment transport over rough surfaces introduces random roughness as an explicit parameter; and integration over grain-size distributions introduces the grain sorting as a parameter. These disparate examples all require the second moments (standard deviation or variance) of their respective distributions, which arise naturally when second power (square) laws relate, for example, sediment transport to overland flow discharge.

Combining the needs of up scaling and downscaling, is often helpful to adopt a formal strategy of nesting models within one another. Although formal integration achieves limited up-scaling, it is generally recognized that different dominant processes are most active at widely different scales, and that efficient models at these different scales may have very different variables and parameters which cannot be completely represented by the integration process. For example, there is some overlap between hillslope and channel erosion processes, and channel heads may change in position dynamically over time, but some of the dominant processes are described in radically different ways. For example, larger channels are usually associated with flood plains, which dominate the behavior of flood waves and sediment storage in a way, which has no parallel in headwaters and flow over hillslopes. Thus, it may be possible to represent a transition from hillslope to headwater channel in one model, and from headwater to alluvial channel in another; but is generally inefficient to attempt to include hillslopes, headwaters, and alluvial channels in a single model. This type of transition is very effectively treated by nesting upstream models within large catchment models, so that each can perform, with appropriate parameters, within the range of our physical understanding. Clearly water and sediment output from the upstream models provides inputs to the catchment model, so that a proper coupling is maintained, within an efficient overall model structure.

As well as a procedure for upscaling such as the formal integration described above, it is helpful to concentrate on relationships and variables, which retain their relevance across a range of scales. Perhaps the most important concept in spanning across a range of scales is that of budgeting for water and sediment down hillslopes and through catchments. Water and sediment budgets rely on the routing of materials according to the Storage Equation:

Input - Output =Net Change in Storage

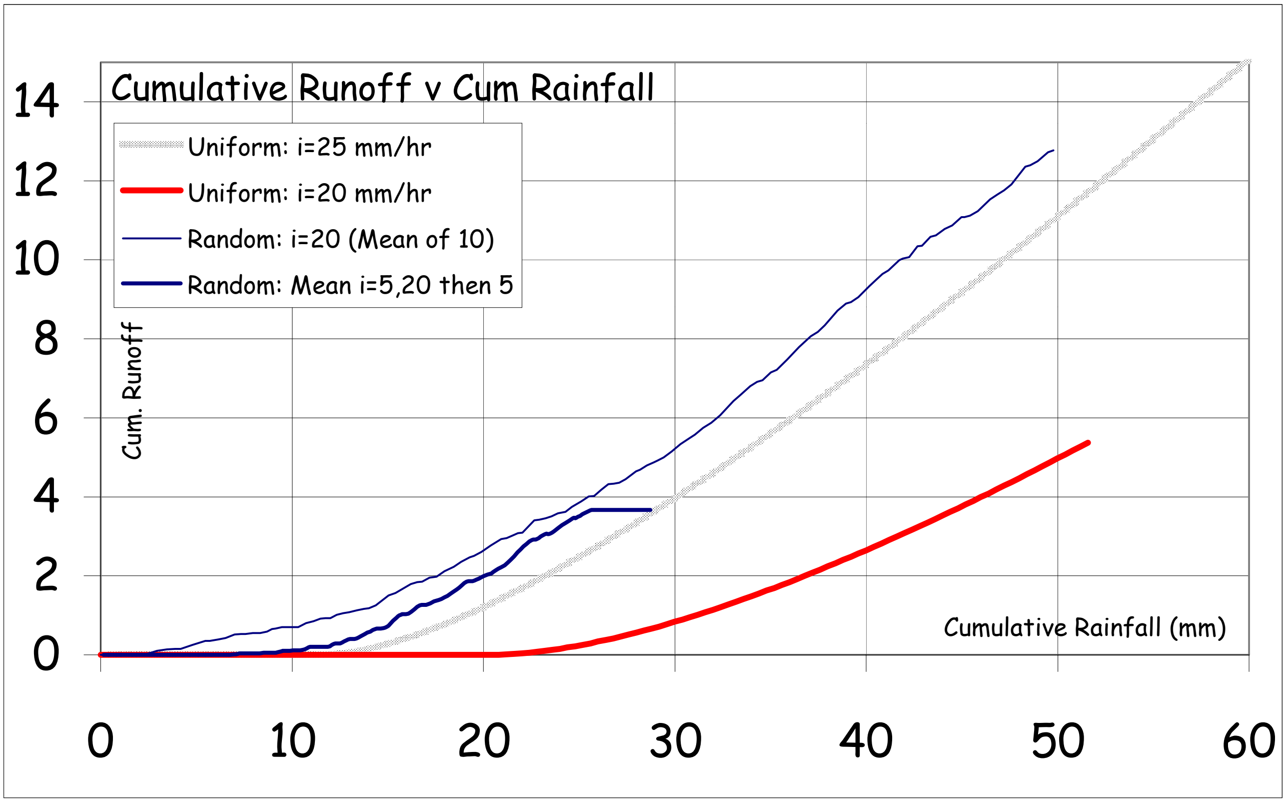

Figure 5. Rainfall-Runoff relationships for a Green-Ampt infiltration equation under different conditions; Uniform rainfalls at 20 mm hr^{-1} and 25 mm hr^{-1}; Exponentially distributed random rainfalls with a mean intensity of 20 mm hr^{-1} and with mean intensities of 5, 20 and 5 mm hr^{-1} for successive hours.

