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The use of GIS as a tool for modelling ecological change and human occupation in the Middle Aguas Valley (S.E. Spain)

1 Introduction

Recently the use of GIS has become a widely accepted way of dealing with spatial phenomena in archaeology (see e.g., Allen *et al.* 1990). Current research has focused on regional settlement studies and it is clear that the number of applications will continue to grow in the coming years. However, the use of GIS for the reconstruction of past socio-natural environments has two clear limitations: the techniques available in GIS cannot adequately deal with temporalities, and secondly, the representation of social structures in GIS is problematic, partly as a consequence of lack of theoretical context in archaeological GIS applications (Wheatley 1993) and because of the massive availability of environmental cartographic data.

As demonstrated in Verhagen *et al.* (1995), the full potential of GIS for archaeologists still has to be explored, but it is also clear that GIS cannot operate as the single means of analysis for questions relating to prehistoric settlement patterns. For the Middle Aguas Project, an effort will be made to resituate GIS as a part of an integrated modelling framework that will be used to evaluate dynamic models of human-environmental interaction, thereby trying to give GIS its place in a larger theoretical and methodological context. This paper presents the first results of a study in erosion modelling that will be part of the larger modelling effort.

2 The Middle Aguas Project

The Middle Aguas Project is an international, multidisciplinary research project funded by the Directorate General XII of the Commission of the European Union. Its main research goal is the understanding of the variability and magnitude of palaeo-environmental change in the Middle Aguas Valley in southeast Spain (province of Almería) over the past 6000 years. The project mainly builds on previous archaeological research in the area (Castro Martínez *et al.* 1993) and the results of the Archaeomedes Project (Van der Leeuw 1994). Unlike Archaeomedes, which focused on the larger geographical context of the Vera Basin and aimed to study the development of land degradation in the Mediterranean during the Holocene, this project is much more concerned with the local dynamics of human occupation and its relation to the development of socio-natural systems.

2.1 ENVIRONMENTAL CONTEXT

The study area concerned is, for the purpose of this project, referred to as the Middle Aguas Valley, although this is not a physiographically correct name. The area, located on the southern edge of the Vera Basin (fig. 1), covers about 16 by 10 km. The climate is characterized by hot, dry and sunny summers and a mild winter. Precipitation is characteristically in the form of torrential showers or *gotas frias* in autumn and spring. The area is located in one of the driest regions of the European continent with a rainfall of generally between 250 and 300 mm per annum. It should be borne in mind that annual rainfall figures may vary greatly because of the high irregularity of rainfall in the Mediterranean in general (see McGlade 1994). Although the conditions for vegetation do not seem very attractive, the area is in fact very rich in botanical species.

The area shows a considerable variability in topographical features. Elevation ranges from sea-level to 934 meters at the summit of the Sierra Cabrera. Slope steepness is generally considerable in the central area of the sierra, which consists of relatively hard metamorphic rocks of Triassic, Permian and Devonian age. The northern edge of the sierra is formed by softer limestones, marls, sandstones and conglomerates dating from the Miocene and later. This area is characterized by badlands and isolated hills. In the lower parts of the Rio Aguas Valley unconsolidated Quaternary fluvial deposits are found, with dispersed remnants of river terraces. In areas protected from erosion on the flanks of the Sierra Cabrera colluvial deposits are found (Kampschuur/García Monzón 1974).

Agricultural land use nowadays is mainly concentrated along the Rio Aguas, with barley, vegetables and fruit trees being the main crops. The main attraction of this area is the combination of deep soil profiles, flat terrain and easy irrigation. On the older river terraces irrigation is less frequent, and the main crops here are barley, wheat, almonds and olives. The shallower soil profiles on the northern flanks of the Sierra Cabrera are used less for

