EROSION RISK MAPPING IN THE TROPICS

J.D.Flach[1], S.M.White[2], W.G.Collins[3], T.R.E.Chidley[3]

1. Image Technology Systems, Aston Science Park, Aston Triangle, Birmingham, UK.
2. NERC Water Resources Systems Research Unit, Dept. Civil Engineering, The University, Newcastle.u.Tyne, UK. formerly: ODU, Hydraulics Research Ltd, Wallingford, Oxfordshire, UK.
3. Dept. Civil Engineering, Aston University, Aston Triangle, Birmingham, UK.

ABSTRACT

This paper investigates the use of remote sensing and Spatial Information Systems as a decision support tool in river basin management; providing information for input to regional hydrological models. The test case highlights a study undertaken in the Philipinnes to determine areas of a river catchment that would benefit most from a re-forestation project. The integration of various types of data into the model is discussed along with the generation of an erosion risk map for the catchment. The use of weather satellites for areal rainfall estimation as input to the model is also discussed.

KEY WORDS: Erosion Risk, Hydrological Modelling, Spatial Information Systems.

1. INTRODUCTION

Soil erosion is a major problem in many third world countries. The response to rising food demand has often been met by increased agricultural production in marginal lands, and the world trade in timber has caused the destruction of many forested upland areas. In many cases this has led to accelerated erosion rates, total degradation of the land, high sediment loads in rivers and canals, and a reduction in water available for irrigation. Ultimately sediment deposition in reservoirs can mean a drastic reduction in operating life.

Unfortunately the modelling of hydrological processes, in particular the prediction of sediment yield, in developing countries is often a subjective task, hampered by lack of data.

This paper describes the basis for a remote sensing based hydrological information system (Ragan and Fellows, 1979), (Allewijn, 1988), and its application in the creation of a database of useful information for input to distributed hydrologic models.

1.1. The Study Area

The study area used as a test case for developing a methodology was the 4123 km^2 Magat River Catchment in Luzon, Philippines. Problems of high localised erosion and rapid sedimentation in the reservoir at the catchment outlet have resulted in plans for re-forestation of parts of the catchment. It was neccesary to identify those areas of the catchment, which if re-forested, would give most return in terms of reduction of soil loss at the site and reduction in sediment yield to the reservoir. This study and subsequent monitoring of the effects of catchment management policies is being undertaken by the Overseas Development Unit of Hydraulics Research Ltd, Wallingford, UK.

2. EROSION RISK MODELLING

The prediction of sediment yield in developing countries is often a subjective task, and has in the past often proved to be extremely unreliable. Numerous examples exist where sediment yields predicted at the feasibility stages of an irrigation project are found to underestimate the real yields by a factor of ten or more. One of the contributory factors to these unreliable predictions is the preponderance of simplistic or inappropriate predictive techniques. Formulae are either simple, relying on only one or two factors, or extremely complex and data-hungry. Most formulae have been developed in climatic and geomorphic zones which are very different from those found in the tropics where many developing countries are located. This does not stop people from using them!

The processes of erosion and sediment transport are dependent on many factors, whose inter-relationships are complex. Prediction of erosion and sediment yield is therefore achieved by combining the various causative and resistive forces for the area under consideration.

Prime examples of this type of approach are the Universal Soil Loss Equation (Wischmeier and Smith, 1978) for individual plots of land, and catchment scale models that average data over the entire catchment (Fleming, 1969). Development of computer based distributed models allow the catchment to be modelled on a grid cell or sub-catchment basis (Beasley, 1960), (Fleming and Walker, 1976). Distributed models of this nature require sediment routing algorithms to account for movement through and between model cells. Data requirements for distributed models are clearly high which normally precludes their use in developing countries. Remote Sensing and Spatial Information Systems provide a possible source of data for these models.

As a basis for modelling erosion risk a modified version of the SLEMSA model, originally developed and used for a study in the SADCC region (Stocking 1987), was investigated. This model takes into account a number of factors:

1. Erosive power of rain
2. Interception by plant cover
3. Topography (slope, etc.)
4. Resistance of soil to erosion.

Given these as required inputs to the model a fine mesh database was required. Remote sensing and spatial information systems provided the key to creating a database from satellite digital data and thematic cartographic data.