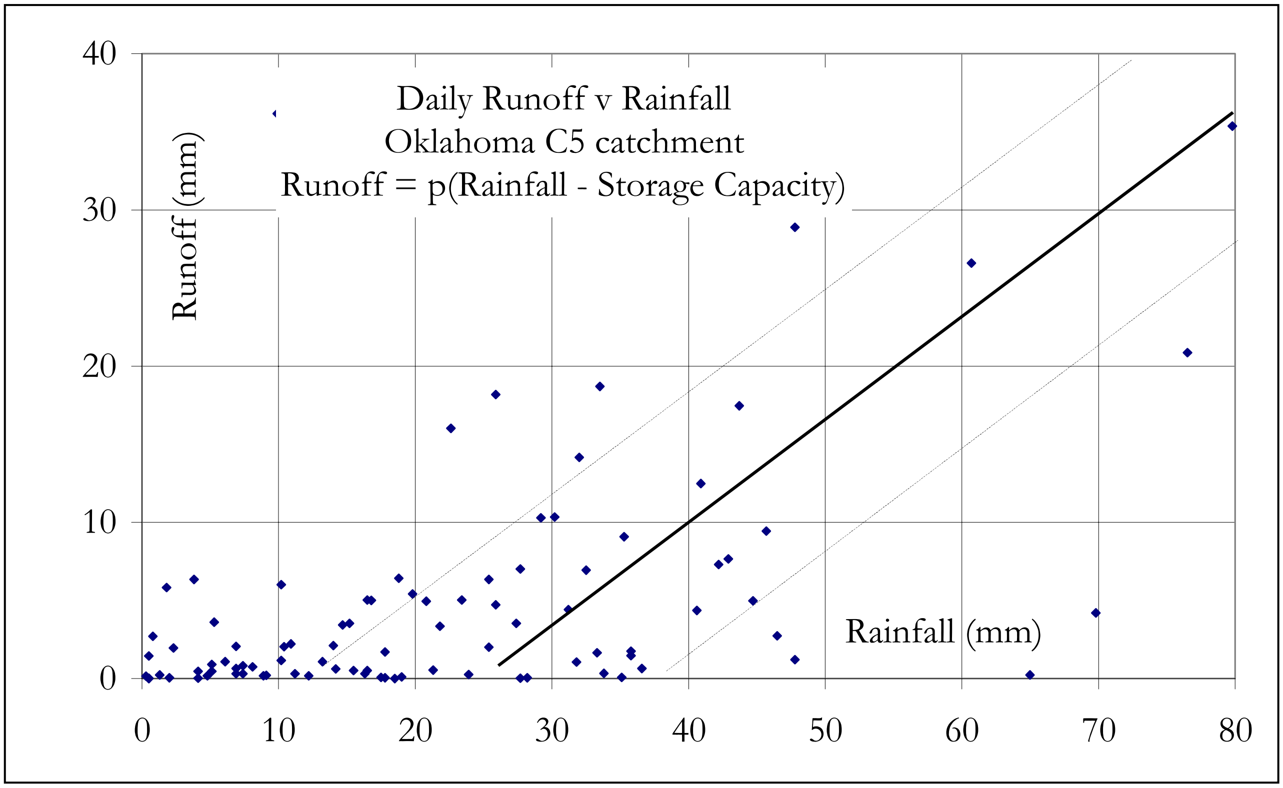

Figure 6. Rainfall-Runoff relationship for storm totals from an experimental catchment in Oklahoma. Plotted points show observed total runoff from individual storms. Solid and broken lines indicate approximate estimated mean runoff and confidence limits for a linear rainfall-runoff relationship.

This can be applied to the transfer of water or soil down successive sections of a field, or for a whole catchment or grid square. The terms are unambiguously identified and are directly relevant to the erosion mechanics. In many forecasting contexts, confirmation that the mass balance is correct for water and sediment is perhaps the most important single goal, and one that is not always achieved. Most of our physical understanding on sediment movement is based on expressions for the rate of sediment transport, and the storage equation is then the essential link to the rate of lowering at a point.

A second, somewhat looser, but valuable approach is the use of robust relationships which have a clearly defined meaning at a wide range of scales, and which behave in a physically rational way across a wide range of values, including those outside the scope of calibration data. Thus, for example sediment transport should certainly be zero when there is zero runoff, and should normally increase with runoff at all values, other things being equal. An example of such a scaleable approach in the context of water erosion is the runoff threshold. The concept of a runoff threshold provides a simplified summary of the infiltration process. Infiltration capacity is commonly expressed in terms of time elapsed or moisture storage in the soil, for example in the Green-Ampt relationship:

$$f = A + \frac{B}{S}$$

for empirical constants *A* and *B* and soil moisture storage *S*.