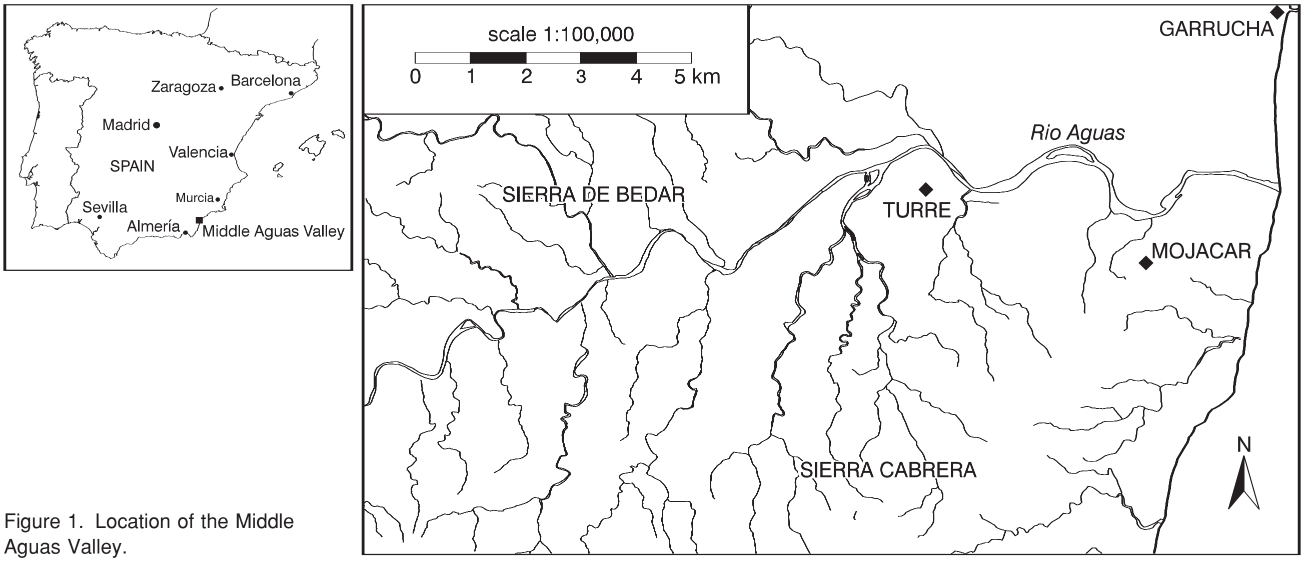

Figure 1. Location of the Middle Aguas Valley.

agriculture. These soils are extremely dry and vulnerable to erosion. Where the slope is more gentle, these soils tend to be used for the cultivation of almonds and olives, and sometimes barley. The ubiquitous terracing found at intermediate altitudes in the Sierra Cabrera is a remnant of the subsistence practices that existed until very recently in this area and date back as far as the Arabic period. In the *ramblas* (dry river beds) terraces were constructed that helped catch the water and fine sediment that comes down via these *ramblas* during rain storms. These terraces have been used to grow olives, almonds and barley but this terracing system is now mostly abandoned. Much of the remaining area was until recently used as grazing land for goats, but this practice has almost come to an end.

2.2 ARCHAEOLOGICAL CONTEXT

The archaeological record of the area indicates that, generally speaking, before the *reconquista* of the area by the Spanish in AD 1492, four 'ecohistorical' periods can be distinguished (McGlade *et al.* 1994). Human occupation evidently started in the Neolithic around 4000 BC. This first occupation phase seems to be characterized by a subsistence strategy of low intensity and high diversity. Only a few settlements have been reported, and they seem to have been short-lived. There is no sign of environmental perturbations in this period, either as a consequence of the diversified land management or as a function of the low population density.

The ensuing period (3000-700 BC) shows a marked contrast in the way the landscape was exploited, and evidences the establishment of social inequalities. Together with an increasing population, the landscape seems to have been subjected to increasing geomorphic instability and aridification. This eventually led to a change in subsistence strategies, culminating in barley monocropping during the Late Agraric period from 1800-1565 BC, accompanied by a shift from the lowland areas to higher ground as well as larger population concentrations in a few settlements. The Argaric system then collapsed, and population densities declined to the level of pre-Chalcolithic occupation. By *c.* 1400 BC, the original deciduous woodland had transformed into a deforested garrigue landscape.

