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Environmental Analysis Using Modelling and Geographic Information Systems

A Case Study

Agricultural Non-Point Source Pollution Modelling Using Geographical Information Systems

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EXECUTIVE SUMMARY

This case study is part of the Impacts of Climate on Ecosystems (ICE) research programme at the Institute of Hydrology (IH), and evaluates a Geographical Information Systems (GIS) approach to modelling by applying the approach to the issue of agricultural non-point source pollution. Following a literature review, an application of the approach to the Bedford-Ouse catchment in the U.K. is described, predicting water quality impacts from source data on topography, soils, land use, river network and other information. The application involves the integration of the agricultural non-point source pollution model (AGNPS), the GIS ARC/INFO, ORACLE based data sources, and connecting software. The primary objective to achieve this integration was met, and a number of scenarios established to explore rainfall variation, model sensitivity, and changes in management practices. Results are reviewed, and mis-matches of the model with observations considered to be primarily due to unavailability of data and limitations to the use of the data sources currently available. More appropriate data sources are suggested as the main priority for improving the application. However this approach to modelling non-point source pollution is considered to be very useful, and the use of GIS played a valuable role, mainly as a tool for communicating information, and also for its spatial analysis and storage capability. The use of a more powerful version of this approach to the ICE programme is recommended.

SUMMARY OF WORK

This report documents a case study carried out for the Institute of Hydrology (IH), and is part of the Institute's Impact of Climate on Ecosystems (ICE) research programme, being undertaken on behalf of the UK Department of the Environment (DoE).

The ICE programme is concerned with modelling large-scale complex issues, and it is intended to use Geographic Information Systems (GIS) to assist the management and communication of this scale and complexity. To evaluate this approach before large-scale use, this case study integrated a computer model, a GIS, and data sources, and applied the approach to a current environmental issue of concern, namely agricultural non-point source pollution, focusing on nitrates.

A literature review formed a context for the study, establishing agricultural NPS pollution of surface and groundwater as a complex issue of increasing concern worldwide. Modelling, using the increasingly powerful and accessible computer, offers major benefits in the research, management, and communication of this complexity, and emerging computing technologies, such as GIS integrated with remote sensing, enable large data volumes to be easily processed, and communicated in visual form. The benefits of integrating models and GIS have led to an increasing number of applications, mostly in the U.S.A.

AGNPS is an NPS, event-based, distributed model intended for management purposes. In this study the model was integrated with the GIS ARC/INFO and applied to the Bedford-Ouse catchment in the U.K. Key ORACLE based data sources were soil type, land use, altitude and the river and catchment boundary. These data sources were translated to AGNPS input data using FORTRAN programs and ARC/INFO; ARC/INFO was used for presentation purposes.

The model was run for various scenarios, including scenarios representing the most likely situation, data input uncertainty, and changes in management practices.

The most likely scenario over-predicted agricultural pollution, but this may be due to processes not represented in the model, and data input uncertainty. However, model predictions suggested that pollution in the dissolved phase dominates that in the solid phase, and lower flows might generate higher pollution levels than high flows which exercise a dilution effect.

Scenarios to evaluate model data input sensitivity identified the SCS curve number as the input parameter dominating model prediction.

The management scenarios demonstrated that reducing fertiliser application rates and availability levels would bring approximately proportional improvements in water quality related to NPS pollution. However a surprising prediction was that changes in erosion management practices would not improve water quality, and in a practical situation investment should be targeted elsewhere.

The use of GIS in the application demonstrated the benefits identified in the literature, although other computing aspects, notably FORTRAN, must take substantial credit for adding the flexibility to integrate software components. However it would have been almost impossible to do some analyses without the GIS, and probably more of the processing could have been done using the GIS had more time and training been available. Certainly the overall approach was very cost-effective in terms of development time, data management, and scenario evaluation.

The main strength of the GIS confirmed in this project is its communication potential. The visual impact of the information is very impressive, for example the nitrogen risk maps generated from model predictions. The power of these images, combined with the discipline imposed by the GIS in creating a common spatial framework, acts as a focus for rational discussion and debate, and the model predictions provide overall indications that are a good starting point for discussion. However care must be taken to prevent the GIS presentation capability giving a false accuracy to the underlying data and model limitations. GIS cannot solve the fundamental problems of data availability, accuracy and translation, and model inaccuracy and inapplicability.

Problems of data availability, accuracy, appropriateness, subjectivity, consistency, and translation were all encountered in this study. In addition the applicability of a U.S. related model a U.K. situation should also be taken into consideration. However these issues were not unexpected, as the main objective was to achieve an application with data readily available.

Having achieved the application, the main priority of future research related to the application, should be to increase source data accuracy, focusing on curve number related parameters and fertiliser application and availability estimates. Further work is justified by the benefits of integrating the model and GIS, which has been demonstrated to be a powerful combination in the communication of NPS pollution related issues of increasing concern.

The benefits demonstrated in this successful case study can also be realised more generally in the Impact of Climate on Ecosystems (ICE) research programme. Indeed the nature of the research suggests that there should be even greater benefits.

The ICE research programme is concerned with modelling complex ecological processes, and the possible effects of climate change on these processes within the U.K., over a long timescale, and in relation to various climate change scenarios. The exploration and communication of complexity and uncertainty is therefore a major features of the research, and this is where the major benefits of a GIS approach have been demonstrated.

In addition to the communication benefits, the GIS approach has significant advantages in efficiently exploring scenarios and managing the data volumes involved. However the larger scale of the ICE programme strongly suggests that a more powerful ARC/INFO version should be used, and in this regard an ARC/INFO version for the SUN workstation is on order. The extra functionality of this version, combined with greater familiarity with the ARC/INFO, should provide additional advantages.

In conclusion the ICE research programme should benefit significantly from a GIS approach demonstrated in this case study. The ICE programme is characterised by complexity, and GIS has the potential to manage, analyze, and above all communicate this complexity very effectively. Integrating a powerful version of the GIS ARC/INFO, with the models under development, should provide greater insight into the study of the serious issue of climate change impacts on ecosystems.

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1. INTRODUCTION

1.1 Background

This report documents a case study project carried out for the Institute of Hydrology (IH), and is part of the Institute's Impact of Climate on Ecosystems (ICE) research programme, being undertaken on behalf of the UK Department of the Environment (DoE).

The ICE programme is concerned with modelling complex ecological processes, and the possible effects of climate change on these processes within the U.K. Inevitably the research involves large data volumes and complex issues. To assist in the management and presentation of this scale and complexity it is intended to use Geographic Information Systems (GIS) in conjunction with computer models. In order to evaluate this approach before large-scale use, it was decided to assess the integration of models and GIS by way of a relevant case study of an environmental issue.

Agricultural non-point source (NPS) pollution, focusing on nitrates, was selected as appropriate for the case study. It is an environmental issue attracting increasing concern, and the diffuse nature of the pollution suggests that the spatial capability of a GIS, in conjunction with a non-point source pollution model, is a potentially useful analytical approach.

The GIS used was ARC/INFO, marketed by the Environmental Systems Research Institute (ESRI), and the model used was the Agricultural Non-Point Source Pollution Model (AGNPS), supplied by the United States Agricultural Service (USARS).

1.2 Project Objectives

The overall objectives established for the project were:

- to integrate, by an appropriate computer-based solution, an agricultural NPS pollution model, a GIS, and relevant data sources

- to apply the approach to a U.K. catchment, exploring the issue of NPS pollution under various scenarios

- to evaluate the approach generally, and specifically for use in the ICE programme, and for analyzing NPS pollution issues.

1.3 Project Methodology

To set a context for the case study, a literature review was undertaken of agricultural NPS source pollution modelling using GIS.

To achieve the integration of the model, the GIS, and the data sources, FORTRAN and ORACLE SQL were used to write programs to transfer and process data as required.

To achieve the application of the model, a suitable catchment was selected, and relevant data extracted for the catchment from the various data sources available. FORTRAN programs were written to enable many scenarios to be run easily.

The evaluation of the modelling approach was made by comparing model water quality predictions against available water quality data, and other studies. The assessment of the benefits of using a GIS based approach were partly derived from lessons learned in developing the application, and partly by discussions with staff at the Institute of Hydrology.

1.4 Report Structure

Following this introductory chapter, chapter 2 is a general review of modelling agricultural NPS source pollution using GIS. Chapter 3 documents the development of the case study application of the AGNPS model and the GIS ARC/INFO to a U.K. catchment. Running the model for various scenarios is documented in chapter 4, with the evaluation, conclusions and recommendations made in chapter 5.

The use of acronyms in this report reflects that generally used in the literature. Each acronym is written out in full on its first use, and in addition Appendix A provides a full glossary of all acronyms used.

2. LITERATURE REVIEW OF AGRICULTURAL NON-POINT SOURCE(NPS) POLLUTION MODELLING USING GIS

2.1 Introduction

Increasing concern over agricultural NPS pollution is a major worldwide trend (OECD,1986). In the U.S.A. it is considered to be a leading cause of the country's remaining water quality problems (USEPA,1985a; Alm,1990; Novotny et. al., 1989). In the European Community (EC) increasing concern is reflected in the recent adoption of a directive intended to limit diffuse pollution from nitrates (Water Bulletin,1991a;HoL,1989), and in the U.K. nitrate sensitive areas (NSAs) are in operation under section 112 of the Water Act (1989). Many studies, for example Roberts (1987), Roberts and Marsh (1987), and Croll and Hayes (1988), record increasing nitrate levels in both surface water and groundwater in the U.K.

The pollutant transport mechanisms of agricultural NPS pollution from runoff to surface water are complex, with hydrological, topographic, chemical transport, soil type and land use factors all potentially significant. Modelling using computers offers the potential to understand and manage this complexity cost-effectively and proprietary models are becoming increasingly available. Rose et. al. (1990) is a useful review of available models.

Models have made significant advances as computing power and accessibility has increased, but challenges remain. Management of larger data volumes is one of these, and Geographical Information Systems (GIS) offers opportunities in meeting this challenge.

2.2 Geographical Information Systems (GIS)

A geographic information system (GIS) can be defined as "a powerful set of tools for collecting, storing, retrieving, at will, transforming and displaying spatial data from the real world for a particular set of purposes" (Burrough,1986). It has great potential, indeed Parker (1988) believes that GIS is on the verge of a major advance from the convergence of increasing computer hardware and software capability, and the political will to search for more efficient approaches to resource management.

GIS offers major benefits to modelling, through its capacity to manage large data volumes cost-effectively (Spooner at. al., 1990), in a common spatial framework (Witt,1989); its potential to integrate with other key technologies such as remote sensing; and its ability to communicate spatially complex natural resource issues simply in graphical form via maps (Ciesla,1991; Walsh,1985).

Conceptually a GIS, and in particular ARC/INFO (ESRI,1990), can initially be thought of as storing a map comprising a range of geographical information. This information is stored as a series of layers named coverages. Each coverage stores information related to a unique geographical feature, such as roads, railways, rivers, land use or soil type. Although stored separately, these coverages can be overlayed to reconstitute the original map.

Each coverage can be stored in raster or vector format; a vector format is used by ARC/INFO. The basic coverage is stored as a series of lines called arcs. Nodes define the ends of each arc. Arcs form the boundaries of areas termed polygons. Thus a road coverage can be thought of as a series of arcs, and a coverage of land use can be thought of as a series of polygons. To the GIS they are stored as related arcs, nodes and polygons.

Each arc and polygon within a coverage is uniquely identified and related information can be stored in tables of columns and rows. Each row relates to one arc or polygon, and each column is an attribute of interest. For example each polygon within a coverage of soil type would have an associated row in a polygon attribute table. One obvious column in this table could denote the soil type, but others could be entered, for example the soil porosity. The tables form the basis of a relational database environment in which information can be analysed and presented. ARC/INFO has its own basic query language, but uses DBASE file structures allowing the use of this more powerful language.

The coverages themselves can be easily manipulated within the GIS. For example labels can be added and the coverages displayed using the graphics facilities available. Coverages can be overlaid and analyses carried out, for example to establish the areas with a particular soil type and land use.

2.3 NPS Pollution Models and GIS

Although there are a limited number of papers relevant to the use of GIS in NPS pollution, these demonstrate the benefits of GIS as a data resource and a management tool. Major themes in the relevant literature are the retention of the spatial dimension in the data allowing the synthesis of new information, and the integration of GIS with NPS pollution models. Other common themes include the close relationship between remote sensing and GIS, and the use of GIS to input data. The most common application themes are screening and management, particularly in risk mapping.

The advantages in retaining the spatial referencing of data are well explained by Potter et. al. (1986) who noted that many of the parameters required to model runoff and non-point source water pollution potential are geographic in character and are obtained from geographic sources, for example soil maps, topographic maps, land use maps, and aerial photographs. Modellers frequently extract these spatially organised data manually, only to input them to a non-spatially organised model. In the process of translating the information, the geographic character is lost, and with it the opportunity to explore the spatial dimension. Potter went on to describe an application for the prediction of runoff and non-point pollution potential, which was calibrated on a portion of a river basin in Nebraska. The system accepted digitally mapped information on soil type, topography, and land use, and other characteristics such as slope were calculated. The system could then generate three dimensional maps of runoff potential, sediment pollution potential, and faecal coliform potential. Potter also remarked on the potential of the application to promote better communication between researchers and policy makers.

Identification of risk areas in terms of pollution potential maps, or risk maps, has been the objective of other papers, that also demonstrate the integration between GIS and mathematical models, a development advocated by Magette et. al. (1989). Hession and Shanholtz (1988) used a GIS to identify and rank land areas based on NPS pollution potential, using the USLE and delivery ratios. For potential NPS pollution to groundwater, Evans and Myers (1990) produced risk maps using a GIS with coverages of land use and cover, soil permeability, septic tank distribution, depth to groundwater, hydroconductivity, and aquifer size. Predictive modelling and the DRASTIC relative weighting system was used to produce the maps. Important factors identified were depth to groundwater, net recharge, aquifer media, soil media, topography (slope) impact of the unsaturated zone, and conductivity of the aquifer. The system could also be used for hazard assessment. Pringle-Baker and Panciera (1990) also used a GIS (RIGIS) for groundwater protection planning and are looking to integrate this with solute transport models. They highlight major problems of source data accuracy and scale mismatch.

Applications with more management emphasis include Younos and Metz (1988) who used a GIS to identify potential agricultural land parcels best suited for land application of wastewater applications. Prato et. al. (1989) used a GIS to estimate erosion and water quality effects by applying management systems to farms in a watershed in Idaho, and Streng (1991) evaluated the effects of measures on groundwater quality from nitrates. Nachtnebel et. al. (1991) recently reported using a GIS with a groundwater model to assist in regional water management. The system comprises a database, GIS, and a two dimensional groundwater flow model. Leachate from dumping sites could also be evaluated.