The amount of infiltration and runoff is highly sensitive to the rainfall intensity and its history over time, both of which are only available in detail for relatively few sites. Figure 5 shows calculated rainfall-runoff curves for several sets of conditions, showing the great range of outcomes according to both average rainfall intensity and the variability around the mean. Two curves show infiltration under steady rainfall intensities of 20 and 25 mm hr^{-1}. Another curve shows the effect of applying a mean of 20 mm hr^{-1}, but with intensity varying, minute-by-minute as a random exponential distribution about the mean. It can be seen that the total runoff is substantially higher with the varying intensity than with the same mean intensity applied at a steady rate. The curve shown is the average of 10 random realisations, most of which show substantially greater infiltration throughout the simulation. Thus, we need not only mean intensity but a great deal of detail within the storm to estimate infiltration and runoff rates reliably. The last curve shows another random storm, with mean intensities of 5, 20 and 5 mm hr^{-1} for successive hours. As expected, there is less runoff than for 20 mm hr^{-1} throughout, but still very much more than for uniform application at the same overall average intensity of 11 mm hr^{-1}, which would produce negligible runoff. Thus, it is argued that, in the absence of unrealistically detailed rainfall data, a simple threshold and proportional runoff relationship may be more valuable as a working tool than an infiltration equation, even though the latter is theoretically better.

This form may be expressed as:

$$Runoff = p.\ (Rain - Threshold)$$

Where *Rain* and *Runoff* are cumulative totals through a storm and *p* is the proportion of *Runoff* after the *Threshold* has been reached

This type of relationship inevitably shows a large amount of scatter, particularly around the threshold, and this is very apparent for actual storm total data, such as that shown in figure 6. Nevertheless, the family relationship between figures 5 and 6 is clear. In some cases, it may be possible to improve the goodness of fit, for example by separating the data into seasons, for which typical rainfall intensities and ground cover differ.

The MEDRUSH model for catchments of up to 2000 km^2

Two specific examples of upscaling up are described here, based on ongoing research, which takes account of the principles set out in this paper. First, the explicit nesting of representative flow strips within each sub-catchment and of sub-catchments within a larger catchment (MEDRUSH model). Second the application of a SVAT (Soil-Vegetation-Atmosphere Transfer) model, in combination with meteorological, soil, topographic and land cover data, to provide a process based Regional Degradation Indicator (RDI) to estimate water erosion risk at regional to continental scales. Reconciliation across this range of scales is achieved through explicit integration over both time and space frequency distributions, through the application of mass balance for both water and sediment and through the use of robustly derived expressions for the distribution of erosion for cultivated and semi-natural landscapes.

The MEDRUSH model (Kirkby et al, 1997; Kirkby, 1998) is specifically designed to address issues of global change, and so therefore to ensure that interactions at decade time scales are clearly identified and modeled. Figure 7 shows the main inter-relationships modeled to achieve this goal. The four sub-systems of the Atmosphere, Vegetation, Surface, and Soil all necessarily inter-act at every point, and with points up- and down-slope through the requirement for mass balance. For example, the atmospheric sub-system, which generates evapotranspiration, responds to current weather, soil hydrology and vegetation canopy, and in turn influences the growth of the vegetation and part of the loss of soil moisture, which will then influence subsequent overland flow and erosion. Similarly, erosion truncates the soil and adds to the surface armor layer if there is no cultivation, so that the soil hydrological parameters are changed, future erosion acts on lower soil horizons and the surface roughness progressively changes. These interactions create feedback loops which gradually change the course of erosion, most dramatically where it is most severe, and in extreme cases leading to an irreversible loss of the entire regolith layer.

The interactions at each point, indicated in figure 7, are then nested or embedded within a flow strip of variable width which is chosen to represent each sub-catchment (Fig. 8) from the flow lines within it. In order to reduce computation time, one representative flow strip is chosen for each sub-catchment of 5-20 km^2, and the changes in this flow strip extrapolated to the remainder of the catchment. This allows some progressive change in soil and vegetation properties as climate and land use change and as erosion and deposition proceeds over time, although the use of a single representative strip limits the time span over which this extrapolation is a reasonable approximation. In the context of global change, we are currently concerned with a 100-year time horizon. Other methods, including a more complete sampling of flow strips in the catchment, would be needed to extend this approach to longer periods for which the catchment morphology might change significantly. The representative flow strip needs to contain elements of both hillslope and channel, and it has been found that the best choice is the strip, which runs up the centre of the sub-catchment, initially following its main channel-way and then a section of hillslope up to the divide. The strongest reason for using this particular flow strip is that sediment transport in the channels is thought to be the most significant process within the sub-catchment.

Within the flow strip, soil moisture budgets control the development of vegetation and its changes month by month and over a series of years. Using hourly time steps, the processes are explicitly integrated over the distribution of short-term rainfall intensities within the hour, over the micro-topographic and cultivation roughness elements on the hillslope and over the distribution of grain sizes in the soil and in the surface armor. This provides the full range of short and long term dynamic responses without too great a computational overhead.

