

1 Introduction

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The movement of sediment and associated pollutants over the landscape and into water bodies is of increasing concern with respect to pollution control, prevention of muddy floods and general environmental protection. This concern exists whether the sediment is derived from farmland, road banks, construction sites, recreation areas or other sources. In today's environment it is often considered of equal or even greater importance than the effects of loss of soil on-site, with its implications for declining agricultural productivity, loss of biodiversity and decreased amenity and landscape values. With the expected changes in climate over coming decades, there is a need to predict how environmental problems associated with sediment are likely to be affected so that appropriate management systems can be put in place.

Whilst it is possible to instrument a few individual farms and catchments in order to obtain the data to evaluate the current situation and propose best management practices, it is not feasible to study every location on the Earth's surface in detail. Instead, evaluation and predictive tools need to be applied to assess current problems, predict future trends and provide a scientific base for policy and management decisions. Erosion models can fulfil this function provided that they are robust and used correctly. Despite, or maybe even because of, the vast amount of research over

the last 30 years or more on erosion modelling, potential model-users are confronted with a multiplicity of models from which to choose, often with little guidance on which might be the best for particular circumstances or the steps required to apply a selected model to a given situation. Many models have been tested for only a limited range of conditions of climate, soils and land use, and little information is available to enable a user to assess in advance how well a model might perform under different conditions. Models range from empirical to physically- or process-based, and vary considerably in their complexity and the amount of data input required. Very little guidance is available on how accurate that data input has to be, or what effect different levels of accuracy can have on the accuracy of the model output. Further, sediment problems can exist at scales that range from a farmer's field or a small construction site to the effects of sediment transport and deposition in small and large catchments. Somewhat limited information exists on the range of scales over which different models can operate successfully, leaving the user uncertain on whether a particular model is the most appropriate for a given scale. In the worst case, as a result of a lack of clear guidance, the user may choose a totally inappropriate model.

Users can obtain a list of the leading soil erosion models from the Internet site http://soilerosion.net/doc/models_menu.html. Links are provided to other sites associated specifically with each model from which the software can be

Table 1.1 Erosion models used in the case studies.

Title	Sources	Case studies
EUROSEM	Morgan <i>et al.</i> (1998) http://www.es.lancs.ac.uk/people/johnq/EUROSEM.html	Chapter 5
GUEST	Misra and Rose (1996)	Chapter 11
LISEM	Jetten and de Roo (2001) http://www.itc.nl/lisem	Chapter 12
Modified MMF	Morgan and Duzant (2008)	Chapter 13
RUSLE	Renard <i>et al.</i> (1997) http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm	Chapter 8
SHETRAN	Ewen <i>et al.</i> (2000) http://www.ceg.ncl.ac.uk/shetran	Chapter 14
SIBERIA	Willgoose <i>et al.</i> (1991) http://www.telluricresearch.com/siberia_8.30_manual.pdf	Chapter 18
WEPP	Flanagan and Nearing (1995) http://topsoil.nserl.purdue.edu/nserlweb/weppmain/wepp.html	Chapters 9, 10, 15, 16

downloaded along with the user manual. Whilst the majority of the links are valid and the site is a useful starting point for finding out what models exist, there are some links which are out-of-date and either do not work or are no longer the most appropriate. Clearly no such site can be fully comprehensive, and there will inevitably be some models which are not included. Table 1.1 lists the models which are used in this Handbook together with details of published sources and, where they exist, relevant Internet sites. Knowing which models are available is only a starting point. As indicated above, the user needs advice on how well the models perform and the conditions to which they can be applied. Previous experience with the models is extremely valuable, particularly where the output of several models is compared for the same conditions. Boardman and Favis-Mortlock (1998) discussed the performance of various models when applied to common sets of data at a hillslope scale, and De Roo (1999) presented the results of a similar exercise carried out at a small catchment scale. More recently, Harmon and Doe (2001) provided details of a range of models, physically-based and empirical, which can be used over various spatial and temporal scales to assess the short- and long-term effects of different land management strategies. These publications,

however, describe erosion models more from a research than a user perspective. Although they are a source of useful information, they do little to help potential model users to answer the questions raised earlier, or to guide them in the selection of the most appropriate model for a specific application, taking account of the objectives, the environmental conditions and the availability of data. Also, since their publication, there has been an increasing use of geographical information system (GIS) techniques in analysing data for planning and decision-making, and erosion models have been increasingly integrated into geospatial systems, particularly at large catchment and regional scales.

The *Handbook of Erosion Modelling* seeks to address these issues and provide the model user with the tools to evaluate different erosion models and select the most appropriate for a specific purpose, compatible with the type of input data that are available. The book is aimed at model users within government, non-governmental organisations, academic institutions and consultancies involved in environmental assessment, planning, policy and research. The intention is to give existing and potential model users working in the erosion control industry greater confidence in selecting and using models by providing an insight

into what users can expect of models in terms of robustness, accuracy and data requirements, and by raising the questions that users need to ask when selecting a model that is appropriate to the type and scale of their problem. It is important that users understand both the advantages and limitations of erosion models.