General applications with a research emphasis include Couillard (1988), who estimated relative contributions of total nitrogen and phosphorus originating from point and nonpoint sources using a database combining data on drainage, land use, population, agriculture, and industry. Van Deursen et. al., (1991) used a GIS and a drainage basin model to analyze contamination from point and diffuse source loadings of cadmium in the Rhine river basin.

The application assessed cadmium sources from phosphate fertiliser, sewage sludge applications, urban sources and atmospheric deposition. Terstriep and Lee (1989) integrated an urban runoff model and a GIS for regional stormwater modelling and Hedges (1990) evaluated the effects of groundwater drawdown on vegetation using GIS to identify sensitive soils. Stuebe and Johnston (1990) compared manual and GIS approaches to the estimation of runoff volume in six catchments, concluding that the use of GIS is an acceptable alternative to conventional methods for larger catchments lacking relatively flat terrain.

The close relationship between remote sensing and GIS arises from the capability of remote sensing to efficiently supply large volumes of relevant data to GIS, which can then be merged and analysed with other data input from other sources. A good illustration is DelRegno and Atkinson (1988), who used LandSat satellite data merged with watershed level estimates of sediment yield and nutrient loadings to identify nonpoint pollution problems. Airola (1989) also showed this relationship in the digital analysis of Hazardous Waste site aerial photographs.

The use of GIS as a data resource is reflected in a major trend in the US to establish centralised georeferenced databases using GIS. Many states now have this powerful data resource. In Europe a similar trend is beginning to emerge in Germany (Buck and Plate,1990). The UK has no plans to establish such a data resource at the moment, although the use of GIS is generally being explored in a number of areas (Woodcock,1991;Dunn et. al., 1991).

2.4 The Agricultural Non-Point Source (AGNPS) Model

The Agricultural Non-point Source (AGNPS) model (Young et. al.,1989; Young et. al., 1987) is a surface runoff model intended for use by policymakers and managers for planning, management and screening (AGNPS,1990) of larger catchments, using data that is relatively simple to obtain. The emphasis of the model is deterministic and empirical. Temporally it is very simple, being event based. It models flow and sediment movement as well as nutrients (nitrogen and phosphorus) and chemical oxygen demand (COD).

AGNPS has model components for hydrology, erosion and sediment transport, and chemical transport. It does not model in-stream processes. The hydrology of the model comprises calculation of runoff volume, based on the SCS curve number method, and peak flow from an empirical relationship proposed by Smith and Williams (1980). Erosion of sediment is calculated using a modified form of the universal soil loss equation. Eroded soil is divided into five particle size classes, namely clay, silt, small aggregates, large aggregates and sand.

Erosion and runoff are calculated for each cell in the catchment, and routed from cell to cell (defined by the user) through the catchment to the catchment outlet. Sediment transport and deposition components are described by Foster et. al. (1981) and Lane (1982). The basic routing equation is derived from the steady state continuity equation, supported by equations for deposition and effective transport capacity, which uses a modified version of the Bagnold (1966) stream power equation.

The chemical transport model components are based on those for the CREAMS model (Frere et. al.,1980). Nutrient yield in the sediment adsorbed phase is calculated as the product of nutrient content in the field soil, sediment yield and an enrichment ratio calculated from sediment yield and a correction factor for soil texture. Nutrient yield in the dissolved phase is calculated as the product of soluble nutrient content in the field, flow, and an extraction coefficient. COD is assumed soluble and calculated simply as the product of flow, and assumptions of COD concentration derived from literature values. AGNPS also has model components for point source inputs, both from user defined sources, and sources from streambank, streambed and gully erosion. Point sources are added to flow from NPS pollution.

The spatial dimension is of major interest. Spatial variation is modelled by overlaying a grid square on the catchment. Information can then be input for a range of parameters for each cell. The model then generates flow, sediment and nutrient predictions for each cell, and routes movement through the catchment to the catchment outlet. Each cell may therefore be analysed as well as catchment outlet.

The model is written in FORTRAN, runs on an IBM compatible computer, is easy to install, and is well supported by a good user manual (Young et. al.,1990), and training and support service. The model also has a quarterly newsletter.

The user interface is generally very user-friendly, comprising a window style menu system, an integral spreadsheet to input parameters, and good facilities (including graphics) to analyze model outputs.

Ongoing model development (Needham, pers. communication) includes a continuous version of the model with links to a weather generator, subsurface water component, and a lake component. Version 3.65 (Young et. al.,1991) of the model creates an additional output file intended for easy transfer to a Geographical Information System (GIS).

The model has been tested on a preliminary basis for runoff estimation with reasonable results. Parts of the model have also been tested for sediment yield estimates and runoff (Bingner et. al.,1987). The chemical components have undergone initial testing

(Young et al.,1989) but limited availability of good field data means that testing has been limited.

The AGNPS model has been used in several states in the U.S.A to prioritise catchments for the potential severity of water quality problems, to identify critical areas within a catchment contributing to pollution, and to evaluate the effects of applying alternative management practices (Young et. al. (1989). AGNPS was also selected for use in two major water quality projects in Georgia, as a screening tool to identify potential NPS problems, and to assess storm sediment loadings (AGNPS,1991). Prato et al. (1989) have used the model to study erosion and pollution control in an Idaho catchment, and to estimate sediment loads in a Missouri catchment experiencing deteriorating water quality (AGNPS,1990). Koelliker and Humbert (1990) applied the model in catchments in Kansas, focusing on the use of the model for the effects of impoundments.

AGNPS requires input data at the level of the catchment and for each cell; tables 2.1 and 2.2 show the respective data requirements for each level.

Table 2.1

AGNPS Model Input: Catchment Level

Data Item	Data Description
Catchment Id.	Brief title for the catchment
Cell area	The area of each cell (acres)
Cell numbers	The total number of cells
Precipitation	Rainfall (inches)
EI Value	Energy Intensity Value

Precipitation is entered as a constant for the catchment and cannot be spatially varied. The drainage pattern is effectively defined by entry of receiving cells and drainage direction. Each cell is assumed to drain mostly to the one defined receiving cell. Other topographic factors include three slope factors to characterise land terrain; the slope length is a correction to allow for the fact that the USLE was based on 75ft slope lengths. Similarly there are three factors to characterise channels, if present in the cell in the form of a river, stream or ditch. Soils related factors include the SCS curve number, which is also related to land use. Mannings roughness coefficient reflects the interaction between the runoff flow and the land surface, either within a defined channel or related to land use. The USLE cover and management factor, and practice factor, reflect the impact on erosion of land use and management practices respectively. The surface condition constant is an adjustment to reflect the time it takes overland runoff to channelise. Two factors are available to input fertiliser application and availability.

Output data from the model comprises hydrological, sediment and chemical information. Table 3.3 summarises the data items available for the catchment outlet and for each cell if required. Note the use of imperial measurement, rather than metric.

Table 2.2

AGNPS Model Input: Cell Level

Data Item	Data Description
TOPOGRAPHIC PARAMETERS:	
Cell Number	The unique number of this cell.
Receiving cell	The cell number into which this cell mostly drains.
Aspect	Indicates principal drainage direction.
Slope	Average land slope (percent).
Slope Shape	Shape factor(straight,convex,concave)
Slope Length	Average field slope length.
Channel Indicator	Indicates existence of a defined channel within cell.
Channel Slope	Average slope of cell channel(if any)
Channel Side Slope	Average slope of channel side
SOILS AND SOILS/LAND USE PARAMETERS:	
K Factor	Soil erodibility factor for USLE.
Soil texture	Sand, silt, clay, or peat dominant.
SCS Curve Number	The appropriate SCS curve number for the cell soil type and land use.
LAND USE PARAMETERS:	
Mannings Coefficient	Roughness coefficient for channel
C Factor	Cover and management factor for USLE.
P Factor	Practice factor for USLE.
Surface Condition Constant	Factor based on land use.
Fertilization Level	None, low, medium, high.
Incorporation factor	Fertiliser left in top cm of soil(%)
COD factor	COD arising within cell.
OTHER PARAMETERS:	
Point source	Indication of point source within cell.
Gully source	Estimate of gully erosion from cell.
Impoundment factor	Presence of an impoundment terrace.

Table 2.3

AGNPS Model Output

Data Grouping	Data Items
Hydrology	Runoff Volume (inches).
	Peak Runoff Rate.
	Fraction of runoff from cell.
Sediment Output	Sediment yield (tons).
	Sediment concentration (ppm).
	Sediment size distribution.
	Upland erosion (tons/acre).
	Deposition (percent).
	Sediment from cell (tons).
	Enrichment and Delivery ratios.
Chemical Output	Sediment associated mass (tons/acre).
(Nitrogen &	Soluble concentration (ppm).
Phosphorus)	Mass of soluble material (lbs/acre).
(COD)	Soluble concentration (ppm).
	Mass of soluble material (lbs/acre).

2.5 Case Studies of AGNPS and GIS

This section focuses in more detail on two case studies that have used AGNPS and the GIS ARC/INFO. Other relevant studies include Evans and Miller (1988) who used a GIS to compute average values for spatial variables that were digitised for input to AGNPS, and Lee et. al. (1990), who integrated AGNPS and GIS for use in a pilot study of an Illinois catchment (Lee and Terstiep,1991).

The following case studies are based on the Highland Silver Lake watershed, Illinois, and the Owl Run watershed, in Virginia, USA.

2.5.1 The Highland Silver Lake Watershed

The Highland Silver Lake Watershed Project was part of the rural clean water program (RCWP) of Illinois, USA, concerned with reducing pollution from nonpoint sources by the introduction of best management practices (BMPs). The GIS ARC/INFO and the AGNPS model were used to evaluate proposed actions, and complemented a field monitoring programme (Lee and Comacho, 1987). AGNPS was selected because of its ability to reflect changes in management practices.

The watershed database comprised five component maps showing land use, soil types, stream network, slope, and subwatershed boundaries. Land use information was obtained from aerial photographs and from land ownership boundaries. These were digitised as polygons and their characteristics represented by an attribute data file. The soil coverage was digitised from field sheets with associated information in a soil attribute file. The stream network was digitised as line data, with a range of associated information. Slope information was based on contour maps, with equal slope areas delineated and digitised as polygons.

The model was verified against field data by varying rainfall input to the model between 0.7 and 5.9 inches, and comparing predicted values of runoff and suspended solids load against observed data. A visual comparison shows that the model output values pass through the scatter points of observed data, but there is a very wide scatter to the observed values. Discrepancies are claimed to be due to seasonal variations in land use and ground coverages in the watershed, and to variations in the antecedent moisture conditions before storm events. The model could not be calibrated against specific storm events due to lack of data, but rather was used to represent the average condition within a year. Prediction of lake sedimentation was 19,100 tons/acre/year, against a survey estimate of 27,850. Annual average predictions for water quality loads showed mixed results. Predictions of total suspended solids was good (2,917 against 2,580 tons/year), but nitrogen, phosphorus and COD load predictions were poor (510 against 145, 106 against 20, and 3414 against 1817 ton/year respectively). It was suggested that discrepancies could be due to the lack of sampling during storm events.

To evaluate the possible effects of best management practices (BMPs), the AGNPS model was run for several scenarios including the future condition of the watershed with and without the RCWP project, and for scenarios incorporating increasing numbers of implemented BMPs.

Alternative scenarios of the future with and without the project showed that the RCWP project could result in a significant (54%) reduction in sediment yields and associated nutrients. Soluble nitrogen also showed a marked (25%) reduction.

The analysis of increasing BMPs included better land management practices to reduce soil loss, grass waterways and impoundment structures, animal waste management practices, and fertiliser management practices. The analysis also explored the spatial variation in benefits arising from these practices. Good land management practices resulted in the most significant reductions in sediment yield and associated nutrients but there was significant spatial variation, for example from negligible reduction in sediment loss in some areas, to more than 50% reduction in others. This variation highlighted the most critical areas to be targeted first. Simulating the addition of grass waterways and impoundment structures resulted in marginal reductions in peak discharge, sediment yield, and nitrogen in sediment but again there was a marked spatial variation. The addition of animal management practices resulted in only a minor reduction in pollution. However a lower cropland fertilisation level indicated a reduction in soluble nitrogen that varied spatially from zero to 22%.

Further spatial analysis was carried out through the identification of critical areas. An analysis using the spatial capability of the model showed that the initial project definition of a critical area was a good surrogate for some pollutants, but not for others. The critical areas were displayed using the GIS.

The use of the model integrated with the GIS was therefore considered to be a powerful addition to the effectiveness of the project. However the report stresses the underlying limitations to modelling, as illustrated by the inconclusive verification exercise in the study. Limitations cited in the project report include variation between actual and model data due to seasonal variations not captured by averaging, changes in actual information after data capture, input errors, unavailability of data (e.g. conservation practice values), uncertainty in model relationships, and the applicability of a general regression model to the specific area of study. The sensible conclusion of the report is that the reductions predicted by the model should only be considered on a relative basis, with much less credibility given to the absolute values predicted.

2.5.2 The Owl Run Watershed

This project, documented by Hession and Huber (1989), arose from the Chesapeake Bay Agreement in 1983, that established a framework for cooperative effort between Virginia, Pennsylvania, Maryland, the District of Colombia and the USEPA in addressing all sources of pollution in the Bay basin. An important objective of the project was to achieve a 40% reduction in nitrogen and phosphorus entering the bay by the year 2000.

The Virginia Agricultural Best Management Practices (BMPs) Cost Share Program was designed to encourage voluntary application by farmers of BMPs, such as conservation tillage and animal waste storage facilities. To quantify the consequences for water quality an evaluation program was undertaken comprising field monitoring and analysis, water quality modelling, and the development of a comprehensive natural resource GIS for Virginia (VirGIS).

Owl Run watershed has been the subject of a ten-year monitoring programme, and AGNPS was used to model the watershed to test the model's ability to predict the effectiveness of BMPs. Relevant data for the catchment was extracted from VirGIS, and input to ARC/INFO which was then used as a data source for the model. Full details of the implementation are in Hession & Huber (1989) but the following summary illustrates the general approach.

ARC/INFO coverages were generated, from VirGIS, for soils, land use, field boundaries, stream networks, elevation and watershed boundaries. A 4ha grid coverage was generated in ARC/INFO and all coverages were limited to the watershed by intersecting them with the overall watershed boundary. Attribute tables were entered into the INFO database for soils, land use, curve numbers and field use/land use. The soils table relates each soil to the AGNPS required values of soil erodibility(K), field slope length, soil texture and hydrologic soil group. The land use table relates land use to the AGNPS input values of Manning's roughness coefficient, cover management factor(C), practice factor(P), surface condition constant, fertilisation level and availability, and COD factor. The curve number look-up table relates SCS curve number to each land use/soil combination. The field/land use lookup table relates field and land use for each year within the Owl Run watershed.

These tables were used to generate additional coverages of land use (using field boundaries), hydrologic soil group, and curve number. The grid coverage was then combined respectively with the soils, land use, and curve number coverages and statistical routines used to create weighted values for each within the grid cells. Manual procedures were used to generate values for receiving cell and aspect, slope shape, channel slopes, and point sources, feedlots, gully sources and impoundments, showing that the interface between the model and ARC/INFO was only partially automated.

