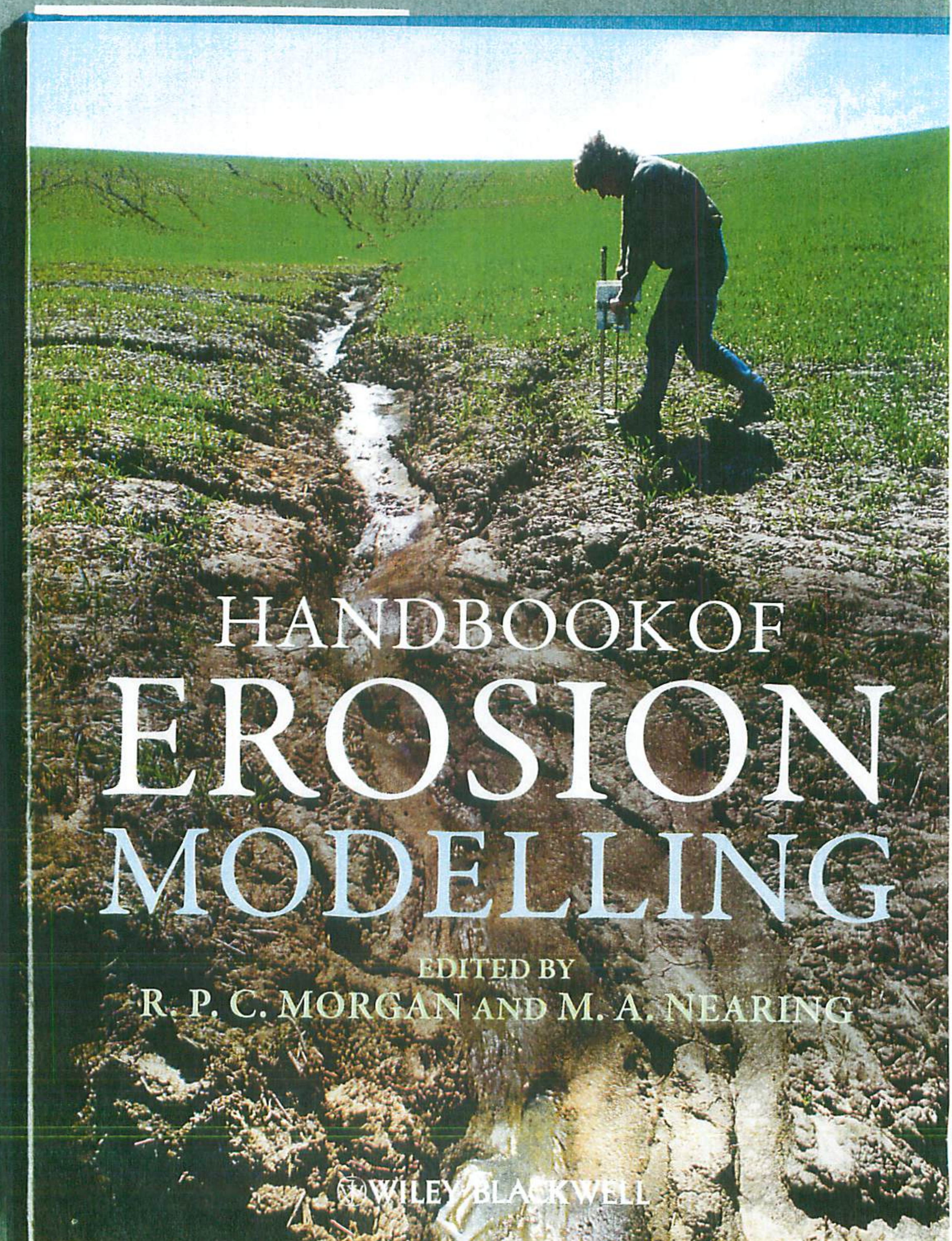

HANDBOOK OF EROSION MODELLING

EDITED BY

R. P. C. MORGAN AND M. A. NEARING

WILEY-BLACKWELL

Handbook of Erosion Modelling

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17 The Future Role of Information Technology in Erosion Modelling

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17.1 Introduction

Natural resource decision-making is a complex process requiring cooperation and communication between federal, state and local stakeholders, balancing biophysical and socio-economic concerns. Predicting soil erosion is common practice in natural resource management for assessing the effects of management practices and control techniques on soil productivity, sediment delivery and offsite water quality. Effective decision-making requires the integration of knowledge, data, simulation models and expert judgment to solve practical problems, and to provide a scientific basis for decision-making at the hillslope or watershed scale (National Research Council, 1999).

A user-friendly decision support system (DSS) would assist different professional or stakeholder groups to develop, understand and evaluate alternative soil conservation strategies. The DSS could integrate a suite of components consisting of database management systems (DBMS), geographic information systems (GIS), simulation models, decision models, and easy-to-understand user interfaces. The difficulty in developing a DSS is not a lack of available data or simulation models for erosion prediction, but rather making these models available to decision-makers, a key observation made by the National Research Council's Committee on Watershed Management (National Research Council, 1999). Over the last 50 years the federal government has spent millions of dollars on the creation of spatial datasets and model development. While these simulation models are used extensively in research settings, they are infrequently incorporated into the decision-making process. Another aspect of erosion modelling is the continued use of simpler, empirically-based erosion models (e.g. USLE, RUSLE) instead of more complex, physically-based models (e.g. WEPP, EUROSEM). Reasons for this exclusion include: data requirements are usually only attained in a research setting; models are complex and underlying assumptions are poorly understood by resource managers; deriving model input parameters is extremely time-consuming and difficult; and the models are difficult to use with the current interfaces.