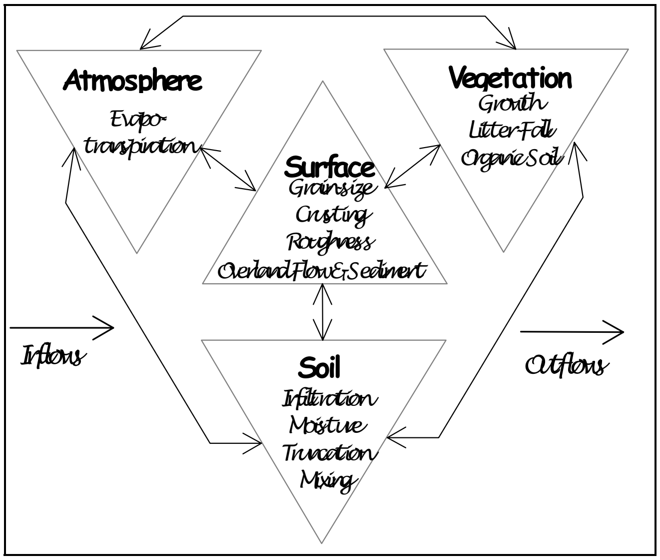

Figure 7. The MEDRUSH model: Fine-scale interactions between sub-systems at a point within a flow strip.

The final level of nesting is the subdivision of the whole catchment of interest into a series of sub-catchments. At present we have restricted the total area to 2000 km^2, with up to 250 sub-catchments, each with its representative flow strip. Sub-catchment size is partly constrained by geometrical considerations, but with a deliberate bias towards smaller sub-catchments in the steeper headwater areas, where erosion tends to be concentrated. A sub-catchment may consist of either a 'leaf' area, which drains from the hillslopes into the head of one or more small unbranched tributaries; or a 'stem' area, which drains hillslopes directly into a downstream channel segment. Computation is carried out separately for each representative flow strip, which delivers water and sediment to the base of its sub-catchment. These flow-strip totals are then scaled up to the complete sub-catchment area to feed water and sediment into the main catchment channel network. Linear transfer functions are then used to route water and sediment through the network to the catchment outlet. Over a period, changes in the forecast flood frequency distribution are used to modify channel and flood plain geometry in accordance with hydraulic geometry relationships (Leopold and Maddock, 1953).

This nested hierarchy is managed within the GRASS GIS, which allows a seamless integration of the C++ model code with GRASS, which is also written in C. The GIS (figure 9) provides an interface for parameter input and graphical visualization of input and output distributions. The complete MEDRUSH model is able to produce forecasts of output sediment and water flux from the whole catchment and all of its sub-catchments, and to map the distribution of erosion and runoff in a generalized way for all sub-catchments. This provides the means to generate a series of replicates of forecast output for periods of up to 100 years, using either present day climate and land use, or decade scenarios generated from Global Climate Models, such as the Hadley Center model, which we are currently applying for southern Europe.

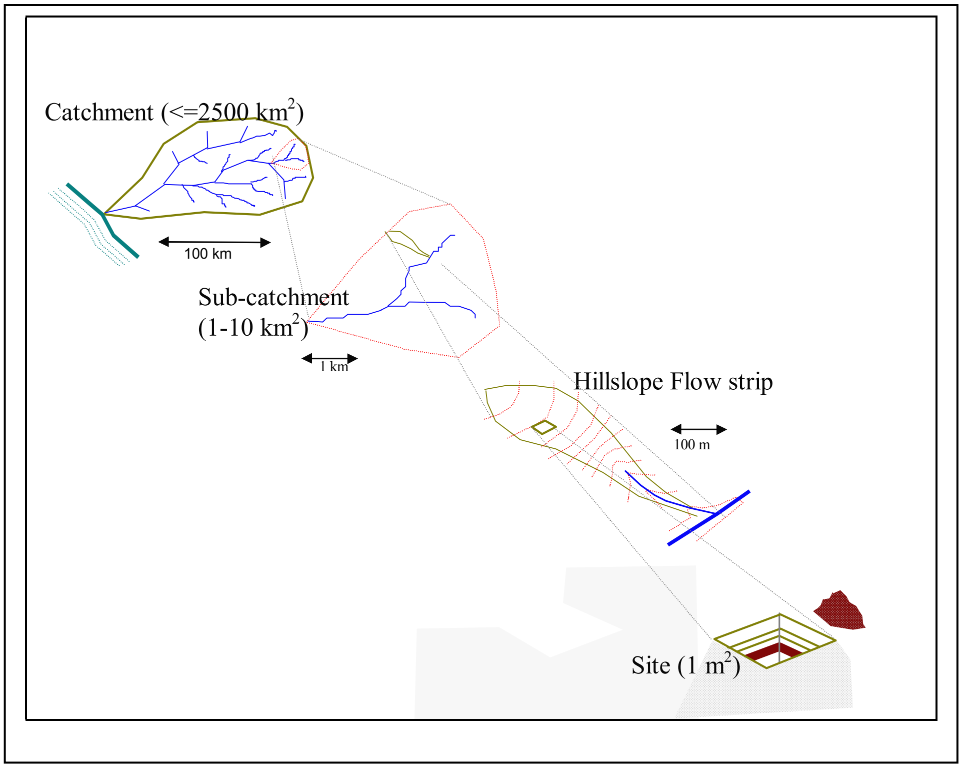

Figure 8. Levels of nesting in the MEDRUSH model: Catchment, sub-catchment, flow strip and site.