Validation of the model was carried out using simulations for runoff volume, peak flow, total nitrogen, total phosphorus, and total suspended solids between 1986 and 1988. Plots of simulated against observed data do not look entirely convincing, but the predictions pass through the scatter points, and the authors attribute discrepancies to seasonal land use and ground cover variation, and soil moisture variations.

Model runs were carried out for a baseline condition reflecting 100% afforestation, a pre-BMP condition, and a post-BMP condition which essentially comprised animal waste management facilities and lower fertilisation application rates. For each scenario six storm events were simulated. The baseline contributions of nitrogen and phosphorus were estimated to be 9% and 7% respectively. The estimated reduction in nutrients due to BMPs was predicted to be an average of 42%, in line with the target set for the overall programme.

The major conclusion from this initial exercise was that further testing of the model is required, although it is suggested that the BMPs are working as intended. The major benefit of the GIS approach is cited as simplified data management and a reduction in difficulty and time involved in creating data input to the AGNPS model. In a similar exercise for another watershed covered by the programme, Hession (1990) suggested the benefits of the GIS approach as its flexibility, potential for reuse and ease of updating compared with a manual approach.

3. THE BEDFORD-OUSE APPLICATION

This chapter, and chapter 4, describe the case study to apply the model AGNPS and the GIS ARC/INFO to a UK catchment. This chapter describes the development of the application in terms of software and data sources to a point where input data to the model is as accurate as possible and the model is ready to run, and chapter 5 describes running the model under various scenarios and analyzing the output.

Section 3.1 presents the criteria for selecting a catchment for study and provides a general description of the selected catchment. Section 3.2 is a summary of the system developed to implement the application, and section 3.3 describes in more detail the data sources used. Section 3.4 describes the translation of these sources into input data for the model, with output data described in section 3.5.

3.1 Catchment Selection

The criteria for selecting a suitable catchment to study were considered to be catchment size, agricultural activity, data availability, and achievibility. Catchment size is important as AGNPS was developed for sizeable catchments, but the size should not exceed the model's capacity constraint. Agricultural activity and related water quality issues should ideally be a feature of the catchment, so that the ability of the model as a management tool can be explored. Data availability is clearly desirable, for possible comparisons of model predictions with actual observations and the predictions of other models. Finally the application should be achievable in the project timescale.

On these criteria the Bedford-Ouse catchment was considered suitable, and the (sub)catchment upstream of Bedford was selected for study. Plate I illustrates the main catchment features, and plate II shows the overlying grid network.

The area of the catchment is 1465km^2, which is a reasonable size for the study, but is within the limits of AGNPS. There is also the link between agriculture and water quality, observed by Beck and Finney (1987), who commented that "the rural character of the catchment prompts a more urgent interest in the nonpoint sources of nitrate nitrogen, the concentrations of which at Clapham, where water is abstracted for potable supply to Bedford, have frequently exceeded the WHO's recommended upper bound of 11.3mg/L-N". Beck and Finney's paper is associated with the Bedford-Ouse study, which was a major exercise carried out by Anglian Water Authority in connection with the construction of facilities for the new city of Milton Keynes, and included water quality modelling and validation studies. Models developed for the 54km river stretch between Milton Keynes and Bedford include steady state (Fawcett,1975), dynamic-stochastic (Whitehead,1975; Whitehead et. al., 1981), and operational management models (Beck and Finney, 1987). These studies provide good prediction data and field observations, and it is readily available for comparison purposes. River flow data is also available from gauging stations, and further water quality data, if required, is potentially available from Her Majesty's Inspectorate of Pollution (HMIP). Data availability, and the familiarity of the catchment to the project supervisors, also suggest that the catchment offers the best opportunity to complete the application efficiently in the given timescale.

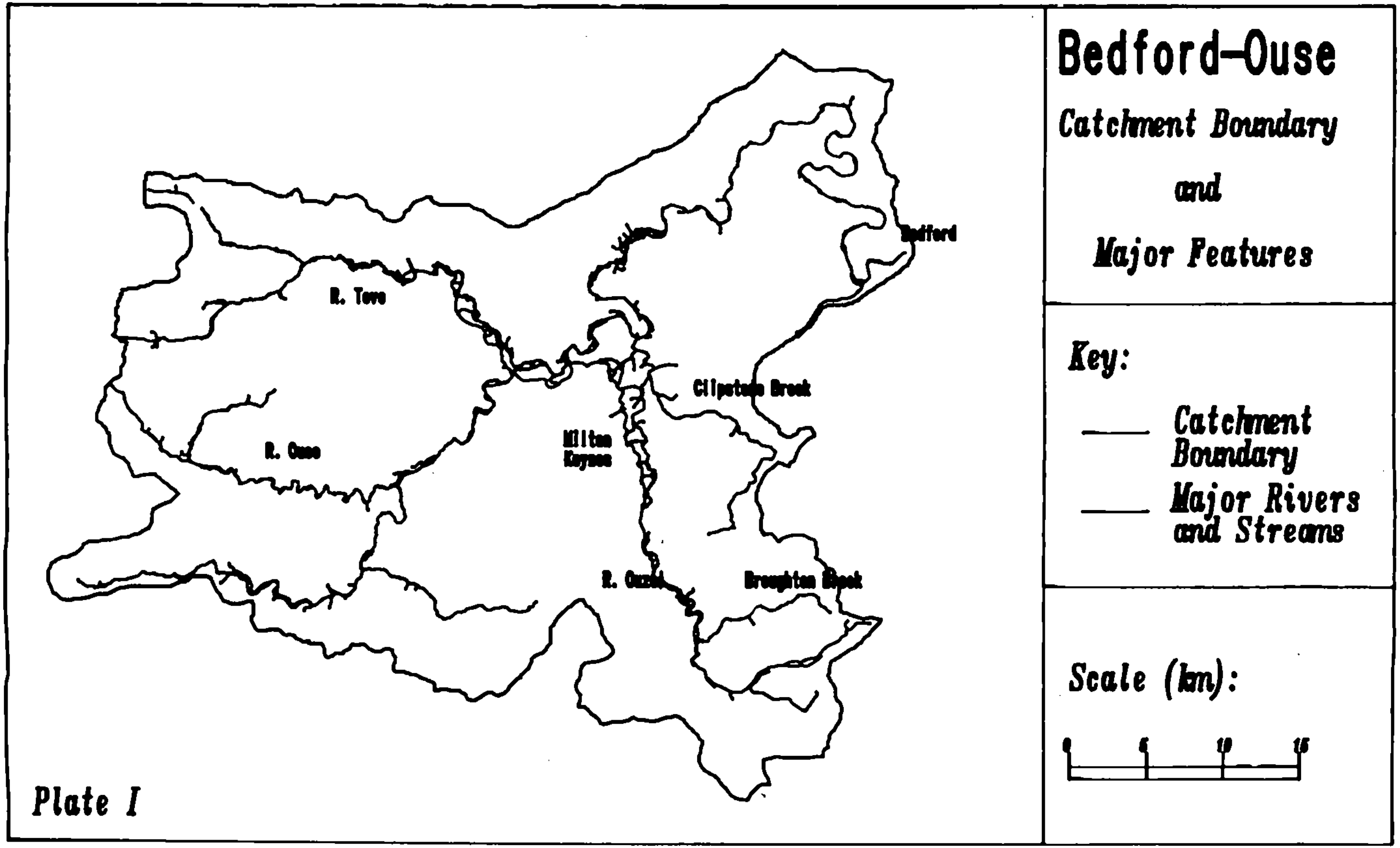

Bedford
R. Tove
R. Ouse
Milton Keynes
R. Ouzel
Broughton Brook
Bedford-Ouse
Catchment Boundary
and
Major Features
Key:
Catchment Boundary
Major Rivers and Streams
Scale (km):
0
5
10
15

Plate I

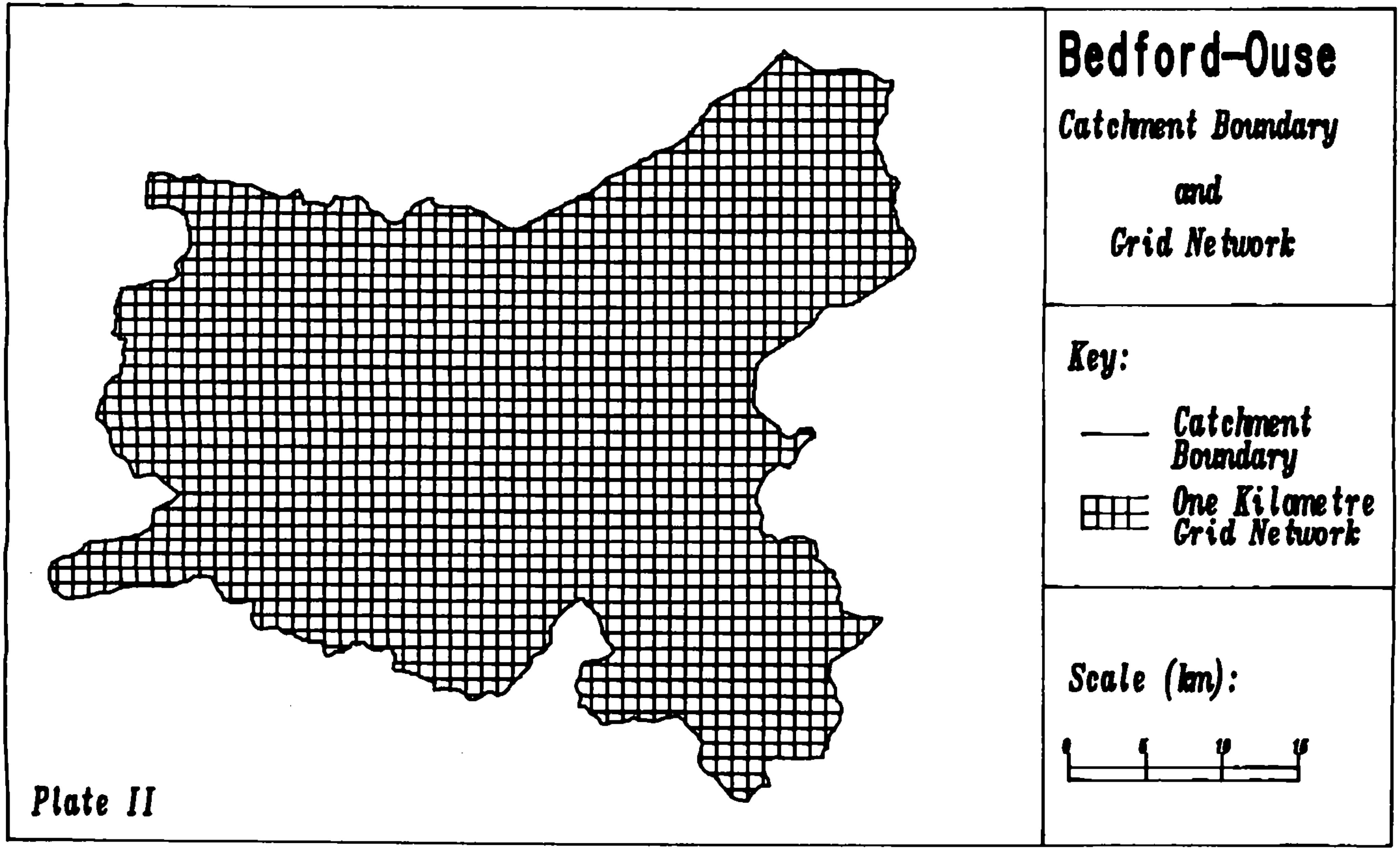

Bedford–Ouse
Catchment Boundary
and
Grid Network
Key:
Catchment Boundary
One Kilometre Grid Network
Scale (km):
0
5
10
15

Plate II

3.2 System Overview

A schematic overview of the system to implement the Bedford-Ouse application is presented in figure 3.1.

The hardware platforms used include the IBM 4381 mainframe running the operating system VM/CMS, and an IBM compatible PC with 4 Megabytes of memory, a maths co-processor, a 300 Megabyte hard disk, and a floppy disk drive. This size and configuration of PC was necessary to run the GIS software, although in practice the extended memory could not be used due to ARC/INFO limitations. The PC did not have direct access to the mainframe. Therefore data transfer between the mainframe and the PC was achieved by using an another PC with 3270 terminal emulation to the mainframe, and a utility to send and receive data between a floppy disk and mainframe data files. The floppy disk could then be transferred between PCs.

The mainframe software of importance to the project was the ORACLE database management system (DBMS) running standard query language (SQL), and the FORTRAN programming language. The PC software of importance was the GIS ARC/INFO (ESRI, 1990) and the AGNPS model software (Young et. al.,1991). Also of great assistance was the NORTON utility for the identification of AGNPS file structures, which were often different from that stated in the user manual.

The source data for the project were almost exclusively held within ORACLE tables set up on the mainframe. Data on land use, soil type and altitude were kept in respective tables with a common format that, from a user perspective, effectively represent a one kilometre square grid system (total size 660*1230 kilometres) overlaying the UK. Each row within a given table represents one square within the grid system, and has data identifying its grid position (easting and northing) and values relevant for that square, for example soil type within the square.