The Handbook is arranged in two main parts. The first part introduces the user to some important generic issues associated with erosion models. Chapter 2 sets out the various stages that a user should go through when selecting and applying an erosion model, and shows that these are much the same as erosion scientists adopt when developing their models. There is much common ground between model developers and model users, probably more so than most users are aware of. The next four chapters take key issues and discuss them in detail, along with solutions which model users might adopt. Chapter 3 looks at the question of calibration. This is a controversial topic with opinions ranging from those who consider that it is impossible to calibrate the more complex, physically-based models and those who believe that calibration is essential. This chapter is broadly in favour of calibration, showing how it can improve the quality of predictions both in terms of erosion rates and the spatial distribution of erosion. Chapter 4 raises the issue of uncertainty in model predictions. After discussing why we should worry about uncertainty, various approaches are described which can be used to reduce the level of uncertainty. How successful these are depends on the causes of the uncertainty, and model users need to be encouraged to appreciate and understand these. Uncertainty is taken further in Chapter 5, which shows how one approach is used in practice with reference to the application of one specific erosion model. Chapter 6 reviews the issues posed by scale. Many problems faced by users relate to a single scale, be it field, hillslope, small catchment or large catchment, but others need to be addressed at a range of scales. This chapter looks at the problems involved when moving from one scale to another with the difficulty of modelling interconnectivity between hillslope and river systems. At present there are

few solutions to the problems that arise when modelling across a range of scales, but several ideas for further research are presented whereby model development and data collection need to become more fully integrated. Chapter 7 shows the importance of choosing the right model for a specific problem and scale, and the implications of using inappropriate models. A frequent occurrence is the misunderstanding by the user of either the problem being addressed or what specific models are able to achieve. Although a dynamic process-based model is often the best choice, there are many situations in which it will not perform better than a simpler statistical model.

Part 2 of the Handbook looks at specific applications and shows how models are used in practice. Each chapter is really a case study in which a problem commonly faced by environmental planners, consultants and managers is presented. An appropriate model is then chosen and the user is taken through the various steps involved in setting-up and applying the model and interpreting its output. Table 1.2 lists the applications under broad subject headings and for each one identifies the relevant chapter and the spatial scale (erosion plot, field, catchment, region) of the problem being considered. Additional information is provided on the temporal scale, which ranges from individual events to mean annual conditions and long-term landform evolution.

Taking each chapter in turn, Chapter 8 reviews the issues typically faced by field officers of the Natural Resources Conservation Service of the US when predicting erosion from agricultural land and planning soil protection measures. Chapter 9 takes a specific example of a small watershed in southwest Missouri and shows how modelling can assist in designing a strategy for sustainable management under both present land use and climatic change. In Chapter 10, modelling is used to predict rates of soil loss in Brazil from hillslopes on forest roads in São Paulo State and from agricultural land under different management systems in Minas Gerais State. Chapter 11 examines how a physically-based erosion model can be used to assess soil erodibility and evaluate different soil

Table 1.2 Issues covered by the erosion modelling applications in the Handbook, together with their spatial and temporal scales.

	Plot (1–100 m ²)	Field/hillslope (100–10,000 m ²)	Small catchment (1–500 ha)	Medium catchment (500 ha to 1500 km ²)	Regional
Agriculture	10 (SP) 11 (MA)	5 (E) 8 (MA SP) 13 (MA) 15 (A MA)	9 (MA SP R) 12 (E) 15 (A MA)	15 (A MA)	15 (A MA)
Forestry	10 (SP)	16 (D A RP)	16 (D A RP)		
Construction		8 (MA SP)			
Mine waste		18 (SP LE)			
Land-use change	14 (MM MA SP)	14 (MM MA SP)	9 (MA SP R) 12 (E) 14 (MM MA SP)		
Climate change	14 (MM MA R)	14 (MM MA SP) 15 (A MA)	9 (MA SP R) 14 (MM MA SP) 15 (A MA)	15 (A MA)	15 (A MA)

Numbers in each cell refer to the chapter, and the letters indicate the temporal scale of model outputs in the applications described (E, event; D, daily; MM, mean monthly; A, annual; MA, mean annual; SP, set period of time; R, return period; LE, long-term landform evolution).

conservation practices at four different locations on tropical steeplands, one in China, one in Malaysia and two in Thailand.

The evaluation of sediment yield from a small catchment in a highly erodible area is the focus of Chapter 12, based on a case study on the loess plateau of China. Chapter 13 addresses a problem at a very different scale, namely the transfer of sediment from individual fields to watercourses in southwest England. Chapter 14 returns to the catchment scale, using a model to examine the impacts of land use and climate change on erosion and sediment yield in small river basins where hillslope erosion, river channel and bank erosion and landslides are all important components of sediment production. Chapter 15 is also concerned with assessing the impacts of climate change, but this time over a range of spatial and temporal scales from hillslope to regional and continental. There is no single model that can apply to all situations, and several models are reviewed. Chapter 16 looks at the risk of erosion in forested areas in Montana, US, following disturbance either by timber harvesting or wildfire. Chapter 17 discusses the potential of the Internet

as both a source of data and a vehicle for operating erosion models to address problems of environmental management. Chapter 18 examines the role of longer-term landscape evolution models (LEMs) for designing hillslope landscapes to encapsulate and contain mining waste. Chapter 19 reviews the question of modelling gully erosion. Although there is no specific gully erosion model that can be recommended, various approaches that a user can adopt are described.

The Handbook ends with a review of the state-of-art of erosion modelling, as illustrated by the case studies, and discusses the developments that users can expect in the near future. These include the inclusion of more models within geospatial frameworks, associated improvements to modelling across different scales, and the increasing use of web-based approaches and risk-based applications. It is hoped that, by combining a general review of the principles of erosion modelling with examples of model applications across a range of management issues, the Handbook will enable potential users to employ models in a more informed way. Hopefully, managers, decision-makers and policy-makers within the erosion

control industry will be encouraged to make more use of models to evaluate present situations, the impacts of control measures and future policies. In addition, model developers may be encouraged to provide better information to model users about the suitability and limitations of their models and what levels of accuracy in prediction they are likely to achieve.

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