The RDI model for estimating erosion risk at regional to continental scales

The second example of upscaling is the Regional Degradation Model (RDI), which provides an estimate of soil erosion risk at regional to continental scales (de Ploey et al, 1991, Kirkby & Cox, 1995, Kirkby et al, in press). This estimate is intended to provide the sediment yield at the base of hillslopes, and does not include any component of channel routing within the stream network. The RDI is normally calculated for regular grid squares of at least 250 m. to 1 km., which should be large enough to include complete hillslope flow paths.

Several assumptions are made to provide a simple physically based erosion indicator. First, runoff is assumed to be by Hortonian Overland Flow, because erosion under this regime is generally greatest; second daily rainfall is used, and it is assumed that daily rainfall represent independent storms, so that no allowance is made for antecedent soil moisture, because the greatest erosion under uncultivated conditions occurs in semi-arid areas where antecedent effects are small. Figure 10 shows the main components of the RDI, which is calculated as the sediment transport calculated at the slope base, divided by the average slope length. Daily runoff is calculated from daily rainfall, using a runoff threshold and proportion of runoff, which are estimated from the land cover and soil properties. At present, the qualitative pedo-transfer functions used are based on individual experience rather than a full validation exercise, and further work is planned to improve these relationships.

The cumulative impact of daily rainfalls can either be derived directly from a historic sequence or, perhaps more usefully for forecasting purposes, from distributions of daily rainfall for each month separately. Daily rainfalls have been successfully fitted to a sum of two exponential distributions, with the parameters estimated from the mean rain per rain-day and its standard deviation.

The effect of changed vegetation, under a near-constant total rainfall, is illustrated in Figure 11, which shows how runoff and sediment yield change together in response to differences in vegetation cover, showing that the strongest effect of vegetation can be expressed through changes in the runoff threshold from about 10 mm for bare ground up to 100 mm or more for a forest cover. Vegetation cover is normally derived either from land-use maps or from remotely sensed data, such as that currently derived from AVHRR at 1 km. resolution. Satellite data has the advantage that it provides a continuously updated record, which responds to both land use change and differences in seasonal conditions from year to year, but it lacks the explicit cultivation diary, which can be associated with surveyed land use data. Soil textural data is also used to provide an estimate of soil moisture storage above field capacity and of the susceptibility of the soil to crusting. The runoff threshold then makes allowance for interception by vegetation, and the development of crusting dictated by the course of plant growth and tillage operations. This methodology provides a clear rationale for distinguishing the hydrological controls on runoff, and of separately estimating erodibility from soil texture and plant stem density.

The cumulative effect of runoff on sediment yield depends on the relationship between discharge or slope length, slope gradient and sediment yield. This sediment transport 'law' must be consistent with three types of experimental data; first from erosion plots, second from the location of stream heads in the landscape and third from the form of slope profiles. These three data sets relate to progressively longer time spans, which bring with them the advantage of including a full range of storm conditions, but the disadvantage, particularly for slope profiles, that they may reflect conditions which are no longer active, in some case reflecting, for example, Pleistocene or pre-cultivation processes and rates. Most are, however, compatible with modified power laws (Kirkby and Bull, 2000) of the form, which is also similar to those applied to fluvial sediment transport:

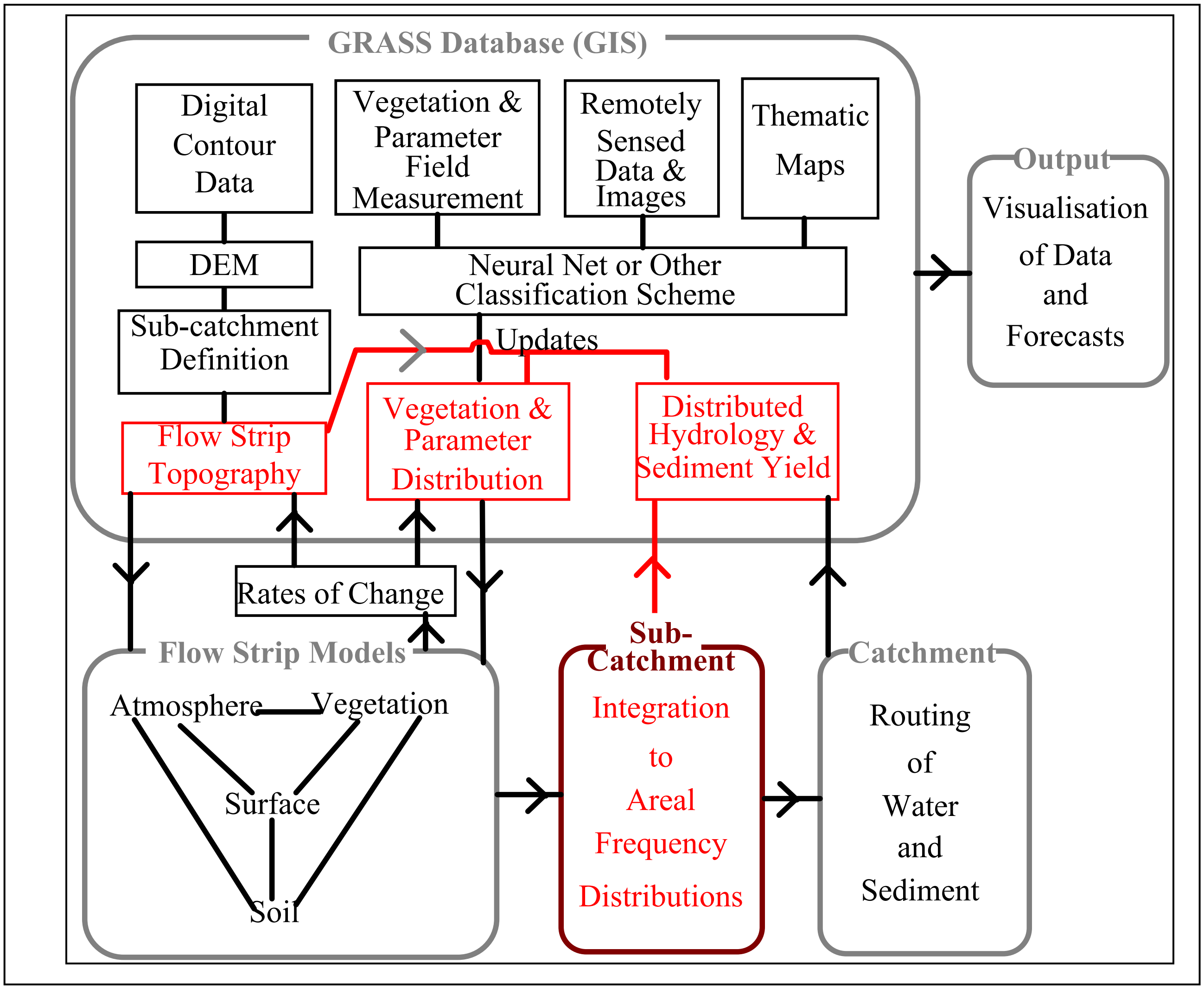

Figure 9. Integration of the MEDRUSH model with the GRASS GIS.

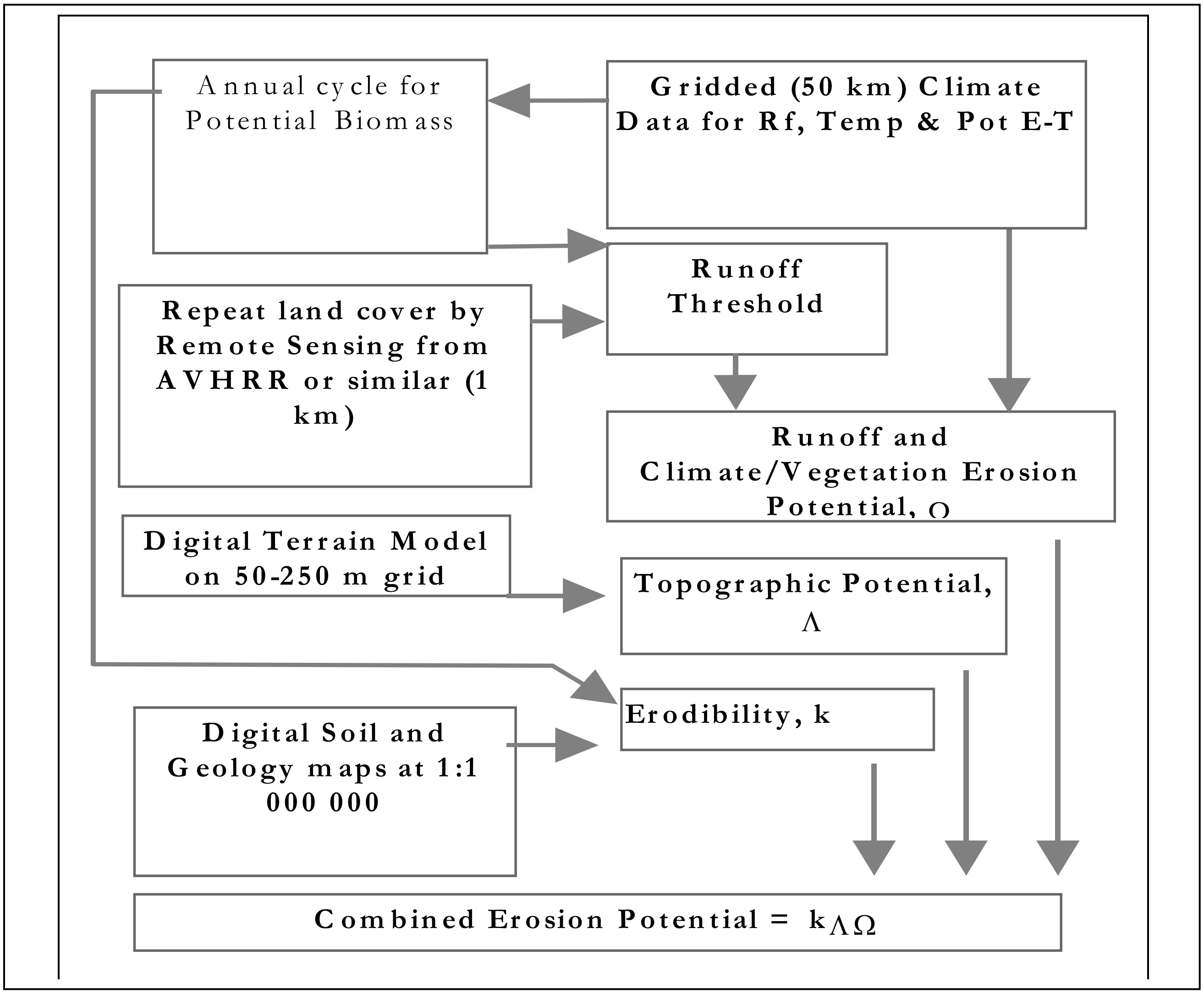

Figure 10. Components and Data required for computation of Regional Degradation Index (RDI)

$$q_s = \kappa g + \mu b q g (qg - \Theta)^b$$

where q_s, q are respectively sediment and water discharge per unit contour width, g is the local slope gradient, Θ is a flow poser threshold, and a, b, κ, and μ are empirical constants.