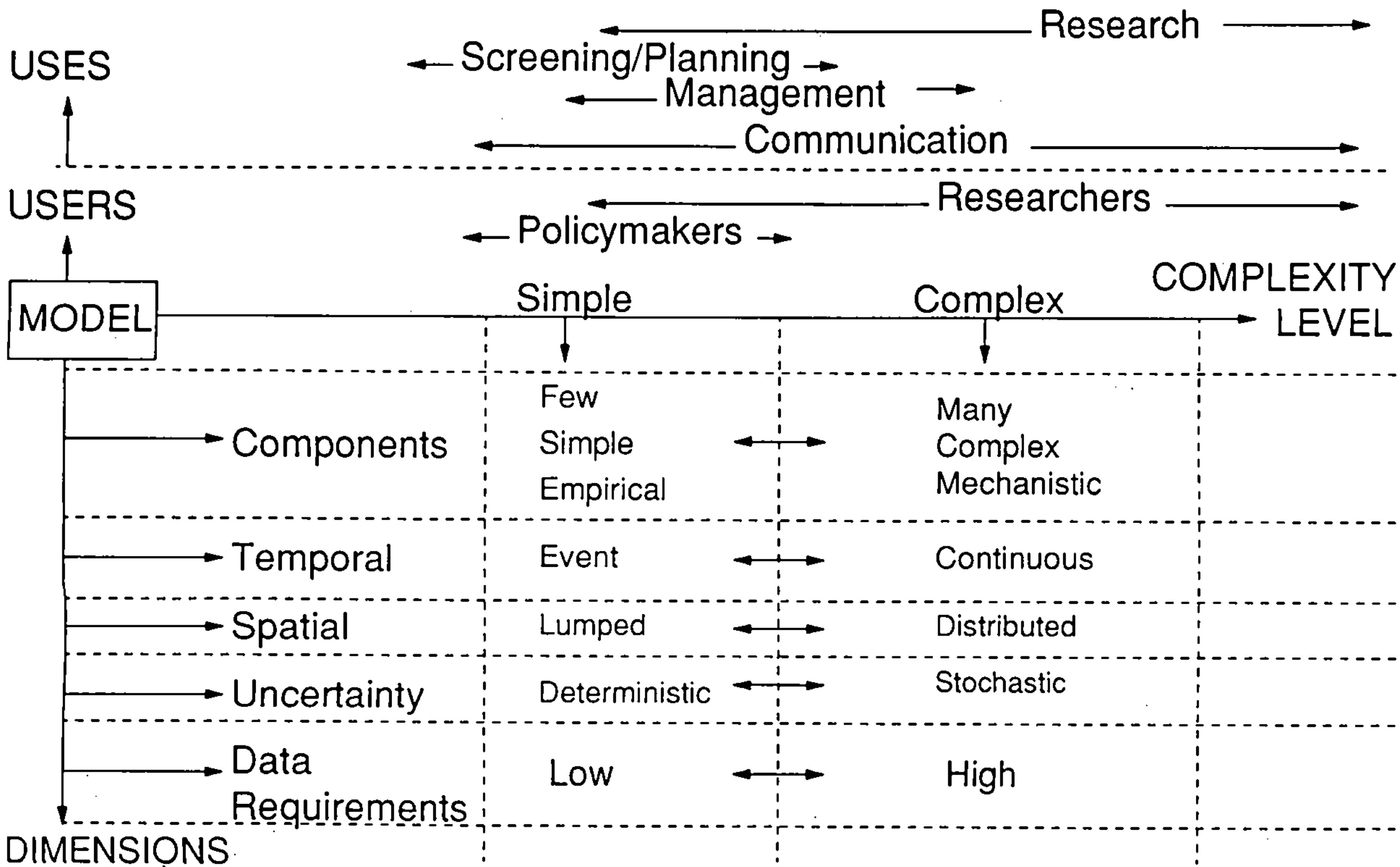


Fig. 3.1. Key Model Concepts

The digitised stream network and catchment boundary were also held in ORACLE tables, and essentially comprise lists of x,y (easting,northing) co-ordinates representing points on the lines (arcs) of the stream network or catchment boundary. Data for each catchment was held by hydrometric area identification, and there was also general information held for each catchment in a header record, defining catchment area, and the minimum and maximum extent (x,y co-ordinates) of the catchment.

Data on soil type, land use and altitude for the Bedford-Ouse catchment was selected by initially using the catchment boundary information (minimum and maximum extent) that define the rectangular "window" within which the catchment can fit. This window was used to initially select soil type, land use and altitude data within the defined rectangle from the relevant ORACLE tables. Data transfer was therefore substantially reduced to a manageable level while maintaining the data in a format that could be easily transferred to the GIS. Further selection of data, to the precise catchment boundary could only be efficiently done within the GIS.

Data on land use, soil type and altitude, for the relevant window was selected using SQL and output to extract files with records ordered by northing and easting coordinates. From a user perspective the data was ordered, row by row, from the top left of the window to the bottom right of the window, a format appropriate for input to the GIS after further processing. For each extract this additional processing primarily entailed the conversion of the extracted file to the Non-compressed ASCII (NAS) file format that is a valid input format for the ARC/INFO command POLYGRID. This additional processing was carried out using a FORTRAN program for each extract. Advantages of using the NAS file format include the ability to view files easily using a text editor, and the fact that data can be extracted from ARC/INFO to a NAS format, thus providing a level of standardisation for the model input program.

The catchment boundary and stream network were transferred to the GIS in a similar way to the grid-based data, but extract files essentially contained long lists of coordinates defining the arcs, and these were processed into input files supported by the ARC/INFO command GENERATE.

The GENERATE command enabled the river network and catchment boundary data to become respective coverages in ARC/INFO. Similarly the GRIDPOLY command enabled the rectangular "window" data for land use, soil type, and altitude to become respective coverages. An additional coverage was generated to represent the one kilometre grid. These rectangular coverages were converted to coverages with the precise outline of the catchment by using the catchment boundary coverage and the ARC/INFO overlay command INTERSECT. These catchment coverages could then be used for display purposes, and to create additional NAS files for the catchment grid and channel identification using the ARC/INFO command POLYGRID, for subsequent input to the model input program.

The model input program, written in FORTRAN, took the NAS files as input and translated the data into the parameters required by the AGNPS model, and in the standard input file format required by the model. Output files from the model were processed by the model output program, also written in FORTRAN, which output NAS files for input to the GIS for display purposes.

3.3 Source Data

This section describes, from an environmental perspective, the source data used in the project. The general choice of data sources used was limited to that readily available within the timescale, and not necessarily the best. However this approach was consistent with the primary objective of the project, to achieve an application of the model.

The main data sources used relate to soil type, land use, altitude, river network and catchment boundary. These are each described in more detail below, with miscellaneous data described in sub-section 3.3.5.

3.3.1 Soil Type

This information is taken from the Hydrology of Soil Types (HOST) classification, made available by the Institute of Hydrology. A good summary of the development of this classification can be found in Boorman and Hollis (1991).

Soil type has a major influence on hydrological processes and on the overall response of a catchment. The Winter Rainfall Acceptance Potential (WRAP) was an early attempt to classify soils according to their hydrological response, and HOST was developed to provide improved precision and predictive qualities. From validation studies HOST has been shown to explain over 80% of the variation in base flows (as measured by Base Flow Index - BFI), and 60% of the variation in runoff (as measured by standard percentage runoff - SPR).

The HOST classification is based on an analysis of the hydrologically important parameters related to soil and its underlying substrate. The most significant parameters are soil hydrogeology, depth to aquifer or groundwater, presence of peaty top soil, depth to a slowly permeable layer, depth to gleyed layer and integrated air capacity. Soil hydrogeology differentiates between mechanisms of vertical water movement and substrate permeability. Peaty top soil indicates saturated surface conditions. A slowly permeable layer promotes lateral water movement at the expense of percolation. Gleying is caused by intermittent waterlogging. Integrated air capacity provides a surrogate for permeability in permeable soils and substrates.

There are obviously many potential combinations of the important parameters. The most significant combinations are represented in a classification system comprising 29 classes. Each class has a general description that, to some extent, is subjective. Lower classes tend to be more permeable, but the relationship between HOST class and permeability is not straightforward.

Each kilometre square on a grid overlying the UK has been analysed for the HOST classes present in the square, and the percentage of the square taken by the most significant classes is available.

For the purposes of this project only the most significant class in each square was available. Table 3.1 is a summary of the dominant HOST classes in the Bedford-Ouse catchment, and the total number of squares (square kilometres) in which each class is dominant in the catchment. The table also includes the general HOST description for that class. Plate I is a graphic representation of the dominant HOST class distribution in the catchment, produced using the ARCPLOT facility of ARC/INFO.

Table 3.1

Bedford-Ouse Catchment

HOST Classes

HOST Class	Area (km²)	Class Description
1	231	Weakly consolidated microporous substrate, composite matrix and fissure flow.
2	26	Weakly consolidated macroporous substrate, intergranular flow predominant.
4	29	Unconsolidated macroporous substrates, intergranular flow.
6	17	As 4, but with high impermeable layer or gleyed layer.
7	47	As 5, but with high impermeable layer or gleyed layer.
17	153	Higher soil water storage, slowly permeable substrate.
19	253	Higher soil water storage, impermeable soft substrate.
20	611	Lower soil water storage, slowly permeable substrate.
22	64	Lower soil water storage, impermeable soft substrate.
97	30	(Predominantly urban).

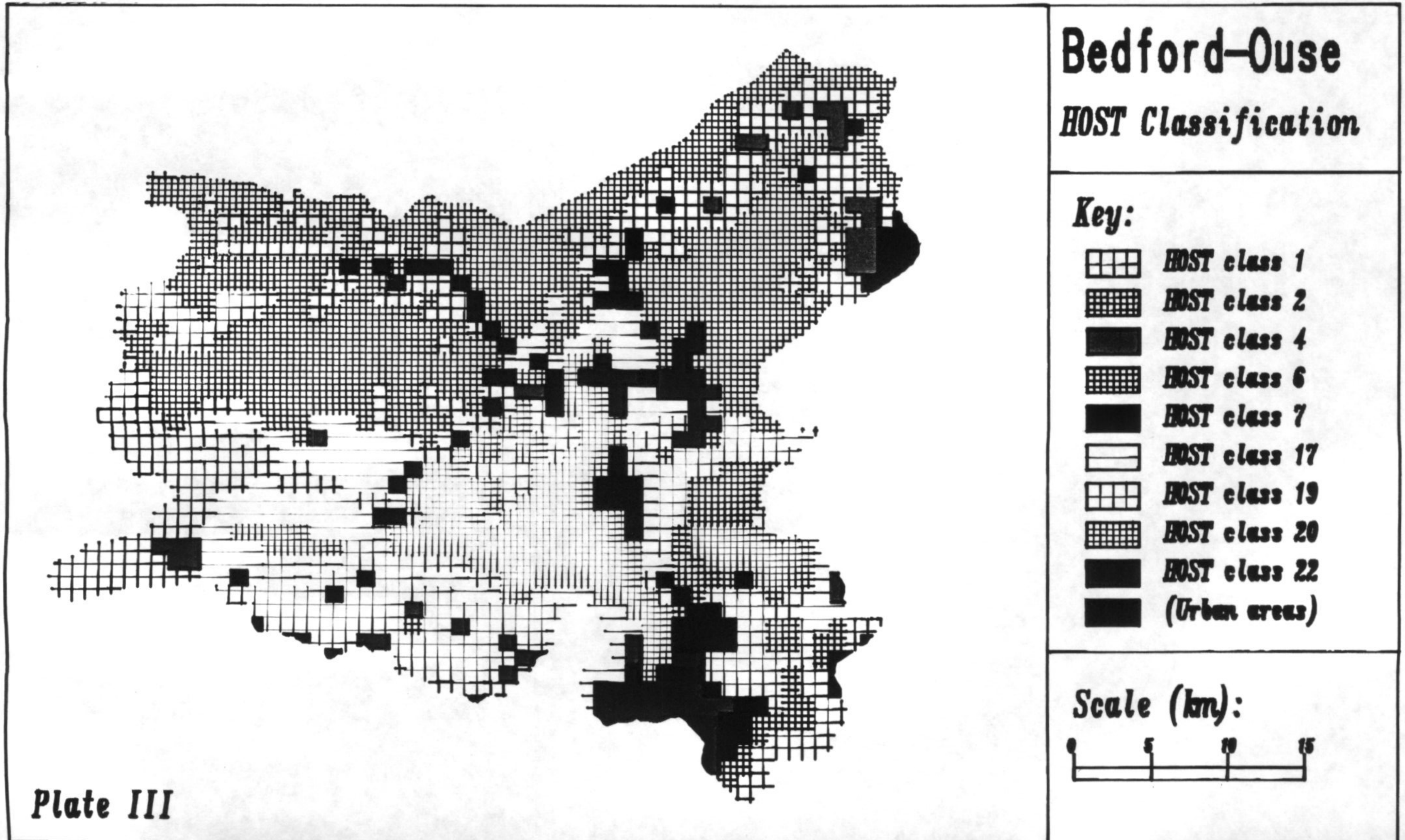

Bedford–Ouse
HOST Classification
Key:
HOST class 1
HOST class 2
HOST class 4
HOST class 6
HOST class 7
HOST class 17
HOST class 19
HOST class 20
HOST class 22
(Urban areas)
Scale (km):
0
5
10
15

Plate III

3.3.2 Land Use

This information was kindly provided by the Institute of Terrestrial Ecology, and is taken from a land classification scheme developed by the Institute, and described in Bunce et. al. (1981) and ITE (1990).

The land classification scheme arose from a need to provide a description of the land types in Great Britain as a sampling framework for field study. A complete census of most environmental parameters would have been impractical, both logistically and financially, and a land based study remains impractical today.

The principle behind the scheme is that major significant ecological variables can be associated with environmental variables that are easily recorded from cartographic sources. If these environmental variables are recorded for various land areas, statistical techniques can be used to identify and classify common patterns. Consequently land areas can be grouped into a number of discrete classes, with the number of classes arbitrarily selected by the researcher but generally reflecting the purpose to which the classified information is to be used for.

To develop the scheme, 1228 one kilometre squares were used as a sample base, and a total of 47 environmental variables for climate, topography, human geography and geology and drift were recorded. By division and further measurement 281 attributes resulted. The data were subjected to Indicator Species Analysis (ISA), and the classification stopped after five levels of division produced 32 classes. The classification, started in Cumbria, has now been extended to the whole of Great Britain (ITE,1991), which means that each kilometre square on a grid overlying the UK has been assigned to a land class. The present classification is based on 1984 data.

For the purposes of this project the land class is the only available data to identify the land use (e.g. cultivated land, pasture etc.). The statistical nature of the scheme means that each land class has an associated prediction of the land use distribution, in terms of percentages of land likely to be used for cultivation, land, urban etc. As with soil type this project took the highest predicted land use as the dominant land use for a given square. Table 3.2 presents a summary of the land classes present in the Bedford-Ouse catchment, together with the total number of squares (square kilometres) of each class within the catchment, and the predicted land use distribution for each class. Plate II is a graphic representation of the land classification distribution in the catchment, produced using the ARCPLOT facility of ARC/INFO.