For example, Elliot (2004) reported that between 1993 and 1998 over 200 Forest Service specialists were trained to use the USDA Water Erosion Prediction Project model (WEPP) (Flanagan & Livingston, 1995; Elliot & Hall, 1997). Of those specialists, only three or four (or 2%!) subsequently applied the model because the interface was too difficult to operate and too much time was required to assemble the data and interpret the results. Occasional users found it difficult to keep track of which combinations of input files should be used for typical forest and range conditions. Some users were observed to

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specify unlikely combinations of soil and management files on these highly flexible interfaces, such as specifying a high severity fire soil in combination with a forest road management file.

Part of this problem can be addressed with improvements to model interfaces, lookup tables for model parameters, and internal file management (Hall & Elliot, 2001; Flanagan *et al.*, 2001). However, as erosion models continue to become more complex and integrate with other technologies, users will be required to have experience in DBMS, GIS, computer operating systems, remote sensing, Internet search engines for data gathering, and graphics, as well as a good foundation in erosion process knowledge. Few professionals have all of the above skills.

The solution to this problem is the development of Internet-based applications (Kingston *et al.*, 2000; Elliot, 2004; Flanagan *et al.*, 2004; Kirkby *et al.*, 2004; Miller *et al.*, 2004). Internet-based tools that support erosion modelling and conservation planning include applications to facilitate sharing datasets and software, direct data visualization, and online simulation. Applications exist for erosion modelling at the hillslope, watershed and regional scales. Many of the applications include a spatial component by either using spatial data or displaying the results in the form of maps representing the spatial distribution of erosion. Geospatial technology tools, such as Internet map services, are increasingly being used. Results from erosion models are also components in resource or environmental planning efforts, which are increasingly using Internet-based applications to support the planning process (Kingston *et al.*, 2000).

17.2 Characterization of an Internet Application

Traditional erosion models and applications are closed centralized systems that incorporate models, interfaces and data (Miller *et al.*, 2004). These desktop systems are platform- and application-dependent, and migrating into different operating systems (e.g. Apple vs. Microsoft) or platforms (e.g. server, desktop, laptop, PDA, or mobile phone) can be time-consuming. Application of new erosion models often requires the use of other applications, such as DBMS, GIS, image processing systems (IPS), and graphic software, all of which must operate on the same OS and platform. The need for different software systems increases the computing requirements (i.e. RAM, disk storage) of the platform, rendering some applications inoperable on some platforms. Users also need expertise in the different applications, and all application data must be stored locally, increasing storage requirements.

Client/server systems are based on generic client/server architecture in network design (Tsou & Buttenfield, 1998; Peng & Tsou, 2003), referred to as 2- or 3-tier systems. A 2-tier system is where the data and applications are located on the same server. A 3-tier system is where the data and applications are located on separate servers. Client/server architecture allows distributed clients (i.e. users) to access a server remotely by using distributed computing techniques such as Remote Procedure Calls (RPCs) or database connectivity techniques such as Open Database Connectivity (ODBC). All necessary applications/models and data are hosted on the server(s). Applications can be developed that integrate functionality from several different software products and models transparent to the client. The computer resource requirements for the client are considerably less since the client does not need to handle data storage and management, or to install the applications on the local platform. In many cases the client only needs an Internet browser and connection. However, the client-side components are usually platform-dependent, and each client component can access only one server at a time (Peng & Tsou, 2003).

Distributed systems (i.e. distributed computing, distributed services) can connect to, and interact with, multiple and heterogeneous systems and servers at the same time (n-tier systems) and without the constraints of traditional client/server relationships (Montgomery, 1997; Peng & Tsou, 2003). Under a distributed architecture there is no difference between a client- or a server-based network. A client is defined as the requestor of a service in a network where a server then provides the service. The advantage is that a distributed architecture permits dynamic combinations and linkages between data services and application services via networking. Consequently, data can be stored on a suite of heterogeneous servers and dynamically accessed at an application's request. Potentially, distributed systems will promote the development of accessible institutional data nodes that provide information to Internet-based applications.

The Internet-GIS architecture determines the complexity and efficiency provided by the application. Currently, there are two types of Internet-GIS applications: client (user)-side and server-side. Client-side strategies require the majority of the processing to be conducted by the client on their own computer platforms. This typically requires the web browser to load a program (such as an applet or plug-in) the first time that users request a service. This 'thicker client' architecture provides the advantage of more functionality for users and requires fewer interactions with the server, potentially saving time and using less bandwidth. With this approach there are usually fewer security risks. However, applets are not persistent and must be downloaded at the inception of the application, and plug-ins are required to be downloaded and installed like traditional applications. This type of architecture is typically best for applications with dedicated application users (Plew, 1997) because users are required to have knowledge of handling and manipulating data. Server-side strategies perform all processing on the server, relying on the spatial server to conduct the analysis and generate output (Peng, 1997). These 'thin-client' applications require a high-performance server due to the computation intensity, and have higher network congestion since each operation performed by users must communicate to the server, increasing the need for bandwidth. However, users have transparent access to large and complex datasets, so they do not need either the software or the skills to manipulate data. Users are not required to have sophisticated computers since client machines perform little processing (Foote & Kirvan, 1997). Since tradeoffs exist between functionality, efficiency and required knowledge, integrated decision support systems should support multiple weight clients, providing access to users with different backgrounds, experiences, and network connection speeds.