The third period (700 BC-AD 718) again shows a change in exploitation strategies: the area is colonized first by the Phoenicians and their Punic successors and later by the Romans. At first, settlements are concentrated along the coast, where intensive ore mining took place, resulting in deforestation. The Romans introduced their own agricultural system, based on the production of a surplus, which survived until the arrival of the Arabs. This system constituted the most intensive agricultural exploitation of the region until modern times. In this period, the whole area can be seen as a zone of extraction, where resources were being used for the benefit of other parts of the Mediterranean. The result of this strategy was an increasing land degradation and aridification, although the system did not collapse.

The Arabic conquest in AD 718 again induced a change in subsistence strategies with the introduction of irrigation. The production system in this period was organized in such a manner that it could provide sufficient means of subsistence to each social unit, and seems to have been relatively well adapted to the environmental circumstances, an achievement that was never reached in succeeding periods.

3 Erosion modelling and archaeology

One of the key elements in the process of land degradation in the Mediterranean is obviously (water) erosion. The first interest in erosion came from agronomers, seeking to predict the consequences of erosion for agricultural land use. Various quantitative models to predict soil loss through erosion have been proposed over the years (see De Roo 1993), which have demonstrated that the process of erosion is a complex, dynamic phenomenon which can be observed at various spatial and temporal scales. Until now no attempt has been made to apply currently available quantitative erosion models to past phases of erosion. It is assumed here that these quantitative erosion models may have two major contributions to archaeology. Firstly, the results of the model may be interpreted in maps of zones where archaeological remains have or have not been preserved, and may therefore be helpful in field surveys and in the interpretation of the observed settlement patterns. Secondly, the erosion model may be able to provide insight into the development of erosion through time by means of scenario building. Using archaeological, palaeo-ecological and palaeo-pedological data, we can attempt to identify the dynamics of erosion in the past and its influence on human-environmental interaction.

In the Middle Aguas Project, the erosion model will be used as part of a larger modelling effort that aims to reconstruct the palaeo-environment of the Middle Aguas Valley for some selected cultural phases and areas. The approach chosen heavily depends on two techniques, namely GIS and ecological dynamic modelling (see McGlade 1995). During the Archaeomedes Project, both have proved their use as tools for 'experimental archaeology', but the incorporation of a spatial element into the dynamic modelling and, conversely, a temporal element into the GIS was not possible within the scope of Archaeomedes. An important objective of the research in the Middle Aguas Project is to implement this connection of GIS and dynamic modelling. Erosion modelling, as a relatively well-developed branch of modelling, is considered a good starting point for this integration that will provide useful data on the erosion processes in the Middle Aguas Valley over the past 6000 years.

3.1 DIFFERENT TYPES OF EROSION MODELS

Several distinctions can be made between erosion models. The first and most obvious one is between quantitative and qualitative models. Models that apply a formula of some kind are referred to as quantitative. The best known example is the Universal Soil Loss Equation or USLE (Wischmeier/Smith 1978), which aims to predict soil loss on the basis of five empirically established parameters. A quantitative model however is not necessarily more reliable than a qualitative model: in the case of the CORINE erosion assessment methodology (Commission of the European Communities 1992) the application of a qualitative model was preferred over a quantitative one for reasons of data availability and resolution. In fact, the USLE has been rather suspect for a number of years as the empirically established parameters were only valid for certain parts of the USA. This has led to a wave of so-called physically based models that try to predict soil loss on theoretical grounds.

Secondly, there is a fundamental difference between so-called lumped erosion models and distributed models. Distributed models are models which take into account the spatial component of erosion, and have become more popular with the increasing availability of GIS software and more powerful computers. The third distinction that can be made is between 'static' and dynamic models. The first category aims at providing predictions of soil loss: the procedure followed is essentially a one-way sequence. Dynamic models on the other hand incorporate the idea of change, using time series and feedback loops (see e.g., McGlade 1994). Sofar, there are no models available that are quantitative, distributed *and* dynamic.