Table 3.2
Bedford-Ouse Catchment
Land Classifications

Land Class	Area (km^2)	<--- (Predicted Land Use(%) ---> Urban	Wood land	Grass	Cultivated Land	Other
1	80	13	15	46	23	3
2	55	22	18	33	26	1
3	119	22	3	18	54	3
4	29	39	22	8	29	2
9	19	17	7	23	48	5
10	1	13	11	38	34	4
11	1129	17	4	28	50	1
12	28	31	4	3	61	1

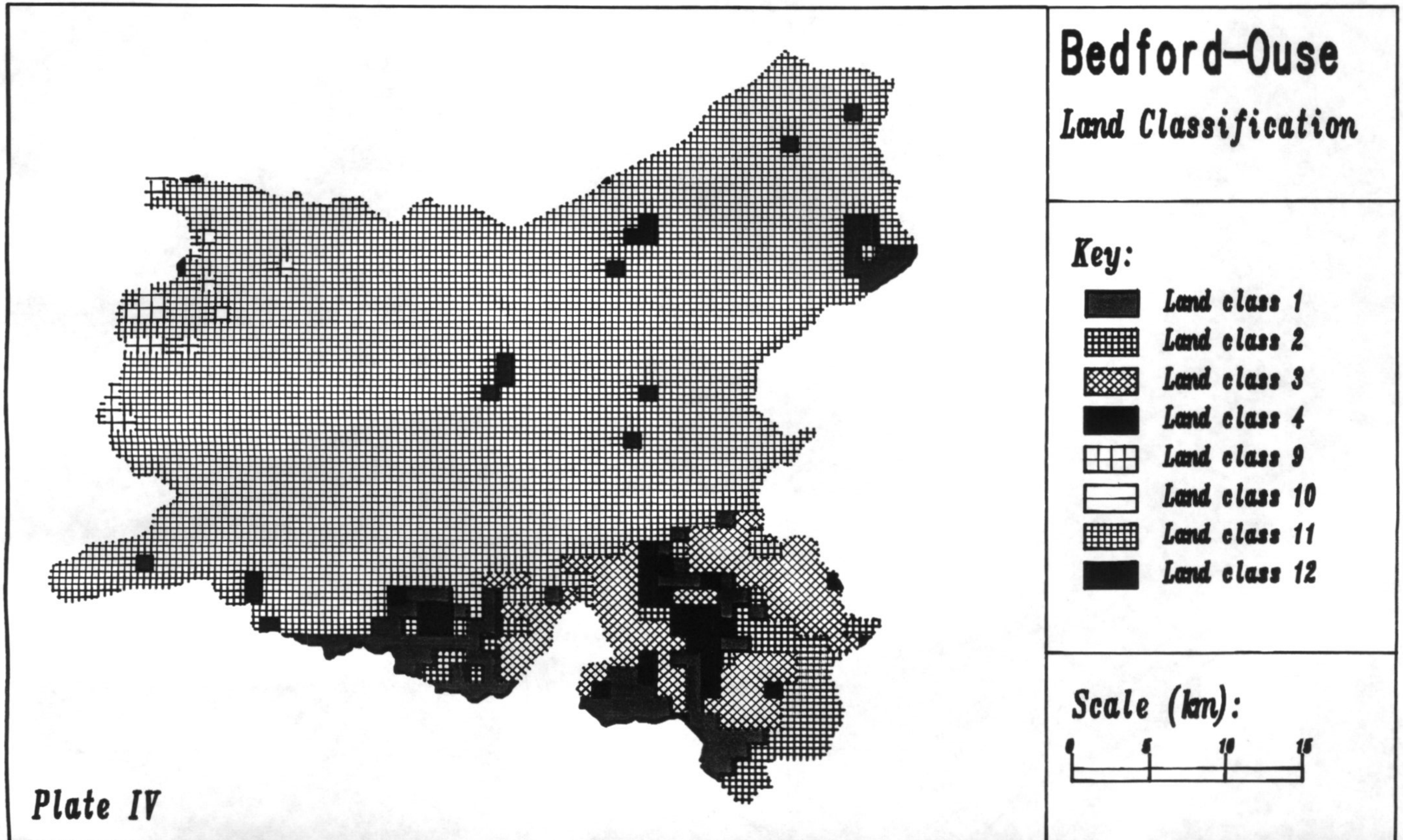

Bedford–Ouse
Land Classification
Key:
Land class 1
Land class 2
Land class 3
Land class 4
Land class 9
Land class 10
Land class 11
Land class 12
Scale (km):
0
5
10
15

Plate IV

3.3.3 Altitude Data

This information was also kindly provided by the Institute of Terrestrial Ecology, and is also data related to the land classification development described in section 3.3.2.

The dataset provided had a range of information for each kilometre square of the grid overlying the UK. This information comprised mean height of the square, gradient, slope, northerly aspect, easterly aspect, and the distance to the nearest hill and valley. Unfortunately it was not possible to obtain detailed data definitions for each data item and it was decided unwise to use the slope and gradient data because they were obviously too high to describe the gentle slopes typical of the Bedford-Ouse catchment. Therefore only altitude data was taken, and used to derive slope using an algorithm within the model input program (see section 3.4).

Table 3.3 presents a summary of the altitude distribution in the Bedford-Ouse catchment, including the total number of squares (square kilometres) within each altitude range. Plate III is a graphic representation of the altitude distribution in the catchment, produced using the ARCPLOT facility of ARC/INFO.

Table 3.3

Bedford Ouse Catchment

Altitude Variation

Altitude Range	Area (km^2)
< 50	95
50-75	222
75-100	464
100-125	454
125-150	210
>150	13

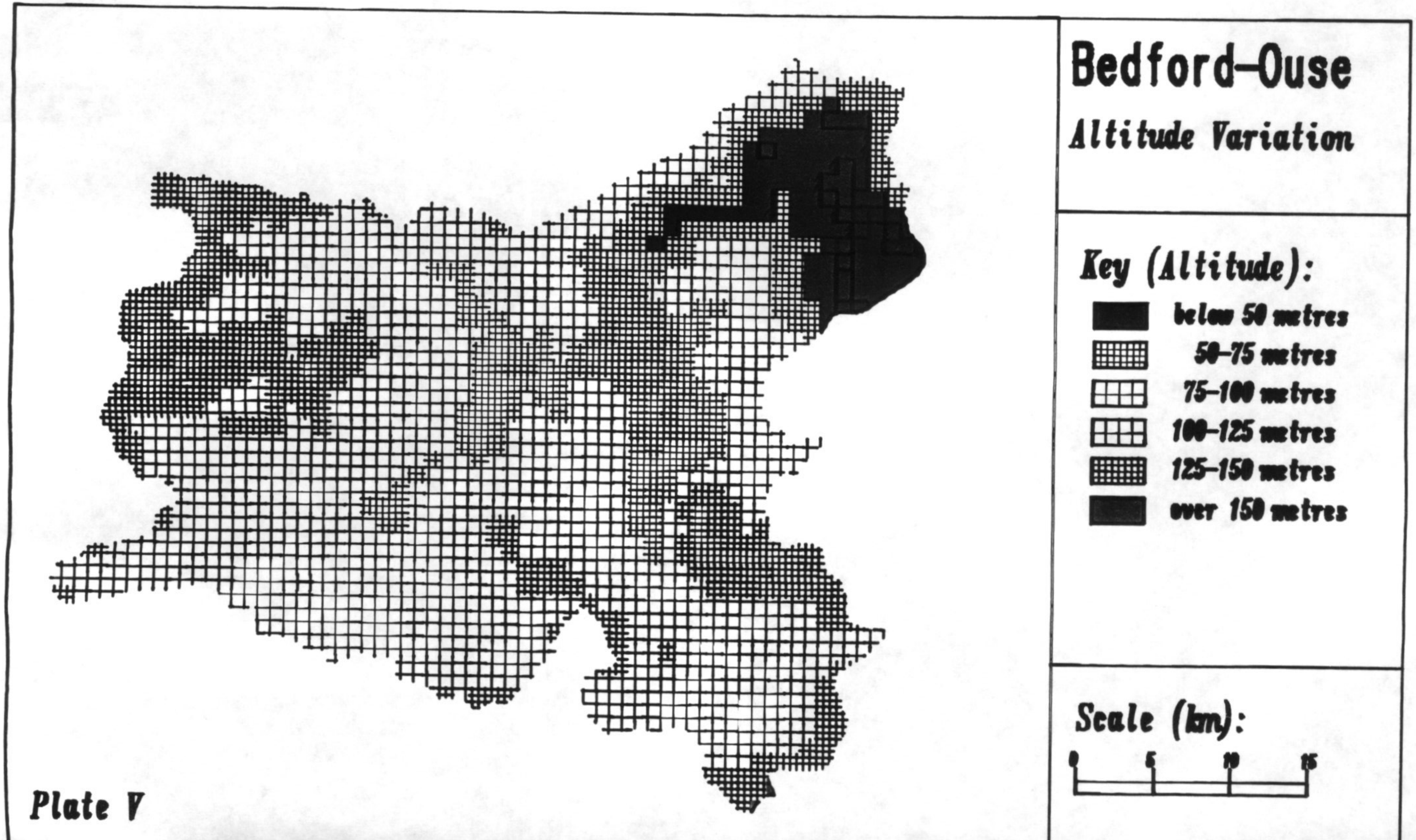

Bedford–Ouse
Altitude Variation
Key (Altitude):
below 50 metres
50–75 metres
75–100 metres
100–125 metres
125–150 metres
over 150 metres
Scale (km):
0
5
10
15

Plate V

3.3.4 River Network and Catchment Boundary

This information was available from the extensive information available at the Institute of Hydrology, and is related to the water surveying responsibilities carried out by the Institute and other organisations in the UK. An interesting account of the development of water surveying in the UK can be found in Lees (1985).

Essentially the UK is divided into hydrometric areas, related to gauging stations that form an extensive network for monitoring flow throughout the UK. The associated numbering scheme ensures that each gauging station, and hence hydrometric area, is defined by a unique number. The relevant number for the Bedford-Ouse catchment, upstream of Bedford, is 033002.

The hydrometric area boundaries (catchment boundaries) and associated river network for each area have been digitised and stored in ORACLE database, stored by hydrometric area identification. This information is now central to the water information system (WIS), a major software product under development at the Institute of Hydrology.

Plate IV is a graphic representation of the stream network of the Bedford-Ouse catchment. Plate V is a demonstration of the OVERLAY capability of ARC/INFO. Altitude and stream network are presented together.

3.3.5 Other Data

The only other category of source data required was precipitation, as the model requires input of storm event levels (in inches). A judgement was made as to a reasonable storm event, based on hourly rainfall records from weather gauges near to the catchment.

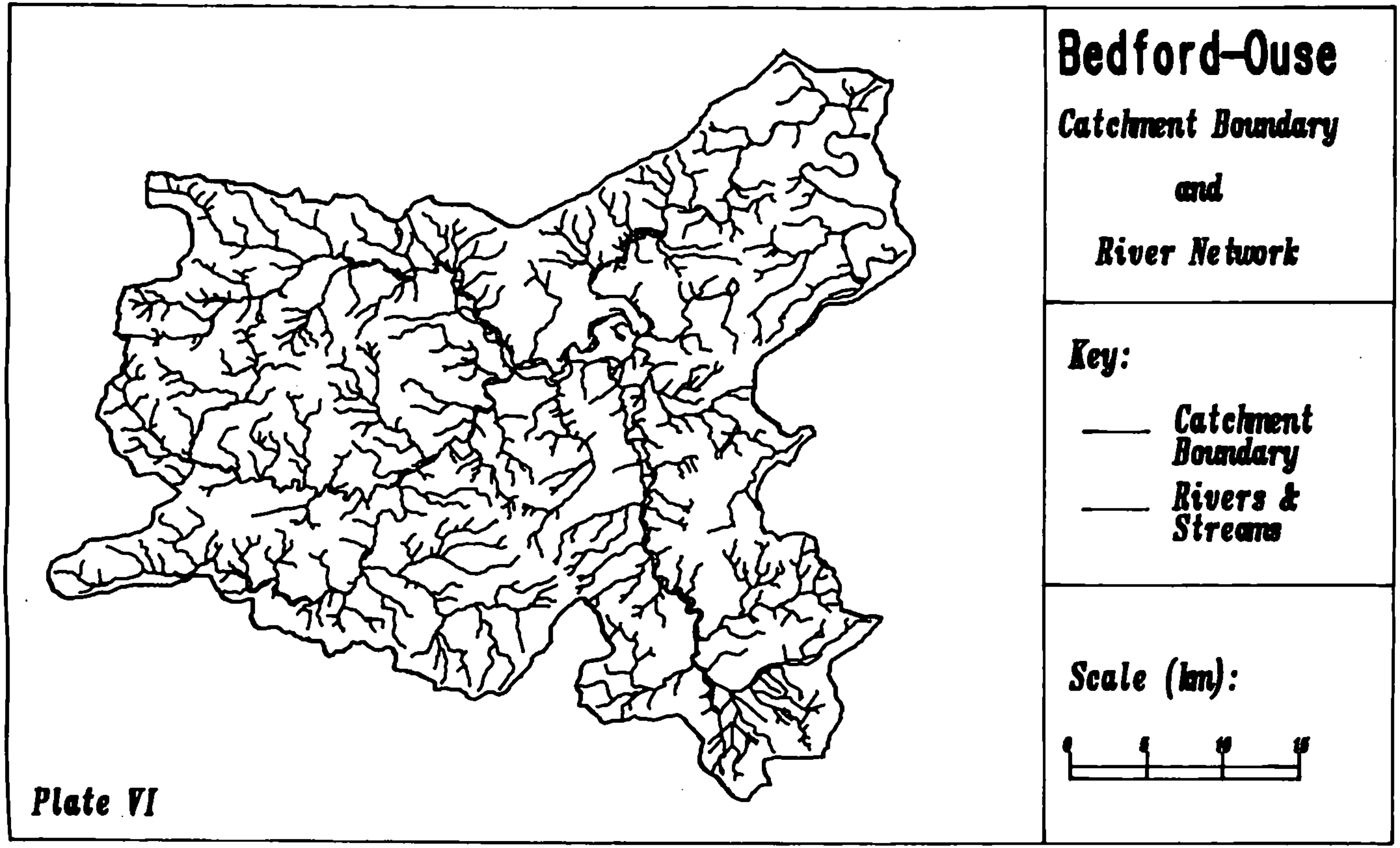
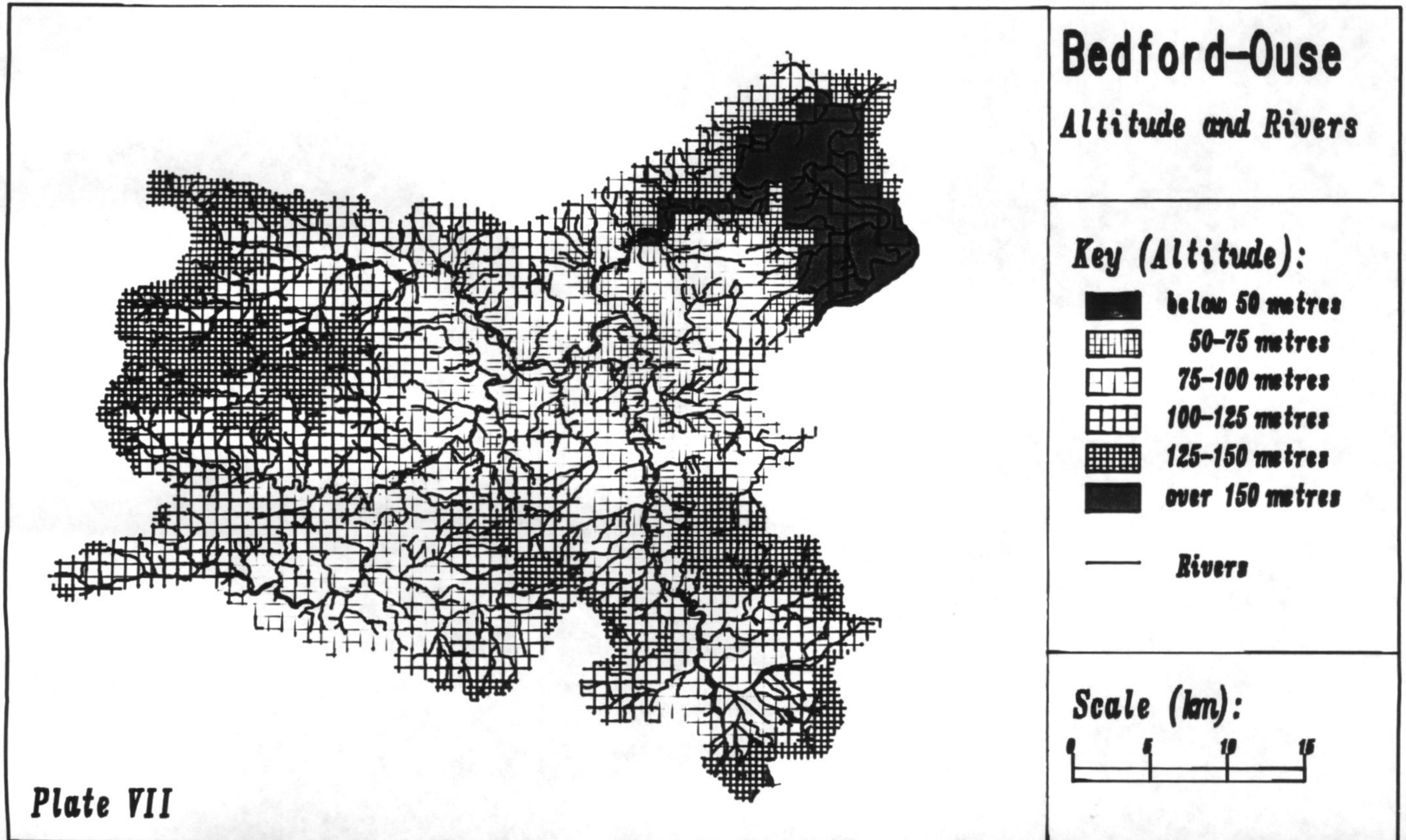