Most Internet-based applications that support erosion modelling and control are thin-clients, being distributed from a client/server system (2- or 3-tier server architecture). For most erosion model applications the user is requested to enter the input information, so the data service requirements are relatively small.

17.3 Advantages of Internet-based Applications

The goal of an Internet-based application is to provide information and tools to a user group in a cost-effective manner. Internet-based applications primarily save time and money by centralizing activities. Databases and models can be maintained and located in the same place, with a single update distributed to all potential client users. A few database specialists can also maintain the system for all client users. Advanced software, such as GISs or statistical programs, can also be centrally located on host computers. Consequently, client users do not need to purchase or maintain the software, assuming the licensing of proprietary software for Internet use is available. Client users can also rely on less powerful hardware systems in terms of processing and storage, since most activities are accomplished on the host computer. The system can also be made more secure.

The ultimate advantage of Internet-based applications is that they promote data sharing and equity between stakeholder groups. Internet-based data services have become the primary mechanism for the distribution of data and information. Internet-based decision support tools, such as erosion modelling applications, can provide advanced analysis capabilities to a wide and untraditional audience. The increase in access to information and analysis tools for all citizens encourages equity and shared governance, advancing transparency between different stakeholder groups when addressing potential conflicts. Internet-based tools provide opportunities for shared learning experiences between stakeholder groups, where modelling results based on different proposed alternatives can be quickly viewed by participants. In the near future most formal and informal learning activities will likely be based on Internet applications (Pickles, 1995; Bruckman, 2002; Aggett & McColl, 2006).

17.4 Issues Related to Internet-based Applications

As applications are developed, integrating models, GIS, decision support systems and the Internet, new issues are introduced that should be recognized. These problems range from incompatibilities of technologies used for integrating disparate applications, to security in Internet environments, and are discussed in more detail below.

Since natural resource decision-making requires a coordinated effort between stakeholders representing different groups and levels of government, integrated decision support systems should facilitate interaction and communication among agencies' information systems to make the decision-making process more efficient (Miller *et al.*, 2004). However, different competing application programming platforms (i.e. .NET, Java, C++, FORTRAN, PHP, etc.), operating systems (i.e. Windows, Unix, Linux, etc.), database management systems (i.e. ESRI ArcGIS Server, Oracle, MSSQL Server, MySQL, etc.) make communication difficult or impossible. Standardizing programming languages, operating systems and database management systems for soil conservation stakeholders is impractical since different groups have different budgets, legacy systems, and requirements of their IT infrastructure. Creating a centralized database repository containing environmental data for decision-making is a possibility, but leads to logistical issues such as what data are contained in the database, who administers the database, how often the database is updated, and who pays for infrastructure. Component-based frameworks have been adopted such as Microsoft's .NET, but lack the inclusion of all programming languages and all operating systems. A standardized protocol that is programming language and platform independent should be utilized when developing integrated decision support systems.

Years of research and development have been spent on developing simulation models that encapsulate our understanding of environmental and erosion processes. These applications represent the current state of knowledge and should be leveraged in the decision-making process. However, these models are often developed using technologies which make interaction with today's object-oriented, web-based technologies cumbersome. Since different programming languages are developed for different purposes, languages that are computationally efficient are often not compatible with languages that have extensive libraries for Internet development, and no single language is ideal for all applications. Therefore, an integrated DSS must be capable of incorporating legacy applications that are built with technology that natively does not communicate with Internet-capable programming languages.

While deploying applications via the Internet drastically increases availability to users, there are still 37% of adult Americans without home broadband access (Horrigan, 2009). Moreover, Internet access is unequally distributed across the US, with only 54% of adult Americans in rural areas having broadband. Low-income Americans also have limited broadband access, with 65% of the households with annual incomes less then $20,000 having no access (Horrigan, 2009). Therefore, rural and low-income Americans are forced to find other alternatives, such as public libraries, to get access to Internet applications. However, the digital divide between the 'haves' and the 'have nots' is narrowing, with a 9% increase in home broadband access between May 2008 and April 2009 (Horrigan, 2009). Importantly, most businesses and government offices have broadband Internet access today, and in the US the Internet is the primary source of information from federal and state agencies.

A limitation in creating richer applications is the lack of bandwidth for Internet access. Bandwidth is the rate at which information can be transferred on a given transmission path (Miller *et al.*, 2004). As internet-based applications become larger and provide more features, the need for high-speed Internet access will increase, especially for server 'thick client' applications. While high-speed access is increasing, applications should target users with broadband. Thus, challenges exist for increasing application functionality while keeping applications available to the majority of Internet users.

Security is always a concern in Internet environments, and reports of security breaches are frequently documented (Grandison & Sloman, 2000; Palmer & Helen, 2001). If Internet-based applications are going to be integrated into the decision-making process, precautions need to taken to assure application security. Secure applications can lead to users trusting the design and architecture of the application; conversely, users are unwilling to expose themselves to unnecessary risks. With land managers storing data in central data warehouses used in Internet applications, data ownership questions arise. For example, does the data placed in a government data warehouse by a watershed group composed of private citizens belong to the private citizen, or become public property? These issues can be argued and must be recognized when using information technology in soil conservation.