3.2 PRACTICAL IMPLICATIONS

If we want to use an erosion model of any kind, we will have to define within which limitations it will have to operate. When considering experiments for modelling erosion in the past, it will be clear that a spatial scale is required that is compatible with the scale of a settlement's exploitation zone. Currently, a number of modelling approaches is only considering soil loss on the spatial level of hill slopes or fields, which introduces an element of uncertainty in the results of the models for larger areas.

Secondly, as we are not so much concerned with the precise prediction of soil loss in kg/ha, but rather with the identification of the spatial and temporal development of the erosion dynamics, it is not necessary to use models that aim at extreme accuracy. Especially the available physically based models require a very large amount of input data, that can only be obtained through time-consuming field measurements and experiments. It was shown by De Roo (1993) that this investment in time does not necessarily yield an equal improvement in the modelling results.

Most models available at this moment do not fulfil these criteria, not to mention the fact that they do not incorporate the equally important process of sedimentation. However, there is little use in developing another 'new' model when time and money do not allow us to validate it. Therefore, it is proposed to evaluate one or more existing models and see how these can be integrated with GIS and dynamic

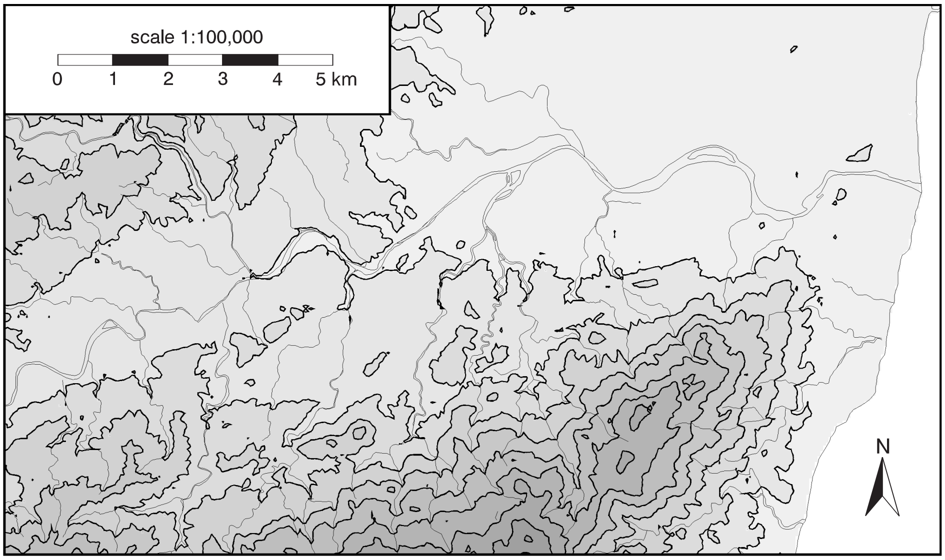

Figure 2. Digital Elevation Map of the Middle Aguas Valley. The contour interval is 100 metres.

modelling. Relatively simple models like the Revised Universal Soil Loss Equation or RUSLE (Renard *et al.* 1987) are supposed to yield realistic results in a wide range of circumstances. It is supposed that these models can therefore be relatively easily adapted to an environment of dynamic modelling procedures.

3.3 Parameters involved and their assessment

Erosion can be thought of as a product of three factors: erosivity, erodibility and transport of eroded material. Of these three, erosivity is synonymous with climate: the kinetic energy of rainfall is the process that starts (water) erosion. Climate operates at a spatial and temporal scale which justifies its interpretation as a constant over long periods of time and usually also over relatively large areas. The climate pattern itself however can be highly variable, especially in an area like the Middle Aguas Valley. Values for the intensity of erosive rain are difficult to obtain, and even more so data on the temporal distribution of these intense rainstorm events.

Erodibility, or the sensitivity of the surface to erosion, is dependent on the vegetation, soil and terrain slope. Plant cover, responsible for the protection of the surface, changes over the year and through the years, which makes it a difficult factor to incorporate in a model that aims to monitor soil loss on a larger time scale. With the aid of remote sensing, the current plant cover can be estimated, but for an archaeological experiment the application of palaeo-botanical data will be inevitable.