Bedford–Ouse
Catchment Boundary
and
River Network
Key:
Catchment Boundary
Rivers & Streams
Scale (km):
0
5
10
15

Plate VI


Bedford–Ouse
Altitude and Rivers
Key (Altitude):
below 50 metres
50–75 metres
75–100 metres
100–125 metres
125–150 metres
over 150 metres
Rivers
Scale (km):
0
5
10
15
Plate VII

3.4 Model Data Input

This section describes how the source data described in section 3.3 were translated into data required by the AGNPS model. The objective was to establish the best estimate of all model parameters for the Bedford-Ouse catchment. In some cases this was relatively straightforward, but in others it was very difficult, often due to data unavailability, inappropriate data, and the subjective nature of the data. Problems are described throughout this section as relevant, and assumptions documented where made.

The model input parameters required were described in section 2.2.3. For the Bedford-Ouse application they are described in the sub-sections below, under the headings of topographic, soils and soils/landuse, landuse and other parameters. Program details are summarised in subsection 3.5.

3.4.1 Topographic Parameters

Model topographic-related parameters are receiving cell, aspect, land slope, slope shape, slope length, and channel indicator, slope and side slope.

For each cell, the receiving cell is that which receives the greatest proportion of drainage from the cell, and the aspect is essentially the direction of the receiving cell. The only relevant data available to calculate these was the mean altitude of each cell.

The initial algorithm programmed was, for each cell, to look at the surrounding eight cells and assume the receiving cell to be the one with the lowest mean altitude; the aspect was then the direction of this cell. However because of the relatively flat terrain, this approach resulted in a number of circular drainage paths in the model of the catchment, and the model could not be run with these.

A more complex approach was therefore attempted. Using ARC/INFO, and specifically the river network coverage, a corresponding grid (NAS) file was created using the ARC/INFO command POLYGRID. This file identified the cells in which there were rivers or identifiable streams. The cell containing the catchment outlet was then identified using the ARCPLOT WHEREIS command, which gives the co-ordinates of a location identified with the PC mouse on a coverage presented on the screen (using ARCEDIT). Having located the outlet cell, an algorithm was programmed to start at the outlet cell, and work outwards through the layers of surrounding cells, including them in the drainage network according to rules applied to each cell. These rules essentially ensured that cells with a channel drained to adjacent cells that had a channel and were already included in the drainage network. And cells without a channel were either drained to an adjacent cell with a channel and already included in the drainage network, or drained to an adjacent cell without a channel but already included in the drainage network. This approach proved very successful in ensuring a drainage path to the catchment outlet, but to what extent it represented reality could not be established. Additional inaccuracies are also inevitable because of the model constraint assuming all runoff drains to the one selected adjacent cell.

The land slope for each cell was assumed to be the average of the mean height difference between the cell and the surrounding cells, divided by the mean distance between the cells.

There was no information available on slope shape (i.e. straight, convex or concave), so a uniform shape (input value 1) had to be assumed for all cells.

Slope length is a factor related to the universal soil loss equation, allowing for different slope lengths from the standard 75ft plots used to generate the universal soil loss equation. The factor had to be chosen from a table that presents factors for various combinations of slope categories and area numbers. The gentle slopes of the Bedford-Ouse are always within the bounds of the lowest slope category (0-3%). However it was difficult to determine the rationale behind the area number (even through consultation with the US support service), which in the relevant literature is limited to a map showing the areas for Minnesota, USA. An assumption therefore had to be made between a factor of 100 (areas 1 and 2), or 200 (areas 3 or 4); a factor of 100 was assumed, and the uncertainty could be evaluated using sensitivity analysis (see section 4.3).

The channel factors relate to any river, stream, or ditch that allows channelised flow within the cell. The file used to generate the drainage network (see above) was used to identify the presence or absence of a river or stream within each cell. If not present it was assumed that no channel (even a ditch) was present. If a channel was present, it was assumed to be a perennial stream for modelling purposes. The channel slope was assumed to be half the cell slope, and the channel side slope assumed to be 10% for all channels (Cully and Hession,1989).

3.4.2 Soils and Soils/Land Use Parameters

Soils and soils/landuse parameters comprise the soil erodibility factor, soil texture number and SCS runoff curve number.

The soil erodibility (K) factor was selected from tables (USEPA,1985) giving factors for various soil categories and three categories of soil organic matter content (0,2 and 4%). The soil categories essentially relate to the soil's clay, sand and silt content, and therefore it is a different basis of classification to that used in HOST. However some inferences could be made given that the relatively permeable soils are more sandy in nature, and the relatively impermeable soils tend to be higher in clay content. From this it was assumed that HOST classes 1-7 relate to sandy loam, otherwise clay loam was assumed. The associated factors were 0.24 and 0.25 respectively, for an assumed organic matter content of 4%.

The soil texture number is similarly related to a soil classification based on whether clay or sand predominates. Following the logic in selecting the erodibility factor, HOST classes 1-7 were assumed to be predominantly sand, and other classes assumed to be predominantly clay.

The SCS runoff curve number is selected from a table of curve numbers for different combinations of land use and soil hydrologic group. The four hydrologic groups (A-D) range from permeable to impermeable soils. No literature based relation was found between this grouping and the HOST classification, but the relation presented in table 3.4 seemed reasonable. The literature provides curve number data for many land uses. The ones selected as relevant for the project are presented in table 3.4. The table also relates these literature classifications to the land use classifications used as source data for the project.

Table 3.4
Bedford-Ouse Catchment
SCS Curve Numbers

Project Land Class	Soil Hydrologic Group: / Relevant HOST Classes: / Land Use (Literature)	A	B	C	D
	Relevant HOST Classes:	1-5	6-7	8-9	17-29
		- (Curve Numbers) -			
3,9-12	Cultivated land. Row crops (good).	67	78	85	89
4	Built up areas	74	84	90	92
1,2	Leys. Fair Pasture.	49	69	79	84

3.4.3 Land Use Parameters

Landuse parameters comprise Mannings roughness coefficient, the USLE cover and management factor and support practice factor, the surface condition constant, fertilisation level and availability, and chemical oxygen demand (COD).

Mannings roughness coefficient is a parameter that reflects the inter-reaction between the surface run off flow and the land surface, either within a defined channel or related to land use. Values are therefore available in the literature for various kinds of channels and for various land uses. Following this distinction, coefficient values for each cell initially depended on whether a river or stream flowed through the cell. This was established using the data generated to establish the drainage network (see subsection 3.3.1. If a channel was present, it was assumed to be clean and winding, with weeds, stones and pools, a description corresponding to a Manning's coefficient of 0.048; this choice reflected the low lying, gentle slopes, and generally slow moving streams of the Bedford-Ouse catchment. If there was no definable channel in the cell, the coefficient appropriate to the dominant land use was selected, specifically 0.060 0.060 and 0.100 for pasture, cultivated land and urban land use respectively.

The USLE cover and management factor reflects the degree of erosion protection given by overlying vegetative cover. Literature values are available for various land uses. For each square a factor was selected depending on land use, specifically 0.03, 0.38 and 0.01 for pasture, cultivated land and urban land use respectively.

The USLE support practice factor reflects the extent to which management practices are employed to protect against erosion. Initially this value was assumed to be 1.0, reflecting no special practices employed. This factor could then be varied as part of further analysis (see section 4.4).

The surface condition constant is an adjustment to reflect the time it takes overland runoff to channelise, and is related to land use. For each grid square, literature values were selected as 0.05, 0.01 and 0.15 for pasture, cultivated land and urban land use respectively.

Fertilisation level had to be selected as high, moderate or low. High was selected for each grid square of cultivated land, reflecting the typical intensive agriculture of the Bedford-Ouse catchment.

Fertiliser availability is the percentage of fertiliser available for runoff in the top layer. An initial value of 20% for cultivate land was selected; a figure that could be varied by further analysis.

Available Chemical Oxygen Demand (COD) is related to land use and literature values were selected as 60, 170 and 80 mg/L for pasture, cultivated land, and urban land use respectively.

3.4.4 Other Parameters

Other input parameters for the model are point source indicators, gully source level, and impoundment factors.

The point source indicator for a cell allows the input of levels of nitrogen, phosphorus, and COD arising from point sources within the square. No point sources were assumed, although the collection of this data might be an interesting development.

Gully source levels indicate the tonnage of gully erosion in the grid square. Zero was generally assumed, as no information was easily available, but this appears reasonable given the Bedford-Ouse catchment topography.

The impoundment factor indicates the presence of an impoundment terrace system(s) within each grid square. Zero was assumed as no information was easily available.

3.4.5. Program Overview

The program designed to implement the translation described in section 3.4 was written in FORTRAN. Essentially the source data in non-compressed ASCII (NAS) format is read into two-dimensional arrays that represent the grid overlying the catchment. The first program loop generates cell numbers, followed by a second loop to generate the drainage direction. The program then loops through each valid cell calling subroutines for each model input parameter. The final loop of the program then writes the parameters to a file in the format required by the model AGNPS.

3.5 Model Output

The output data from the model are summarised in section 2.2.3. The model produces various values for sediment loss, and nutrient and COD information related to runoff in both the solid and liquid phases. This information is available for the catchment outlet but also for each cell within the catchment. It is obviously an advantage to transfer this information to the GIS for presentation purposes.

For ease of transfer it was decided to use the NAS file format as an intermediary between the model output files and the GIS. The main data items of interest were related to nitrates, and so a program was written to generate a NAS file of a data item of interest, from the GIS output file from the model. This could then be input to ARC/INFO via the command GRIDPOLY.

4. RUNNING THE MODEL

This chapter describes the use of AGNPS to model the Bedford-Ouse catchment under various scenarios, including full details of model input parameters and analysis of model output data from running the model.

The criteria for selecting the various scenarios is described in section 4.1. Sections 4.2 to 4.4 then present details for the various model runs under the three main scenario categories.

4.1 Scenario Selection

The scenarios selected are the logical consequence of input data uncertainty and the intended purpose of the model.

There were many input data uncertainties. As described in chapter 3, many of the required input parameters for the model were not available, of questionable accuracy, or were translated from data sources requiring further assumptions to be made.

The intended purpose of the model is to assist in the assessment of the possible consequences from changing management practices. The effects of changing management practices can be explored, through scenarios.

Three categories of scenarios were therefore established, namely base scenarios, model sensitivity scenarios and management scenarios. Base scenarios provide an opportunity to explore the most likely present situation for various storm events, and the relative contribution to this situation from anthropogenic activity and natural background sources. Model prediction of parameters at the catchment outlet (at Bedford) can also be compared and contrasted with predictions from other models and field observations reported in the literature. Spatial variation can also be explored through the identification of risk areas.

Model sensitivity scenarios explore input data uncertainty, as identified in chapter 3. These scenarios assess the effect on model predictions of variation in input parameters across their likely range of uncertainty. This analysis identifies the key parameters to be improved in accuracy and precision, which in turn will improve the predictive capacity of the model.

Management scenarios assess the effect of changes in management practices by exploring the changes in model prediction resulting from the change in the relevant affected input parameters. The cost-effectiveness of various strategies can therefore be assessed.

4.2 Base Scenarios

Table 4.1 presents the model data input values at catchment and cell levels for the most likely scenario (L), and an afforestation scenario (F). The likely scenario represents the best estimate of the situation in the Bedford-Ouse catchment, and the development of this scenario was described in chapter 3. Additional scenarios are also included to analyze various storm event inputs from 1.5 inches, to a range between 0.5 and 3.0 inches.