This form may be formally integrated over the frequency distribution of daily rainfalls to give an expression in terms of distance, in which the first term (κg) is negligible at the slope base. The remainder takes the form:

$$Q_s \propto f(xg)$$

for a defined function *f*.

Ignoring the small rain-splash term above, *f* is approximately a power function in *xg*.

The average sediment loss, *Y*, can then be estimated from:

$$Y = \frac{\int(H)}{L}$$

where H is local relief and L is the mean slope length.

Since the product, *xg* is a good estimator of local hillslope relief. The mean slope length is relatively conservative within an area, and is directly related to regional drainage density. Both of these parameters can be well estimated from maps or digital elevation models.

Thus, the RDI is seen as a rational upscaling of the sediment transport 'law' and at-a-point hydrology to the whole slope scale, and to the estimation of average monthly and annual erosion rates. Although the formulation for an individual flow strip is much simpler than that used for the MEDRUSH model, the explicit nature of the dependence on slope form can be used to cross-calibrate between MEDRUSH and the RDI models in a consistent way. The main differences in principle between the RDI and MEDRUSH models are the different time steps (1 day and 1 hour), and the additional detail in the MEDRUSH model associated with its dynamic response of runoff to short term soil moisture storage, and with the incorporation of grain size and long-term (decadal) interactions which make MEDRUSH the more effective in scaling up to longer time

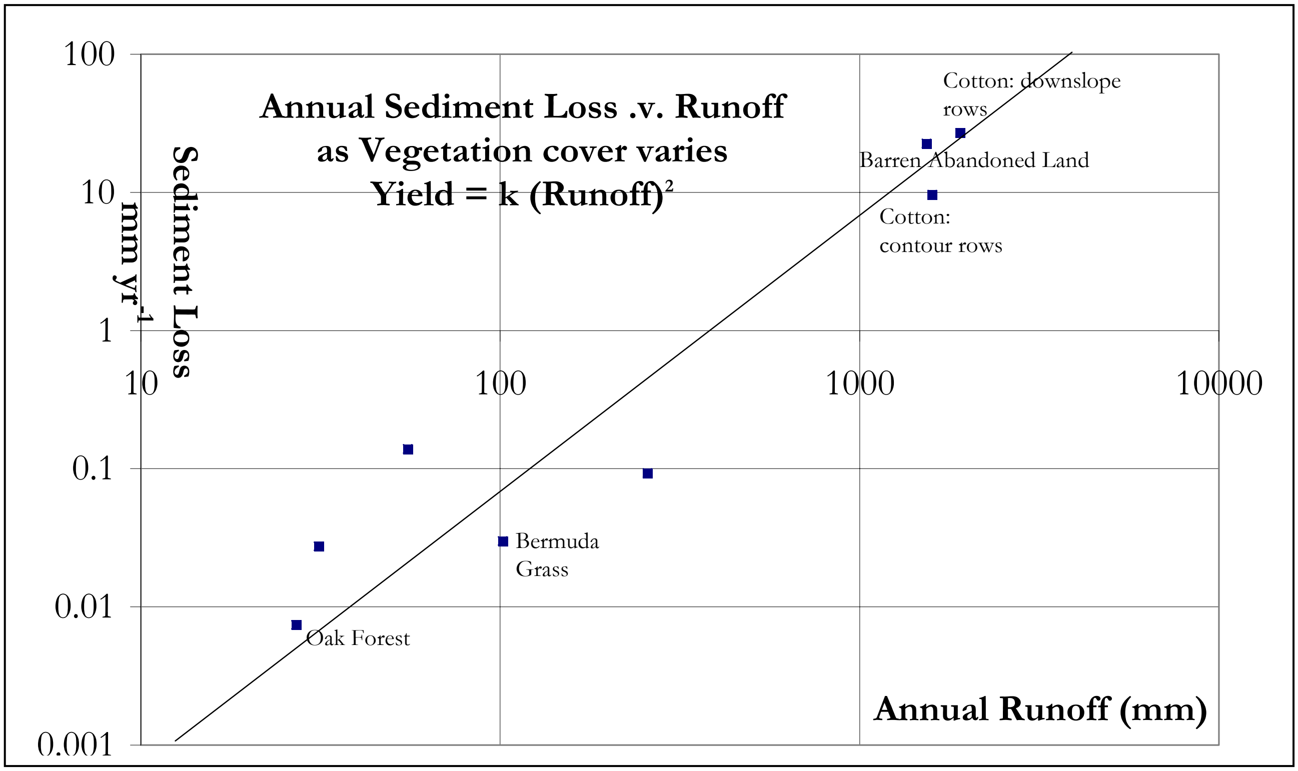

Figure 11: Sediment yield, vegetation cover and runoff from erosion plots at Holly Springs, Mi (after Meginnis, 1935).