Slope, which determines whether eroded material can be transported, is relatively easily and accurately determined using a Digital Elevation Model (DEM) and is a supposedly independent variable over relatively long time periods. For the Middle Aguas Project, a DEM (fig. 2) has been interpolated using regularized spline with tunable smoothing and tension (Mitášová/Mitaš 1993) from 1:10,000 topographic maps (vertical contour interval 10 m) and is expected to be of good quality, although of course the situation in the past may have been different.

The soil factor is usually given most consideration in current models, as it is the most difficult to assess given the enormous spatial variability of soil types. The soil characteristics themselves that determine the rate at which soil can be eroded can only be assessed through soil mapping. The principal constraint of using standard soil maps is their limitation to chloropleth mapping, which ignores (or at least does not quantify) the considerable spatial variability within mapping units, hence the focus of most researchers on the improvement of methods to estimate this variability (see e.g., Burrough 1993). The existing soil map 1:100,000 of the area is clearly insufficient for the estimation of the desired parameters, and additional data will have to come from satellite imagery and field survey.

Lastly, for the estimation of the transport of water and eroded material, several methods of determining cumulative overland flow from DEMs have been incorporated in various GI systems. This is basically a hydrological problem; the transport of water is a function of rainfall, infiltration and runoff, and the transport of eroded material is determined by the amount of overland flow generated and the transport capacity.

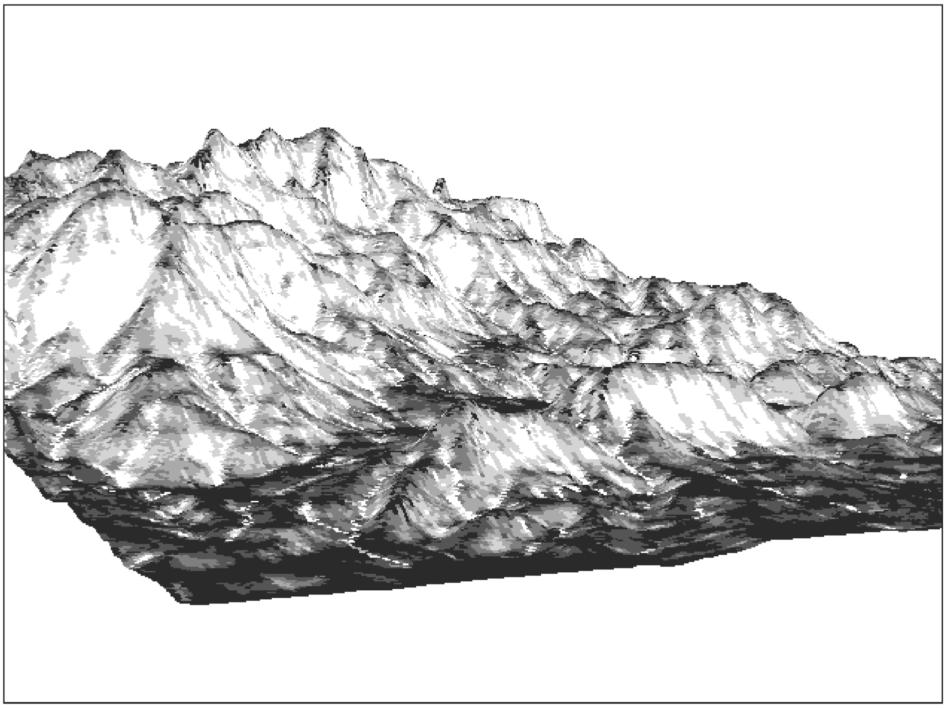

Figure 3. Map of sediment transport capacity draped on DEM. View from the NNE on a section of the Sierra Cabrera around La Alcantarilla of approximately 3 by 4 km. Pixel size is 10 by 10 metres, vertical exaggeration 1.5 times. Light colours indicate high transport capacity rates, dark colours indicate low values.