17.5 Examples of Internet Applications

17.5.1 Data, information and model sharing

The common Internet-based applications being used today support the distribution of data, information and software. Websites (see Table 17.1) have been developed for professional societies (e.g. European Society for Soil Conservation; International Erosion Control Association; Soil and Water Conservation Society), individual sites for erosion control equipment, installation and training companies (see the Erosion Control Magazine, Erosion Control Technology Council for potential vendors), and there is even an erosion control information clearinghouse site with an Erosion BLOG (Erosion Control Forum). There are numerous websites supported by federal and local government agencies or non-profit organizations that provide information on erosion control practices (e.g. US EPA – Polluted Runoff, Natural Resource Conservation Service; California Department of Transportation; Tennessee Department of Environmental & Conservation; Center for Watershed Protection).

Most of the traditional erosion models (standalone versions), and supporting information (e.g. documentation), are available for download from websites. Examples of models or modelling support tools used in erosion and water quality assessment currently available from websites include the Universal Soil Loss Equation (USLE), Revised USLE (RUSLE; Ouyang & Bartholic, 2001), Water Erosion Prediction Project model (WEPP; Flanagan *et al.*, 2001), Geo-spatial interface for WEPP (GeoWEPP; Renschler, 2003; Renschler *et al.*, 2002), Wind Erosion Prediction System (WEPS; Hagen, 1991; Wagner, 2001), European Soil Erosion Model (EUROSEM; Morgan *et al.*, 1998), Soil and Water Assessment Tool (SWAT; Arnold & Fohrer, 2005), Automated Geospatial Watershed Assessment tool (AGWA; Miller *et al.*, 2007), and US EPA's Better Assessment Science Integrating Point and Non-point Sources (BASINS) water quality tools and models portal (EPA, 1998; Di Luzio *et al.*, 2009). Several of the websites also provide support data for the different models or links to access data from other websites. Most websites also provide tutorials on using the tools and lists of available publications.

Most of our commonly needed datasets can now be found from source agency websites, including terrain (US Geological Survey), soils (Natural Resource Conservation Service) and land use/land cover (US Geological Survey). There are also data portals available where users can find different sources of geospatial data (e.g. NRCS Geospatial Data Gateway; GIS Data Depot).

Table 17.1 WEB Resources (October, 2009).

Descriptions	URL
California Department of Transportation Erosion Control Toolbox	http://www.dot.ca.gov/hq/LandArch/ec/
Center for Watershed Protection	http://www.cwp.org/
Erosion Control Forum	http://erosioncontrolforum.com/
Erosion Control Magazine International Erosion Control Association Free Trade Journal	http://www.erosioncontrol.com/
Erosion Control Technology Council	http://www.ectc.org/links.asp
European Commission European Soil Data Center	http://eusoils.jrc.ec.europa.eu/
European Society for Soil Conservation	http://www.essc.sk/
European Soil Bureau Pan European Soil Erosion Estimates (PESERA Map Server)	http://eusoils.jrc.ec.europa.eu/website/Pesera/viewer.htm
Kangwon National University, South Korea Sediment Assessment Tool for Effective Erosion Control	http://www.envsys.co.kr/~sateec/)
Lancaster University, UK European Soil Erosion Model, EUROSEM	http://www.es.lancs.ac.uk/people/johnq/EUROSEM.html
Michigan State University Revised USLE (RUSLE) Online Soil Erosion Assessment Tool	http://www.iwr.msu.edu/rusle/
MindSites Group, LLC GIS Data Depot	http://data.geocomm.com/
Minnesota Department of Transportation Approved/Qualified Product Lists	http://www.dot.state.mn.us/products/
Purdue University Sediment and Erosion Control Planning, Design and SPECification Information and Guidance Tool	http://cobweb.ecn.purdue.edu/runoff/sedspec/
International Erosion Control Association	http://www.ieca.org/
Soil and Water Conservation Society	http://www.swcs.org/
Tennessee Department of Environmental & Conservation Erosion and Sediment Control Handbook	http://www.state.tn.us/environment/wpc/sed_ero_controlhandbook/
US Department of Agriculture Agricultural Research Service Universal Soil Loss Equation (USLE)	http://topsoil.nserl.purdue.edu/usle/index.html
US Department of Agriculture Agricultural Research Service Soil and Water Assessment Tool (SWAT)	http://www.brc.tamus.edu/swat/
US Department of Agriculture Agricultural Research Service Automated Geospatial Watershed Assessment Tool (AGWA)	http://www.tucson.ars.ag.gov/agwa/
US Department of Agriculture Agricultural Research Service Water Erosion Prediction Project (WEPP) Official Website	http://www.ars.usda.gov/Research/docs.htm?docid=10621
US Department of Agriculture Agricultural Research Service Water Erosion Prediction Project Climate Assessment Tool (WEPPCAT)	http://typhoon.tucson.ars.ag.gov/weppcat/
US Department of Agriculture Agricultural Research Service Water Erosion Prediction Project (WEPP) Web browser interface Online	http://www.geog.buffalo.edu/~rensch/geowepp
US Department of Agriculture Agricultural Research Service Wind Erosion Research Unit Wind Erosion Prediction System (WEPS)	http://www.weru.ksu.edu/new_weru/

Table 17.1 (cont'd).