3. PRODUCTION OF THE MODEL INPUT DATABASE

The production of data for use as input to the erosion risk model can be separated into three main sources of data : thematic maps, topographic maps and remote sensing. All these data were converted into a common form using the PC based ICONOCLAST Image Processing and Spatial Information System, developed by Image Technology Systems Ltd.

Prior to the digitisation process the effective scale of the required data was chosen. As the input to the model and manipulation of these data is essentially a grid cell (raster based), the size of the cell is the major factor. This was chosen to be 150m, giving a thematic database of 500 x 700 cells (pixels).

3.1. Thematic Maps

The production of the thematic map database produced inputs related to the resitance of soil to erosion, namely the Geology and Soils of the region.

Digitisation of soil and geology class boundaries was achieved using both a digitising tablet, and a process of video digitisation and boundary extraction. Both resulted in a class boundary vector database extracted in the pre-defined co-ordinate system.

The boundary data from various mapped sheets was then aggregated and any map sheet edge problems resolved. The boundaries were then used in a graphical seed fill process, thus converting each pixel within a boundary to a pixel value indicative of class. The boundaries are then removed by a process of line replacement from adjacent pixels.

In this type of raster based Spatial Information Systems, pixel brightness is related to a table describing class attributes. Thus to obtain the class of any pixel is a simple case of looking up the class table. The location and topology of each pixel is only known from its position in the grid.

A number of other thematic databases where also created at this stage to assist in future work. These included Land Management Units, (official) Land Use and Stream Sub-catchments.

3.2. Topographic Maps

Given that slope and slope length, aspect and elevation are important considerations in the model a digital elevation model (DEM) had to be constructed. In may parts of the developed world DEM are commercially available, for developing countries this information is often restricted. It is therefore necessary to have tools for generating a DEM from any available data. For the study area large scale topographic maps were not available, due to government restriction, and an alternative source of data was needed. Tactical Pilotage Maps are generally available worldwide and this was used as a source of all topographic information for the study.

Individual section of the pilotage map were raster digitised at high resolution to facilitate the extraction of contour data. All relevant contour information was extracted by a manual process of on-screen digitisation - an extremely laborious task. Other topographic features such as roads, built areas and the drainage network were also extracted to assist in the geometric rectification of the remote sensing input.

The elevation data consisting of contours and spot heights was then converted to a raster representation of height by an interpolation process. A number of methods were tested including various Least Squares (Jancaitis and Junkins, 1973) and Multiquadric (Hardy, 1971) procedures. Later work suggested the more efficient use of triangulation routines.

Given a satisfactory raster representation of elevation, where pixel brightness is directly proportional to height, slope, aspect and other related measures can be derived. The algorithm used for generation of slope and aspect for the model was a modified version of the algorithm developed by Ritter (1987).

3.3. Remote Sensing

The difference between land use detailed on available maps and actual land use was considered to be significant; particularly in upland areas where considerable de-forestation had occurred. Satellite remote sensing was seen as a means of providing up to date land use information at sufficient scale for use in the model.

A Landsat MSS scene was acquired and subsequently used to produce a land use map using multi-spectral classification techniques. A 1536 x 1536 extract was taken from the full MSS scene. This was first used to define a number of ground control points using on-site experience and the topographic map.

The extract was then corrected to the database co-ordinate system, primarily for use as a frontispiece in a report overlayed with topographic features and catchment boundaries. What is also extremely evident on this image is the siltation of the reservoir compared to the downstream irrigation channel.

The extract was then used to define training areas for land use. Training statistics were produced and used in a Maximum Likelihood classification of the extract. The accuracy of the classification was visibly checked for a further set of areas for which ground truth was known. In light of the available alternative, and subsequent empirical processes involved in the model, the classification was considered to be sufficiently accurate and the classification was then corrected to the database co-ordinate system.