3.4 SOME PRELIMINARY RESULTS

The collection of the necessary environmental data will be an ongoing part of the project, and at this moment not all the desired data is available to present a complete erosion model. However, it was possible to produce some first results with regard to topography. The main objective of a distributed erosion model is to adequately model the transport of sediment through space. With the advent of better interpolation methods for elevation data and more sophisticated techniques for the calculation of derivatives (gradient, aspect and curvature) it is possible to arrive at more realistic interpretations of the sediment transport than was formerly possible within the context of e.g. the RUSLE. In the RUSLE, the so-called LS or *length-slope* factor, which is equivalent to the sediment transport capacity, was calculated without the inclusion of flow convergence and divergence, and could only be applied to areas experiencing net erosion (Mitášová *et al.* in press). In order to give a more realistic estimation of transport capacity, Moore and Burch (1986a) proposed to use the 'unit stream power based LS factor' that incorporates the upslope contributing area. The potential for erosion and deposition (Moore/Burch 1986b) could then be defined as the change in sediment transport capacity in the direction of flow. Using the techniques described in Mitášová *et al.* (1995) it was possible to create maps of transport capacity and erosion potential for a selected region on the north flank of the Sierra Cabrera. The upslope contributing area, defined as the area from which the water flows into a given grid cell, can be computed by determining the sum of grid cells draining into a cell. The *r.flow* program in GRASS, developed by Mitášová and Hofierka (1993), provides an improved method of determining this upslope contributing area and takes into account the fact that water flow converges in channels. The application of this parameter to the unit stream power based LS factor calculation, shows that transport capacity (fig. 3) dramatically increases in stream channels, and decreases on concave slopes where deposition is supposed to occur, which gives a far more realistic interpretation of the erosion potential of a landscape than using the standard tools in GRASS for determining cumulative overland flow. We may be able to use these maps for the identification of zones where the regime of erosion and deposition has changed through time.

The maps show that in areas of decreasing gradient local deposition may occur, even in the higher reaches of the sierra. It should therefore be possible to simulate the effects of terraced agriculture, which effectively diminishes the transport capacity.

The method for determining upslope contributing area is restricted by the accuracy of the DEM: a pixel size of 2-10 m is desired, which limits its use for larger areas, and the tracing of overland flow stops at barriers or points with zero gradient. Most DEMs however, especially in highly irregular terrain like the Sierra Cabrera, will contain interpolation artefacts like pits and bumps in places where in fact flow is not obstructed. This means that for a realistic modelling of transport capacity the DEM should be near perfect, which involves time consuming post-processing in order to eliminate the undesired interpolation errors.

4 Concluding remarks

The results presented here show that there is a still a long way to go in order to make quantitative erosion modelling accessible to archaeologists, and even a longer way to integrate it into a dynamic modelling framework. Nevertheless, the potential of the existing techniques is promising as is shown by the modelling of sediment transport capacity. The main problem encountered in making these techniques operative will be the availability of data: the existing information on soils, vegetation, climate and topography will in most cases be insufficient for quantitative erosion modelling studies, and requires the input of knowledge from other disciplines. On the other hand, once these conditions are fulfilled, the use of such models may help clarify the history of erosion and deposition of an area and provide new insight into the way in which human subsistence strategies and environmental circumstances influence each other. It is expected that the Middle Aguas Project will give us an excellent opportunity for this kind of experiments.

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references

Allen, K.M.S.
S.W. Green
E.B.W. Zubrow (eds)
1990 *Interpreting Space: GIS and Archaeology*. London: Taylor & Francis.

Burrough, P.A.
1993 Soil variability: a late 20th century view, *Soils and Fertilizers*, 56 (5), 529-562.