Descriptions	URL
US Department of Agriculture US Forest Service Forest Service WEPP Interfaces	http://forest.moscowfsl.wsu.edu/fswepp/
US Department of Agriculture Natural Resource Conservation Service Agronomy and Erosion	http://www.nrcs.usda.gov/technical/agronomy.html
US Department of Agriculture Natural Resource Conservation Service Geospatial Data Gateway	http://datagateway.nrcs.usda.gov/NextPage.aspx?HitTab=1&Progress=0
US Department of Agriculture Natural Resource Conservation Service Soil Data Access	http://soils.usda.gov/
US Department of Agriculture Natural Resource Conservation Service Soil Use	http://soils.usda.gov/use/
US Environmental Protection Agency Better Assessment Science Integrating Point and Non-point Sources (BASINS)	http://www.epa.gov/waterscience/basins/b3webdwn.htm
US Environmental Protection Agency Multi-Resolution Land Characteristics Consortium (MRLC) 2006 National land Cover Data (NLCD 2006)	http://www.epa.gov/mrlc/nlcd-2006.html
US Environmental Protection Agency Office of Wetlands, Oceans, and Watersheds Polluted Runoff (Nonpoint Source Pollution)	http://www.epa.gov/owow/nps/
US Department of the Interior, US Geological Survey National Geospatial Program	http://www.usgs.gov/ngpo/
US Department of the Interior, US Geological Survey National Elevation Dataset National Map Seamless Server	http://seamless.usgs.gov/
University of Buffalo – SUNY GeoWEPP	http://www.geog.buffalo.edu/~rensch/geowepp/

17.5.2 Direct Access

Direct Access (also called Direct Read) refers to applications that allow users to view erosion modelling results directly using a web browser. Non-profit organizations provide erosion potential or vulnerability maps, using a map server, as part of watershed information portals. For example, the Arizona Nonpoint Education for Municipal Officials program (AZNEMO) provides erosion potential in their watershed-based plans that cover Arizona. The erosion potential maps are used to identify watersheds at risk for water quality impairment (http://arizonanemo.org). The Watershed Center in the Grand Travers Bay Watershed on the northwest of Michigan's lower peninsula maintains an Interactive Maps website that includes maps on public lands, wetlands, watershed boundaries, water quality monitoring locations and erosion potential (http://www.gtbay.org/maps.asp). The US Department of Agriculture Natural Resources Conservation Service (NRCS) has a website with maps (in Adobe Portable Document Format) and charts developed using National Resource Inventory (NRI) data (http://soils.usda.gov/use/). NRCS also has information on world soil resources including maps on erosion.

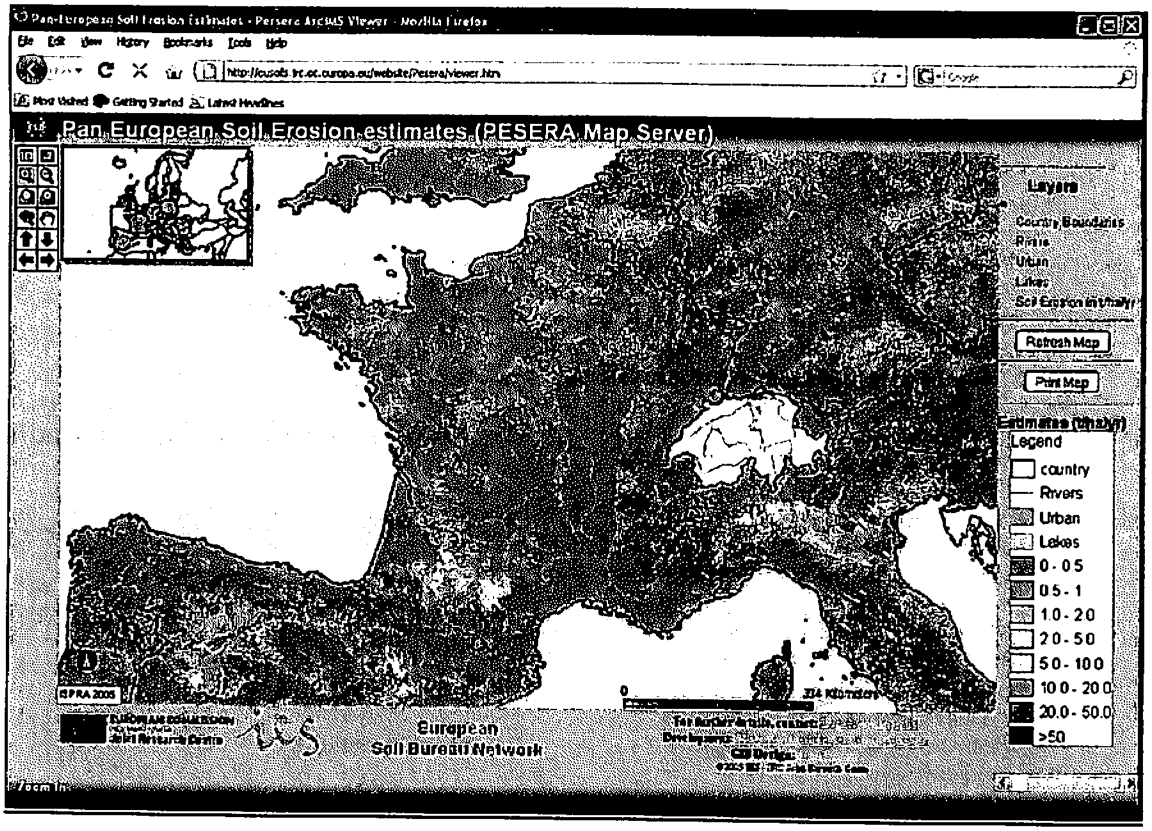

Fig. 17.1 The PESERA Map Server supported by the European Commission Joint Research Centre. The map server is based on ESRI's ArcIMS Internet technology.