3.4. Rainfall

Rainfall throughout the catchment was monitored by a handfull of rain gauges, all of which were in easily accessible lowland areas. These had been used to produce mean annual rainfall measures from which isohyets had been sketched. This is not the best basis for estimating rainfall on a per pixel basis, but is invariably the only source of available data in developing countries.

The rainfall data was treated as contours and spotheights and interpolated to produce a mean rainfall surface.

Another possibility, investigated as a possible future study, was the use of weather satellites in the estimation of precipitation. For this a PC based weather satellite receiving station would be installed, in this case to receive the Japanese GMS geostationary satellite and possibly the polar orbiting satellites NOAA 10 and 11. This would provide rainfall estimates on an hourly or daily basis. Caibration of the satellite derived estimates could be achieved using the existing rain gauges. This would require the continual monitoring of rainfall over large periods of time, but would produce estimates of rainfall in the not so easily accessible upland areas; and also provide a source of data for use in surface runoff and soil moisture models.

4. THE EROSION RISK MAP

The combined data set was then used in production of an erosion risk map, based on the SLEMSA model. This rated the relative risk of erosion for each pixel in the database.

In this process empirical measures were used to assess the effects of various plant canopy cover on the interception of rain water and the blanketing of erosive soil with plant litter. This is therefore of particular significance in the accuracy of the model, and only relative risk could be produced. In the determination of the potential benefits of re-forestation of certain areas this is adequate.

Application of the Universal Soil Loss equation (USLE) was also investigated, using parameters derived for the Philippines. This gave a much better quantification of erosion rates from the catchment. However, it should be remembered that both predictive techniques were being used outside the parameter ranges for which they have been designed and tested. Further work on the quantitative modelling of sediment yield and the routing of sediment through a series of nested catchments is currently being undertaken.

5. CONCLUSIONS

This study has shown the application of remote sensing and spatial information systems in the support and monitoring of a typical catchment management project. In this case the identification of areas susceptible to soil erosion, related to current land use, soil type and topography. The same system can be used to monitor the progress of such policies over a number of years; and provides a means of integrating data from satellites, cartography and point sources in a form that facilitates use in hydrological models.

6. REFERENCES

Allewijn, R., 1988, Regional Hydrological Systems Analysis using Satellite Remote Sensing Data and a Geographical Information System. International Journal of Remote Sensing : Special Issue - 1987 EARSeL Symposium, 9(10 & 11):1775-1785.

Beasley, D.B., 1960, ANSWERS: A Mathematical Model for Simulating the Effects of Land Use and Management on Water Quality. Ph.D. Thesis, Purdue University, West Lafayette, Indiana, USA.

Fleming, G., 1969, Design Curves for Suspended Load Estimation. in Proceedings of the Institution of Civil Engineers, 43:1-9.

Fleming, G., R.Walker, 1976, A Runoff Erosion Model for Land Use Assessment and Management. Technical Report, Department of Civil Engineering, University of Strathclyde, Glasgow, UK.

Hardy, R.L., 1971, Multiquadric Equations of Topography and Other Irregular Surfaces. Journal of Geophysical Research, 76(8):1905-1915.

Jancaitis, J.R., J.L.Junkins, 1973, Modelling Irregular Surfaces. Photogrammetric Engineering, 39(4):413-420.

Ragan, R.M., J.D.Fellows, 1979, Computer-aided Watershed Analysis using Remote Sensing Based Regional Information Systems. The Contribution of Space Observations to Water Resources Management, Pergammon Press. pp. 181-193.

Ritter, P., 1987, A Vector-based Slope and Aspect Generation Algorithm. Photogrammetric Engineering and Remote Sensing, 42(12):1539-1545.

Stocking, M., 1987, A Methodology for Erosion Hazard Mapping of the SADCC Region. SADCC Coordination Unit, Report No. 9, Maseru, Lesotho.

Wischmeier, W.H., D.D.Smith, 1978, Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. USDA-SEA Agr. Handbook 537, Agricultural Research Service, USDA, Washington, USA.