Castro Martinez, P.
E. Colomer
S. Gili
P. Gonzalez Marcen
V. Lull
R. Mico
S. Monton
M. Picazo
C. Rihuete
R. Risch
M. Ruiz Parra
M.E. Sanahuja-Yll
M. Tenas
1993 Proyecto Gatas: sociedad y economía en el sudeste de España c. 2500-800 a.n.e. In: *Investigaciones Arqueológicas en Andalucía 1985-1992, Proyectos*, 401-416, Huelva: Consejería de Cultura y Medio Ambiente de la Junta de Andalucía.

Commission of the
European Communities
1992 *CORINE soil erosion risk and important land resources in the southern regions of the European Communities*. Luxembourg: Office for Official Publications of the European Communities.

De Roo, A.P.J.
1993 *Modelling surface runoff and soil erosion in catchments using Geographical Information Systems*. Nederlandse Geografische Studies 157, Utrecht, PhD thesis.

Kampschuur, W.
G. Garcia Monzon
1974 *Mapa Geológico de España escala 1:50.000, 1031 Sorbas*. Madrid: Instituto Geológico Y Minero de España.

McGlade, J.
1994 Dynamics of change in the human-modified environments of the Vera Basin. In: S.E. van der Leeuw (ed.), *Understanding the natural and anthropogenic causes of soil degradation and desertification in the Mediterranean Basin, Volume 2: Temporalities and Desertification in the Vera Basin*, 143-295, Brussels: Commission of the European Union.

1995 Archaeology and the ecodynamics of human-modified landscapes, *Antiquity* 69, 113-132.

McGlade, J.
P. Castro
M.A. Courty
N. Fedoroff
M.K. Jones
1994 The Socio-ecology of the Vera Basin: towards a dynamic reconstruction. In: S.E. van der Leeuw (ed.), *Understanding the natural and anthropogenic causes of soil degradation and desertification in the Mediterranean Basin, Volume 2: Temporalities and Desertification in the Vera Basin*, 297-321, Brussels: Commission of the European Union.

Mitášová, H.
J. Hofierka
1993 Interpolation by Regularized Spline with Tension: II. Application to Terrain Modelling and Surface Geometry Analysis, *Mathematical Geology*, 25, 657-669.

Mitášová
Mitaš, H.
L. Mitaš
1993 Interpolation by Regularized Spline with Tension: I. Theory and implementation, *Mathematical Geology*, 25, 641-655.

Mitášová, H.
J. Hofierka
M. Zlocha
L.R. Iverson
in press Modelling topographic potential for erosion and deposition using GIS, *International Journal of Geographical Information Systems*.

Moore, I.D.
G.J. Burch
1986a Physical basis of the length-slope factor in the Universal Soil Loss Equation, *Journal of the Soil Sciences Society of America*, 50, 1294-1298.

1986b Modelling erosion and deposition: topographic effects, *Transactions of the ASAE 29*, 1624-1630 and 1640.

Renard, K.G.
G.R. Foster
G.A. Weesies (coordinators)
1987 *Predicting soil erosion by water – A guide to conservation planning with the revised Universal Soil Loss Equation*. Tucson: ARS Aridland Watershed Management Center USDA.

Van der Leeuw, S.E. (ed.)
1994 *Understanding the natural and anthropogenic causes of soil degradation and desertification in the Mediterranean Basin, Volume 2: Temporalities and Desertification in the Vera Basin*. Brussels: Commission of the European Union.

Verhagen, P.
J. McGlade
S. Gili
R. Risch
1995 Some Criteria for Modelling Socio-Economic Activities in the Bronze Age of south-east Spain. In: G. Lock/Z. Stančič (eds), *Archaeology and Geographic Information Systems: A European Perspective*, 187-209, London: Taylor & Francis.

Wheatley, D.
1993 Going over old ground: GIS, archaeology and the theory of perception. In: J. Andresen/ T. Madsen/I. Scollar (eds), *Computing the Past, Computer Applications and Quantitative Methods in Archaeology CAA92*, 133-137, Aarhus: Aarhus University Press.

Wischmeier, W.H.
D.D. Smith
1978 *Predicting rainfall erosion losses – a guide to conservation planning*. Agricultural Handbook No. 537. Washington D.C.: Science and Education Administration USDA.

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