Afforestation is generally associated with the lowest levels of nutrient release, and this scenario represents the background nutrient contribution from natural sources. Model output predictions for the scenarios are presented in table 4.2. The parameters presented are for the catchment outlet cell, although this information was available for each cell in the catchment. The range of parameters comprise hydrology, and nitrogen,

Table 4.1

Bedford-Ouse Catchment

AGNPS Model Input Data: Base Scenarios

Data Item	<-------- Base Scenario -------->	
	Most Likely (L)	Afforested (F)
CATCHMENT DATA:		
Cell area:	<------------ 247.1 ------------>	
Cell numbers:	<----------- 1463 --------------->	
Precipitation:	1.5" (0.5-3")	1.5"
CELL DATA:		
TOPOGRAPHIC PARAMETERS:		
Cell Number:	<- Assigned using AGNPS rules. ->	
Receiving cell:	<- Algorithm for drainage network	
Aspect:	described in section 3.4.1. ->	
Slope:	<Average slope to adjacent cells>	
Slope Shape:	<--------- Uniform(1) ---------->	
Slope Length:	<----------- 100 --------------->	
Channel Indicator:	<- Yes (1), if channel in cell ->	
Channel Slope:	<-------- Slope * 0.5 ---------->	
Channel Side Slope:	<----------- 10% --------------->	
SOILS & SOILS/LAND USE PARAMETERS:		
USLE K Factor:	<-- HOST 1-7: Sandy Loam: 0.24 ->	
	<---- (ELSE): Clay Loam: 0.25 -->	
Soil texture number:	<-- HOST 1-7: Sand: 1 ---------->	
	<---- (ELSE): Clay: 3 ---------->	
SCS Curve Number:	<----- (See Table 4.1a) -------->	

LAND USE PARAMETERS:

Data Item	Most Likely (L)			Afforested (F)
	Past.	C.Lnd.	Urban	
Mannings Coeff't:	0.060	0.060	0.100	0.300
(Channel):	<----------- 0.048 ------------->			
USLE C Factor:	0.03	0.380	0.010	0.001
USLE P Factor:	<----------- 1.0 --------------->			
Surf. Cond. Const:	0.15	0.22	0.01	0.59
Fert'ser Level:	Low	High	None	None
Fert'ser Avail.:	10%	20%	100%	10%
COD factor:	60	120	80	65

Table 4.1

(continued)

Data Item	Most Likely (L)	Afforested (F)
	<-------- Base Scenario -------->	
OTHER PARAMETERS:		
Point source	<-------- None Assumed --------->	
Gully source	<-------- None Assumed --------->	
Impoundment factor	<-------- None Assumed --------->	

Table 4.1a

Bedford-Ouse Catchment

AGNPS Model Input Data: SCS Curve Numbers

	Soil Hydrologic Group:		A	B	C	D
Land	Relevant HOST Classes:	1-5	6-7	8-9	17-29	
Class	Land Use (Literature)		- (Curve Numbers) -			
MOST LIKELY SCENARIO:						
3,9-12	Cultivated land. (Row crops (good))		67	78	85	89
4	Built up areas	74	84	90	92	
1,2	Leys. Fair Pasture.		49	69	79	84
AFFORESTATION SCENARIO(F):						
-	Forest with heavy litter	25	55	70	77	

---

phosphorus, and COD in the solid and dissolved phases. The model predicts the dissolved phase for pollution to be much more important than the solid phase.

Table 4.2

Bedford-Ouse Catchment

AGNPS Model Output Data: Base Scenarios

Rain fall	R/O Vol.	Peak R/O	Sed. N	R/O N	R/O [N]	Sed. P	R/O P	R/O [P]	R/O COD	R/O [COD]
MOST LIKELY SCENARIO:										
1.5"	0.5	6939	0.03	1.85	17.0	0.02	0.37	3.4	12.7	117
STORM VARIATION SCENARIOS:										
0.5"	0.0	422	0.01	0.23	32.8	0.00	0.04	6.4	0.8	118
1.0"	0.2	2976	0.02	1.05	22.3	0.01	0.21	4.4	5.6	117
2.0"	0.8	11811	0.04	2.53	13.8	0.02	0.51	2.8	21.4	117
2.5"	1.2	17273	0.05	3.11	11.7	0.03	0.64	2.4	31.0	117
3.0"	1.6	23152	0.06	3.60	10.2	0.03	0.76	2.1	41.3	116
AFFORESTATION SCENARIO:										
1.5"	0.2	2317	0.02	0.09	2.4	0.01	0.01	0.3	2.4	65

TABLE COLUMNS:

R/O Vol. : Runoff (cubic feet seconds).
Peak Vol.: Peak runoff (cubic foot seconds).
Sed. N : Nitrogen in sediment (lbs/acre).
R/O N : Nitrogen in runoff (lbs/acre).
R/O [N] : Nitrogen concentration in runoff (ppm = mg/L)
Sed. P : Phosphorus in sediment (lbs/acre).
R/O P : Phosphorus in runoff (lbs/acre).
R/O [P] : Phosphorus concentration in runoff (ppm = mg/L)
R/O COD : Chemical oxygen demand in runoff (lbs/acre).
R/O [COD]: Chemical oxygen demand in runoff (ppm = mg/L)

The most likely scenario predicts pollution values that generally too high. The nitrogen prediction in runoff of 17 mg-N/L is significantly higher than the EC directive limit of 11.3 mg-N/L for surface water intended for abstraction, and significantly higher than the general figure of 8 mg-N/L observed by Whitehead et. al. (1981). The predictions for phosphorus are also too high.

Two possibilities for the poor prediction of nitrogen are in-stream processes and data input uncertainty. The model ignores stream processes such as denitrification which is an important factor reducing dissolved nitrogen from NPS pollution. However data input uncertainty is probably a much more important factor explaining the model results, especially as both nitrogen and phosphorus are over predicted. This uncertainty can be explored using sensitivity analysis, and the factors most relevant are examined in section 4.3.

The scenarios reflecting variations in storm events indicate greater pollution problems at lower flows, suggesting dilution is a more important consideration than the efficiency of the process of nutrients dissolving in runoff. However it may also be a reflection of the model making simple assumptions regarding nitrogen availability and the process of dissolving.

The afforestation scenario confirms that pollution from nitrogen and phosphorus is very strongly associated with anthropogenic activity, with perhaps only 5% of these nutrients becoming available from natural background sources.

It is interesting to contrast the predictions of the model with the predictions and observations of Beck and Finney (1987) and Whitehead et. al. (1981). A formal comparison is probably not appropriate as the approaches are concerned with different issues. Essentially this AGNPS application models pollution from non-point sources, neglecting point sources and stream processes. In contrast the other models were concerned primarily with point sources (mainly sewage works), and modelled stream processes well. However Beck and Finney (1987) estimate NPS loads of nitrate N, with peaks of 3-10,000 Kg/day. Taking the AGNPS nutrient release figure of 1.9lbs/acre, and assuming this is released over the whole catchment, of 1400*2.7 acres in a 24hr storm, an approximate value for loading would be 1400*2.7*1.9/2.2 = 3300, a figure which is in broad agreement with the Beck and Finney estimates.

In general, however, the predictions from other models seem to be significantly more accurate than the predictions of AGNPS. An exception to this might be in relation to some event loads which were not well predicted by other models, and in some side streams where nitrate-N levels can be high (up to 45mg/L).

The spatial variation in agricultural NPS pollution in the Bedford-Ouse was evaluated by looking at the spatial variation in nitrate concentration in runoff, and following the popular use of the model and GIS in generating risk maps. For each cell, the nitrogen concentration was assigned to one of three classes denoting low (0-5mg-N/L), medium (5-10mg-N/L, and high (>10mg-N/L) nitrate pollution risk.

The resulting map is illustrated in plate VII, and was generated using the ARCPLOT facility of ARC/INFO. It was in this exercise that the main drawback of PC ARC/INFO was encountered, as it seemed appropriate to colour the cells within the catchment as green, yellow and red, for low, medium and high risk respectively. However the PC implementation appears to be able to draw only simple maps using a reasonable colour set (including yellow for example); any moderately complex map can only be realistically plotted using a smaller colour set. The risk maps therefore use blue, instead of yellow, for medium risk. Another problem encountered was the variation in shading (note the variation in red in the plate) and this was probably the plotter speed being set too high by the ARC/INFO PLOT command (a setting that could not be changed).

The risk map, even with the choice of categories, is still high risk in general character. However, comparison with plates III and IV (pages 44 and 47) show some correlation of lower risk areas with permeable soils and non-arable land uses (pasture and urban areas). This correlation is clearly plausible, and an obvious implication is the higher threat to groundwater below permeable soils.

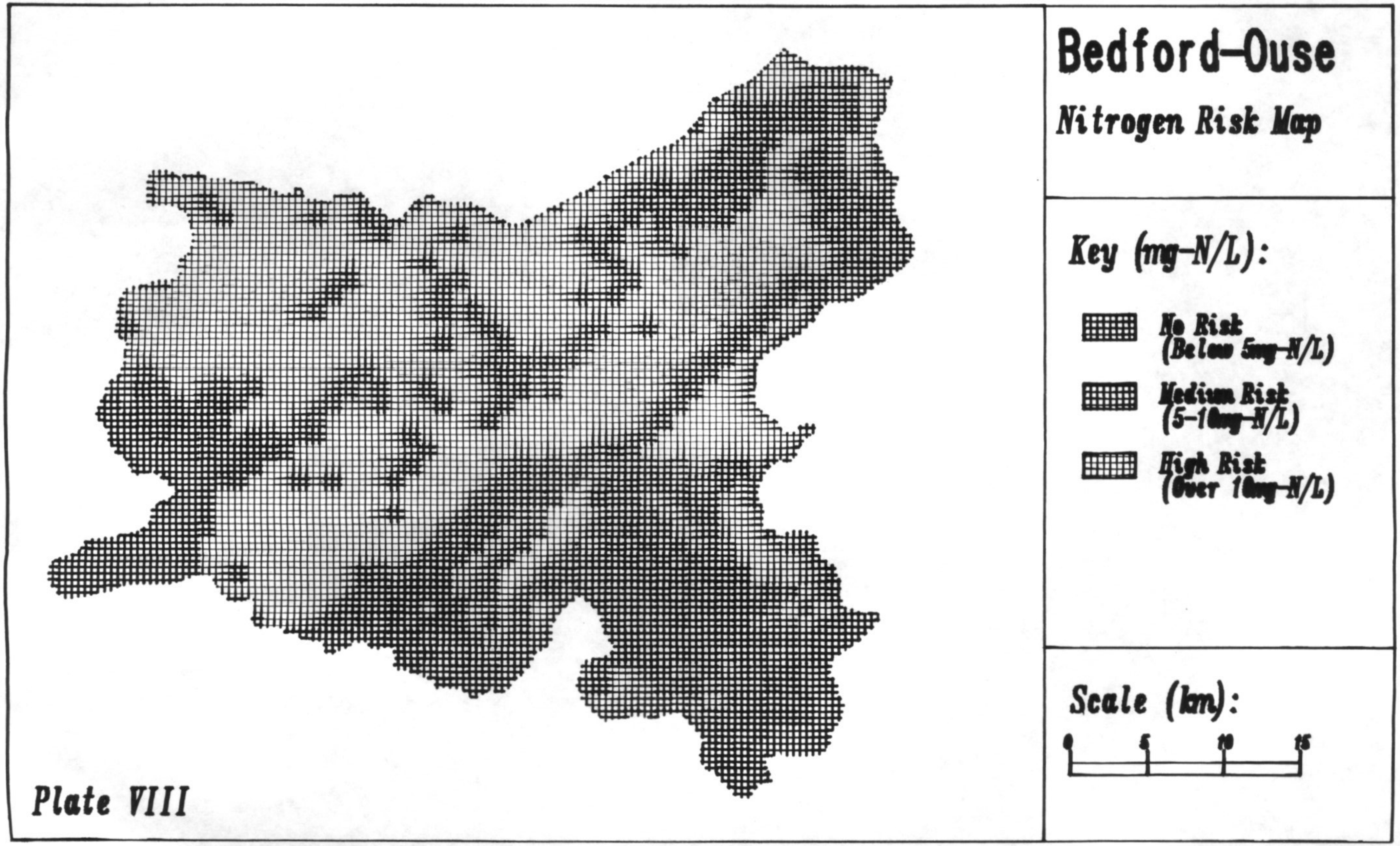

Bedford–Ouse
Nitrogen Risk Map
Key (mg–N/L):
No Risk (Below 5mg–N/L)
Medium Risk (5–10mg–N/L)
High Risk (Over 10mg–N/L)
Scale (km):
0
5
10
15

Plate VIII

4.3 Input Sensitivity Analysis

Table 4.2 presents, for each input parameter, a best judgement of the most likely range of uncertainty in that input parameter. This variation can be used to assess the sensitivity of the model to the uncertainty range, similar to other applications of the model (Vinney,1990).

The information for this exercise was derived from USEPA (1985) and other sources. The uncertainty variation of some parameters could not be reasonably estimated, as documented in table 4.3.

Variation in slope was represented by varying the slope in each cell between the minimum (0%) and maximum (3%) slopes calculated for the Bedford-Ouse catchment. Slope shape was varied between its few alternatives, and slope length varied between the few area numbers available for the only steepness category relevant (0-3%). The other topographic features varied were the channel related factors of channel slope and side slope; the figures in table 4.3 appear reasonable.

The uncertainty in soil related parameters arises from the assumptions made regarding the relation between soil HOST classes and precise soil types. The ranges selected therefore relate to sand-based (relatively permeable) soils and clay-based (relatively impermeable) soils.

The uncertainty in land use related parameters similarly arises from assumptions made about the relationship between land classification and precise land use. As urban land use is small any uncertainty is not considered. For pasture the range reflects literature values for pasture and fallow land in various conditions. For cultivated land the range reflects literature values for various rotation and management practices for wheat production. Note that some values are not varied as they relate more to changes in management practices which are explored in section 4.4.

Table 4.3

Bedford-Ouse Catchment

AGNPS Model Input Data: Sensitivity Scenarios

Data Item	Most Likely (L)	Uncertainty Range
	<----- Sensitivity Scenarios	----->
CATCHMENT DATA:		
Cell area:	247.1	None
Cell numbers:	1463	None
Precipitation:	1.5"	(See section 6.2)
CELL DATA:		
TOPOGRAPHIC PARAMETERS:		
Cell Number:	Assigned	Not applicable.
Receiving cell:	Assigned	Unknown.
Aspect:	Assigned	Unknown.
Slope:	Av'ge slope	0-3%
Slope Shape:	Uniform	Convex,concave.
Slope Length:	100	100-200
Channel Indicator:	Assigned	Unknown.
Channel Slope:	Slope*0.5	Slope*0.5 - Slope.
Channel Side Slope:	10%	5%-20%
SOILS & SOILS/LAND USE PARAMETERS:		
USLE K Factor(HOST 1-7):	0.24	0.02-0.27
(OTHER):	0.25	0.13-0.29
Soil Texture (HOST 1-7):	1	None
(OTHER):	3	None
SCS Curve Number:	<----- (See Table 6.3a)	-------->

LANDUSE PARAMETERS:

Data Item	Most Likely (L)			Uncertainty Range	
	Past.	C.Lnd.	Urban	Pasture	Cult. Land
Mannings Coeff't:	0.060	0.060	0.100	0.05-0.13	.045-0.25
(Channel):	<---- 0.048 ----->			<---- 0.03-0.07 --->	
USLE C Factor:	0.03	0.380	0.010	0.04-0.01	0.10-0.45
USLE P Factor:	<----- 1.0 ------>			<(See section 6.4.)>	
Surf. Cond. Const:	0.15	0.22	0.01	0.01-0.22	0.05-0.29
Fert'ser Level:	Low	High	None	<(See section 6.4.)>	
Fert'ser Avail.:	10%	50%	100%	<(See section 6.4.)>	
COD factor:	60	120	80	40-80	100-170

Table 4.3

(continued)

Data Item	<----- Sensitivity Scenarios -----> Most Likely (L)	Uncertainty Range
OTHER PARAMETERS:		
Point source	None Assumed	Add feedlots, sewage.
Gully source	None Assumed	Unknown
Impoundment factor	None Assumed	Unknown

Table 4.3a

Bedford-Ouse Catchment

AGNPS Input Data: SCS Curve Number Uncertainty

Land Class	Soil Hydrologic Group: / Relevant HOST Classes: / Land Use (Literature)	A	B	C	D
	Relevant HOST Classes:	1-5	6-7	8-9	17-29
	Land Use (Literature)	- (Curve Numbers) -			
3,9-12	Cultivated land:Likely	67	78	85	89
	(Range)	72-62	81-71	88-78	91-81
1,2	Fair Pasture:Likely	49	69	79	84
	(Range)	25-68	59-79	75-86	83-89

The other parameter of significance is the facility to add point sources to the model. Clearly the discharge of sewage effluent and feedlots could be added to the model, but the time required to collect the relevant data prevented this addition.