Pan European Soil Erosion Estimates Map Server (Fig. 17.1) is an interactive application that allows the user to navigate in the Pan European Soil Erosion Estimates (PESERA) map and data. The PESERA Map Server (http://eusoils.jrc.ec.europa.eu/website/Pesera/viewer.htm) may represent the largest internal map on erosion. Soil erosion estimates (t ha^{-1} y^{-1}) are made by applying the PESERA GRID model at 1 km, using the European Soil Database, CORINE land cover, climate data and a digital elevation model. The resulting estimates of sediment loss are from erosion by water. The PESERA model produces results that depend crucially on land cover as identified by CORINE and the accuracy of the interpolated meteorological data.

17.5.3 Erosion model applications

One area where there has been considerable effort is the creation of hillslope erosion model applications. In most cases the user is expected to provide input information on the hillslope characteristics (e.g. soil type, cover, slope gradient) and there is little to no linkage to external databases, making the applications self-contained. Examples of web-based hydrological applications have been developed by scientists at the USDA Agricultural Research Service (USDA-ARS) and by scientists at the USDA-FS Rocky Mountain Research Station, in Moscow, ID.

In the later 1990s the USDA-ARS Southwest Watershed Research Center developed an

Internet-based hillslope erosion and sediment yield model (HEM: http://eisnr.tucson.ars.ag.gov/hillslopeerosionmodel). The model predicts runoff volume, sediment yield, inter-rill and rill detachment, rill deposition, and mean concentration of sediment for each hillslope segment, provided that the lengths, slopes, percentage canopy and surface ground cover for each hillslope segment, along with runoff volume and a soil erodibility value for the entire hillslope, are known. The HEM model produces graphs depicting the input hillslope profile and distribution of cover on the hillslope, and output for sediment discharge, detachment and deposition, and mean sediment concentration along the hillslope profile (Lane *et al.*, 1995).

The Rocky Mountain Research Station developed the Forest Service Water Erosion Prediction Project (FSWEPP: http://forest.moscowfsl.wsu.edu/fswepp/) interfaces (Elliot & Hall, 1997; Elliott, 2004), which provide the capability to evaluate erosion and sediment delivery from disturbed forest and rangelands. The application uses the Water Erosion Prediction Project (WEPP) model (Flanagan & Livingston, 1995) to estimate erosion rates and sediment delivered using input values developed at the Rocky Mountain Research Station (Elliot & Hall, 1997). The interface provides links to different applications capable of simulating sediment yield from burned areas, a road segment across a buffer, erosion from forest roads, erosion from rangeland, forestland, and forest skid trails. The applications are linked to the Rock:Clime climate generator with a database from more than 2600 weather stations. The different applications found on the US Forest Service WEPP Interfaces website are:

- *Cross Drain* – interface to the Water Erosion Prediction Project soil erosion model (WEPP) to determine optimum cross-drain spacing for existing or planned roads, and for developing and supporting recommendations concerning road construction, reconstruction, realignment, closure, obliteration, or mitigation efforts based on sediment yield.
- *WEPP: Road* – interface to the WEPP model that allows users easily to describe numerous road erosion conditions. The interface presents the results as a summary and extended WEPP output, and has an optional log to store the results from a series of runs.
- *Disturbed WEPP* – interface to the WEPP model to allow users easily to describe numerous disturbed forest and rangeland erosion conditions. The interface presents the results as a summary and extended WEPP outputs, and also presents the probability of a given level of erosion occurring the year following a disturbance.
- *WEPP FuME* – interface to the WEPP model (WEPP) to analyse soil erosion rates associated with fuel management activities. This interface estimates background erosion rates, and predicts erosion associated with mechanical thinning, prescribed fire, and the road network.
- *ERMiT* – the Erosion Risk Management Tool (ERMit) is a web-based application that uses the WEPP model to estimate erosion, in probabilistic terms, on burned and recovering forest, range and chaparral lands, with and without the application of erosion mitigation treatments (Robichaud *et al.*, 2007). User inputs are processed by ERMiT to combine rain event variability with spatial and temporal variabilities of soil burn severity and soil properties, which are then used as WEPP input parameters. Based on 20 to 40 individual WEPP runs, ERMiT produces a distribution of rain event sediment delivery rates with a probability of occurrence for each of five post-fire years.

Examples of three of these applications are described in Chapter 16.

The WEPP (Water Erosion Prediction Project) web interface can be found at http://milford.nserl.purdue.edu/wepp/weppV1.html (Flanagan *et al.*, 2001, 2004). As noted in earlier chapters, the WEPP model is significantly more complex than the RUSLE model. Consequently, more extensive databases must be bundled with the model in the web interface to enable ready execution via the Internet. In this case, over 20,000 soil database records, climate described at over 2600 locations within the US, and an extensive set of land management examples comprising operation types and dates for cropland and rangeland, are bundled with the website. Four hillslope shapes can be represented (e.g. uniform, convex, concave, S-shape). Once simulation selections are made, and the simulations are completed, WEPP model input files in ASCII format are available on the website. In addition, a wide variety of detailed graphics can be displayed ranging from climatic inputs, plant and residue attributes as a function of simulation time, to time-varying hydraulic and erosion parameters and model outputs.