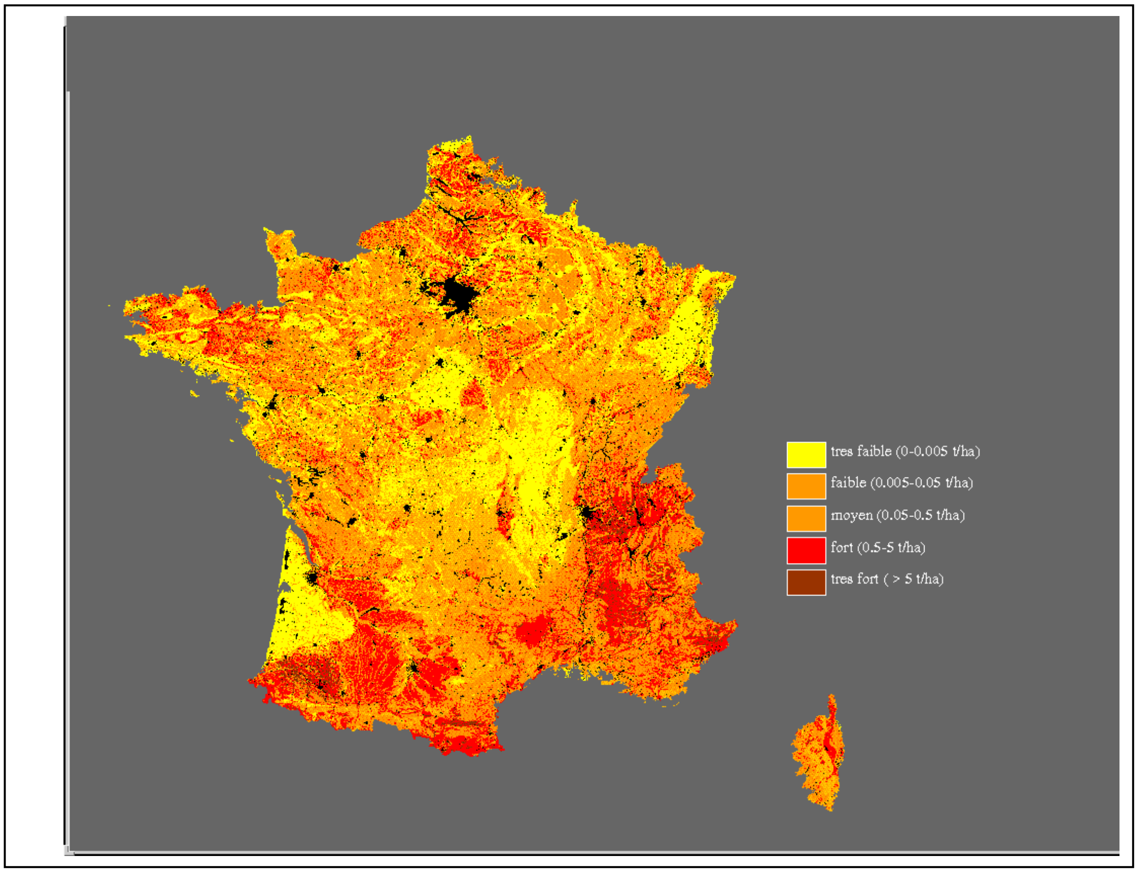

Figure 12: RDI map of France, computed at 250 m resolution.

spans. The results from the RDI are presented as a raster grid, and have no element of channel routing, but the RDI retains an underlying topographic dependence, which is sufficiently explicit to be used in making direct comparisons.

CONCLUSIONS

Although there are inevitably shortcomings in the examples presented, work on the MEDRUSH and RDI models shows that there can be a proper physical basis for constructing coarse-scale models, and that coarse and fine scale models can be linked together consistently, and with a sound physical basis. The practical implementation of these linkages must, however, recognize the existence of emergent variables, which change the dominant process balances between disparate scales. Changes in dominance limit the extent to which models at one scale can be used to validate models at another scale, because there may not be sufficient sensitivity to the newly dominant variables. Thus, for example catchment sediment response may respond much more sensitively to changes in the flood plain than to events on the hillslopes, so that catchment data may not be of much practical value for validation of erosion plot or flow-strip models.

Even though coarse scale models still have many shortcomings, it is clear that fine scale models can never be suitable on their own for grappling with the resource issues of 'The Global Farm'. Equally, coarse scale models on their own can do no more than identify problem areas in an objective way. The future has to lie in a marriage between coarse and fine scale models, and that marriage will be most convincing where there is a true physical compatibility between the principles of the end members. This implies a carefully planned trade-off between the levels of detail and the areas and/or time spans addressed. Coarse scale models must have low levels of detail, both for computability and also because good quality data is scarce at continental and global scales, so that we have to make the best of what there is. US Soil Conservation databases are an important resource for parameterizing and validating relevant global models, but they need to be supported by the collection of existing data for other areas, and the establishment of measurement programs in a global network which deliberately fills the gaps in our conceptual knowledge.

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