The well-known RUSLE erosion model (Renard *et al.*, 1997; and see Chapter 8) has been set up as a web-based application for the state of Michigan (Ouyang & Bartholic, 2001; http://www.iwr.msu.edu/rusle/). For this application, erosion can be calculated for agricultural and construction land uses. A simple graphical interface is displayed for the user to select an individual county within the state. Drop-down menus are then displayed for the user to enter run identification information, hillslope characteristics, and soil types from NRCS databases for the selected county. For the agricultural land-use case the user then selects from a list of cropping rotations and tillage practices by year for up to five years. From these selections the various factors of RUSLE equations are obtained from databases and lookup tables built into the system. The calculation for annual erosion is then completed. The *C*-factor (cover) can also be manually set.

The Water Erosion Prediction Project Climate Assessment Tool (WEPPCAT: http://typhoon.tucson.ars.ag.gov/weppcat/) is a further refinement of the hillslope version of WEPP in which simultaneous assessments of climate change and the effectiveness of end-of-field filter strips for mitigation of erosion can be evaluated. It is an easy-to-use, web-based system that allows users to adjust climate inputs for user-specified climate scenarios within the continental US. It allows the user to modify monthly mean maximum and minimum temperatures, the monthly mean number of wet days, monthly mean precipitation, and rainfall intensity in order to predict changes in surface water runoff and erosion rates. WEPPCAT allows the user to assess erosion changes under a large variety of land management alternatives. It does not require specialized scientific expertise to run, and scenarios are quick and easy to set up.

The Sediment and Erosion Control Planning, Design and SPECification Information and Guidance Tool (SEDSPEC; Tang *et al.*, 2004) predicts small watershed peak runoff and will assist in the design of hydrological, sediment, and erosion control measures. The SEDSPEC system is composed of a model, database, and user interface. Two hydrological models (the Rational Method and TR-55) simulate short-term peak runoff based on site-specific hydrological soil groups and land uses. The hydrological models estimate peak runoff using design storm data stored in associated databases. The DSS integrates WebGIS technology to help users to estimate watershed boundaries and access a spatial database to obtain land use and hydrological soil group data for the watershed. As the final output, SEDSPEC calculates dimensions and costs of hydrological, sediment and erosion control structures based on users' specifications, and provides structure maintenance information. SEDSPEC will provide customized drawings of the structures, and there is a limited amount of interaction which allows users to determine what size structure fits their needs.

17.5.4 Watershed model applications

Unlike the hillslope erosion models, the development of watershed model applications is just beginning, and to date no application is currently available 'online' that specifically addresses erosion and sediment yield. One difficulty with watershed model applications is their need for geospatial information (e.g. digital elevation models, soil maps, land use/land cover). Making the geospatial information for a region locally available for an Internet application using a 2- or 3-tier architecture would be costly (i.e. creation costs, storage requirements, maintenance). The costs would be considerably greater if national or international applications are desired. Requiring users to provide their own data creates other problems related to data quality, storage requirements, greater user capability, and security. Importantly, watershed models are typically more complex then hillslope erosion models and take longer to execute, which requires more processing power or user patience. In the future distributed systems (n-tier architecture) would address some of these issues where datasets would be stored and accessed from different host servers with application datasets assembled as needed. Distributed systems will require high bandwidth access, which is not always present. Examples of Internet-based watershed model applications that address erosion and sediment yield include •AGWA and Web-based SWAT (Park *et al.*, 2009). •AGWA is discussed below.

One of the first watershed applications was •AGWA ('Dot AGWA'), the Internet version of AGWA that grew out of the PC-based Automated Geospatial Watershed Assessment (AGWA) tool developed by the USDA's Agricultural Research Service, in cooperation with the Environmental Protection Agency and the Universities of Arizona and Wyoming. Many of the initial concepts for •AGWA were conceived by Miller *et al.* (2004) and the system was fully developed and implemented as an alpha version (Cate *et al.* 2005, 2006; Cate, 2008). AGWA was developed as a multipurpose hydrological analysis system for use by watershed, water resource, land use, and biological resource managers and scientists developing watershed and basin-scale studies (Miller *et al.*, 2007; Semmens *et al.*, 2008). AGWA incorporates several spatial datasets, GIS mapping, analysis and visualization tools, and two watershed and erosion models into one package, providing easy access to these features. The two watershed models embedded within AGWA are SWAT (Arnold & Fohrer, 2005; http://www.brc.tamus.edu/swat/) for relatively large basin applications, and KINEROS2 (Goodrich *et al.*, 2006; Semmens *et al.*, 2008; http://www.tucson.ars.ag.gov/kineros) for small to medium watershed applications. This enables rapid multiscale watershed analysis.

•AGWA employs ESRI's ArcIMS and Spatial Data Engine (SDE) as well as Oracle's spatial database to provide the GIS data and interactions. Java-based web server technology is used to connect •AGWA to the watershed models in the application. The web application is based on the Model-View-Controller (MVC) design pattern. This design pattern is useful in separating the presentation components of the system architecture from the data storage and processing components. In this architecture, the Model component allows the different system components to be represented as individual entities. The View is simply the user interface, and the Controller ties the Model and View components together. This separation is useful as it allows changes, replacements or alterations to one of the three components without major changes in other parts of the system. For example, if MySQL is the initial supporting database used in the system and it becomes inadequate when the user base expands greatly, then another database like PostgeSQL can be inserted into the existing system with minimal effort or interruption.

Users can define management scenarios, and like AGWA, have the application parameterize and run the models for the defined management plan. Both of the watershed models are spatially distributed so that simulation results for erosion and sediment transport, as well as hydrology, can be imported back into •AGWA and mapped back onto upland or channel elements within the internet view. Different output formats (i.e. XML, Word doc, HTML) for the resulting simulation output can also be specified by the user. As noted, the tool leverages client-server architecture so that changes and improvements in core components will not disrupt end-user interaction with the application. The alpha-based application is currently undergoing further development and is not supported for general Internet access at this time.

17.6 Example of an Internet-Based Application

Flanagan *et al.* (2004) described the Internet-based WEPP-GIS application (WEPP-GIS; http://milford.nserl.purdue.edu/wepp/gis2.php?IES=1). The application utilizes the core procedures developed by Cochrane and Flanagan (1999) and implemented in GeoWEPP (Renschler *et al.*, 2002; Renschler, 2003), but within an interface that only requires a web-browser and Internet connection on the user's computer (a 'thin-client' application). GIS Viewer software allows users to specify an area of interest to model with WEPP, then digital elevation model (DEM) data for the area are sent to topographic parameterization software to delineate watersheds, channels and hillslopes. The DEM data are processed on the server side, and then images of the delineated watershed and hillslopes are passed to the user's web-browser. Once the hillslopes and channels have been located, WEPP model simulations of representative hillslope profiles and channels, and/or all flowpaths in the watershed, are conducted. The simulated soil erosion results in graphical format are sent as images to the client computer. Subsequent model simulations using different land management practices can help to show the impact of conservation practices on hillslope runoff and erosion.

Plate 14 provides a schematic of the WEPP-GIS application. The application uses the open source MapServer environment from the University of Minnesota (http://mapserver.gis.umn.edu) as the basic Web GIS. The TOPAZ (Topographic PArameteriZation) (Garbrecht & Martz, 1997) digital landscape analysis tool is used for channel, watershed and sub-basin (hillslope) delineation. There are six major software components of the Internet-based WEPP GIS application. Users can select a US State of interest. They then can zoom in to find their specific area of interest. The data for display are obtained from the TerraServer site (http://terraservice.net) and from local spatial data on the National Soil Erosion Research Laboratory (NSERL) server. Image data are sent from the MapServer software (1 in Plate 14) to the client's web-browser, and MapServer also handles requests for zooming and panning in the display. After the location of interest has been identified, TopazPrep software (2 in Plate 14) extracts a region of the DEM to process with TOPAZ. TopazPrep is custom software coded in C++ and PHP. PHP is an open-source scripting language used for web development and it can be inserted into HTML (HyperText Markup Language).

The TOPAZ software (3 in Plate 14) is run at least twice. The first time is to delineate the entire network of channels within the displayed region of the DEM. Once the delineated channels are visible, the user can either accept them, or alter the critical source area and minimum channel length parameters and rerun TOPAZ until a satisfactory representation of the channel network is obtained. The user must then select the outlet point for the watershed of interest, after which TOPAZ is run a second time to delineate the watershed boundary and sub-basins (i.e. hillslope regions). The area the user can model is currently limited to 0.25 degrees latitude by 0.25 degrees longitude, in order to ensure that TOPAZ can handle the extracted DEM and have a reasonable response time. Once an acceptable watershed has been delineated, the WeppPrep (4 in Plate 14) program (custom software also written in C++ and PHP) generates WEPP inputs from the extracted DEM, land use, soils and TOPAZ watershed configuration. WeppPrep also executes the CLIGEN (5 in Plate 14) weather generator (Nicks *et al.*, 1995) to create a climate input file for WEPP. Finally, the WEPP model (6 in Plate 14) is run on the hillslopes/channels and/or flowpaths. Once the WEPP simulations are completed, WeppPrep prepares the output files, interprets the results and produces maps which are sent to the client using MapServer.

The WEPP-GIS application represents a client/server system (2- or 3-tier architecture) if only the NSERL server is used to provide spatial data. However, if users utilize topographic map images (digital raster graphs) and aerial photography to assist in locating the area where they wish to apply the WEPP watershed model, they are using a distributed system (n-tier architecture) since the data is retrieved on demand from TerraServer USA (http://terraservice.net) using a Web Mapping Services protocol. The WEPP-GIS is a 'thin-client', where the client (i.e. user) only needs a web browser to access the application. All other data processing is accomplished on the host server, in the above example the execution of TOPEZ, CLIGEN and WEPP, gathering input data for the map server and/or the models, and preparing the output.

17.7 Conclusion

The WEPP-GIS application provides a glimpse of how future Internet-based applications will be developed. With improvements in bandwidth and Internet access, applications will increasingly be based on distributed systems where input data will be accessed as needed and data will be stored temporarily. It is foreseeable that tools such as TOPEZ and CLIGEN will become application services in themselves, in which the WEPP-GIS client would request their services. What is known for certain is that Internet-based applications will evolve to become the primary mechanism by which most users apply erosion models.

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