An analysis of model output predictions of the sensitivity scenarios is presented in table 4.4. The predictions for the likely scenario is listed, but the main purpose of the table is to highlight the maximum percentage variation in each predicted output parameter caused by varying the given input parameter across its range of uncertainty given in table 4.3.

The main conclusion from inspection of table 4.4 is that most input parameters have a zero or minor effect on the model predictions, but a few parameters are critical for accuracy.

Topographic parameters related to slope and channels have zero effect on the model. This is probably reasonable given the relatively flat terrain of the Bedford-Ouse catchment. Other factors having little or no effect are the soil erodibility factor, the surface condition constant, and the COD level (apart from its obvious effect on COD). The irrelevance of these parameters is more surprising, but could be reasonable for erodibility and surface condition if they too depend on land terrain.

The input parameter variation having the most effect on the model in this application, is the SCS curve number. Across the likely uncertainty range, this parameter can change the prediction of hydrology by more than 40%, with correspondingly large changes in dissolved nutrient predictions. For solid phase pollution an important factor might be rounding errors of very low figures.

Clearly the SCS curve number is the key parameter for further research to improve its accuracy.

The likely range in Manning's roughness coefficient and the cover and management factor of the USLE, influence nutrient pollution substantially, but only in the solid phase. Rounding errors of low figures may also be a factor here.

COD values significantly with input values of COD, as expected.

Table 4.4

Bedford-Ouse Catchment

AGNPS Model Output Data: Sensitivity Scenarios

Param. Varied	R/O Vol.	Peak R/O	Sed. N	R/O N	R/O [N]	Sed. P	R/O P	R/O [P]	R/O COD	R/O [COD]
MOST LIKELY SCENARIO:										
(None)	0.5	6939	0.03	1.85	17.0	0.02	0.37	3.4	12.7	117
OUTPUT VARIATIONS (%) FROM VARIATION IN RANGE OF:-										
Slope	–	–	–	–	–	–	–	–	–	–
Channel	–	–	–	–	–	–	–	–	–	–
K Fact.	–	–	–	–	–	–	–	–	–	–
SCS CN	40	46	33	34	35	50	65	38	48	–
Mann.	–	–	100	–	–	50	–	–	–	–
C Fact.	–	–	–	–	–	–	–	–	–	–
SCC –	–	–	–	–	–	–	–	–	–	
COD –	–	–	–	–	–	–	–	41	40	

SCENARIO SUMMARY:

Slope : Slope, slope shape and slope length variations

Channel : Channel slope and side slope variations.

K Fact. : USLE erodibility (K) factor variation.

SCS CN : SCS Curve number variation.

Mann. : Manning's roughness co-efficient variation.

C Fact. : USLE cover and management (C) factor variation.

SCC : Surface condition constant variation.

COD : COD variation.

4.4 Management Scenarios

To analyze the possible consequences from changes in management practices, a number of management scenarios were developed and the model run for each scenario. Outputs were compared with the most likely scenario described in section 4.2.

The main AGNPS input parameters that reflect management practices are presented in table 4.5, although other parameters can be influenced. Table 4.5 shows the parameter values for the most likely (L) scenario, and indicates the likely variation in each parameter arising from better management practice. Only changes to cultivated land have been considered, partly because this land use dominates the Bedford-Ouse catchment, but also because of data availability.

Changes in the USLE supporting practice factor arise from practices such as contouring, contour strip cropping, contour listing or ridge planting and contour terracing. The factor is influenced by land slope, but in this catchment only the values for slopes less than 2% realistically need to be considered, and the range included in table 4.5 reflects this.

Fertiliser levels can be altered from high to medium to low, reflecting the application of 200, 100, and 50 lbs N/acre respectively, and 80, 40 and 20 lbs P/acre, again respectively.

Table 4.5

Bedford-Ouse Catchment

AGNPS Model Input Data: Management Scenarios

	<----- Management Scenarios ----->				
Data Item	Most Likely (L)			Management Change	
LAND USE PARAMETERS:					
	Past.	C.Lnd.	Urban	Pasture	Cult. Land
USLE P Factor:	<-----	1.0	------>	1.0	1.0-0.3
Fert'ser Level:	Low	High	None	None	High-Med-Low
Fert'ser Avail.:	10%	20%	100%	None	20-10%

Fertiliser availability reflects tillage practice and the 20% value given could be reduced to as little as 10% using a moldboard plough.

Table 4.6 presents the analysis of the results of running the model for the improved input data listed in table 4.5. As for the sensitivity scenarios, the table lists the predictions for the likely scenario for reference, but primarily highlights the percentage improvement from changing the various parameters relating to management practices.

The change in the practice factor made no difference to the output parameters, as compared with the most likely scenario. This was a surprising result, and a model error cannot be ruled out. However a rational explanation might be that the practice factor only leads to improvement where land slope is significant, which is clearly not the case in the relatively flat terrain of the Bedford-Ouse. Clearly this result requires further investigation.

The predictions for reducing pollution by reducing fertiliser application generally appear to be related approximately linearly, but only for pollution in the dissolved phase; there is no predicted change in effect for pollutants in the solid phase. Note also that nitrogen concentration reduction from low fertiliser application is less than a linear correspondence, at 61%.

Similarly the reduction in pollutant availability (a 50% reduction from 20% to 10%), suggested in table 4.5, may be linearly related to the consequent reduction in nutrient concentrations, but again the solid phase is not affected.

Table 4.6

Bedford-Ouse Catchment

AGNPS Model Output Data: Management Scenarios

Param. Varied	R/O Vol.	Peak R/O	Sed. N	R/O N	R/O [N]	Sed. P	R/O P	R/O [P]	R/O COD	R/O [COD]
MOST LIKELY SCENARIO:										
(None)	0.5	6939	0.03	1.85	17.0	0.02	0.37	3.4	12.7	117
OUTPUT REDUCTIONS (%) FROM VARIATION IN:-										
P. Fact.	-	-	-	-	-	-	-	-	-	-
F. Med.	-	-	-	47	47	-	49	49	-	-
F. Low	-	-	-	71	61	-	73	70	-	-
F. Avail.	-	-	-	47	47	-	49	49	-	-

SCENARIO SUMMARY:

P. Fact.: Change in land practices (USLE P factor).

F. Med. : Reduce to medium fertiliser application.

F. Low : Reduce to low fertiliser application.

F. Avail: Reduce fertiliser availability.

Table 4.6 therefore presents perhaps an obvious conclusion, that both reducing fertiliser application and availability reduce corresponding pollution, probably with a linear relationship. However this suggests further work to establish the most cost-effective approach to reducing agricultural pollution.

The risk map associated with using less (low) fertiliser is presented in plate IX, and can be compared with plate VIII (page 67). Essentially the high risk areas tend to become medium risk areas, with low risk areas correlating to some extent with permeable soils and non-arable land uses.

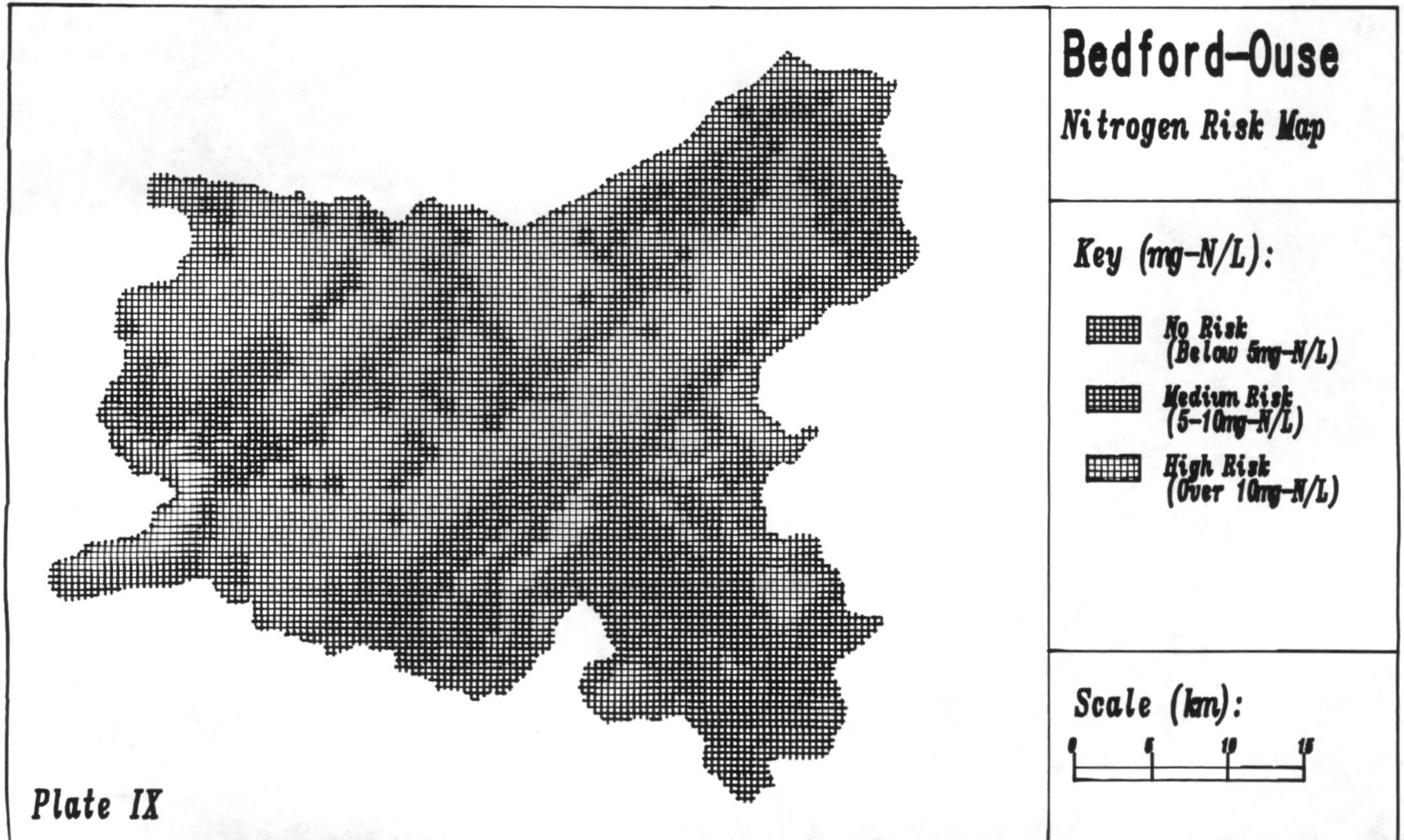

Bedford–Ouse
Nitrogen Risk Map
Key (mg-N/L):
No Risk (Below 5mg-N/L)
Medium Risk (5-10mg-N/L)
High Risk (Over 10mg-N/L)
Scale (km):
0
5
10
15

Plate IX

5. GENERAL CONCLUSIONS

This chapter concludes this report by summarising the overall conclusions of the case study, and suggesting areas of future development.

In terms of the key objectives set in chapter 1, the project has been successful in achieving an integration of a NPS pollution model and a GIS, and in achieving an application to a catchment in the U.K.

From the literature review it was established that agricultural NPS pollution of surface and groundwater is an issue of increasing concern worldwide. The main focus of attention is the agriculturally related pollutants of widespread use, namely pesticides, and nitrates and phosphates from fertilisers. Possible consequences from NPS pollution are a subject of uncertainty and debate, and although scientific assessments are generally reassuring but inconclusive, public risk perception is high, influencing the trend of increasing legislation.

Agricultural NPS pollution is a complex issue, and this is reflected in the related institutional framework. The diffuse nature of the problem requires diffuse control measures, both technically and institutionally. The most cost-effective measures overall emphasise prevention rather than treatment.

Modelling, using the increasingly powerful and accessible computer, offers major benefits to the research, management, and communication of NPS pollution issues. Models are increasing their capability, but many challenges remain both in characterising the complex processes involved, and in data related issues of availability, accuracy, and the processing and communication of larger data volumes.

Emerging computing technologies, such as GIS integrated with remote sensing, enable large data volumes to be easily processed, and communicated in visual form. The benefits to modelling have led to an increasing number of applications, mostly in the U.S.A., that integrate models and GIS. These studies confirm the synergistic benefits of models and GIS.

AGNPS is an NPS, event-based, distributed model intended for management purposes. In this case study the model was integrated with the GIS ARC/INFO and applied to the Bedford-Ouse catchment in the U.K. Key data sources are soil type, land use, altitude and the river and catchment boundary. These data sources were translated to AGNPS input data using FORTRAN programs and ARC/INFO analytical tools, and ARC/INFO was used for presentation purposes. The model was run for various scenarios, including scenarios representing the most likely situation, data input uncertainty, and changes in management practices.

The most likely scenario over-predicted agricultural pollution, but this may be due to processes not represented in the model, and data input uncertainty. However, model predictions suggested that pollution in the dissolved phase dominates that in the solid phase, and that lower flows might generate higher pollution levels than high flows which exercise a dilution effect. Scenarios to evaluate model data input sensitivity identified the SCS curve number as the input parameter dominating model prediction. The management scenarios demonstrated the, perhaps obvious, conclusion that reducing fertiliser application rates and availability levels would bring proportional improvements in water quality related to NPS pollution. However a surprising prediction was that changes in erosion management practices would not improve water quality, and in a practical situation investment should be targeted elsewhere.

The use of GIS in the application demonstrated the benefits identified in the literature, although other computing aspects, notably FORTRAN, must take substantial credit for adding the flexibility to be able to integrate software components together. However it would have been almost impossible to do some analyses without the GIS, and probably more of the processing could have been done using the GIS had more time and training been available. Certainly the overall approach was very cost-effective in terms of development time and data management. The total application was developed in a few months, and some 28,000 data points were managed by the application for input to the model. Each scenario could be run easily in a few minutes, and some 25 scenarios were run with relatively little extra effort required. The approach could be used for catchments up to 50% larger than the Bedford-Ouse, but the AGNPS model could not be used beyond this level, and in addition the GIS processing times would increase correspondingly. Certainly more computer power would be required for a U.K. scale application.

The main strength of the GIS confirmed in this project is its communication potential. The visual impact of the information is very impressive, for example the nitrogen risk maps generated from model predictions. The power of these images, combined with the discipline imposed by the GIS in creating a common spatial framework, acts as a focus for rational discussion and debate. And even though the predictions are subject to error, they do provide overall indications that are a good starting point for discussion. However care must be taken to prevent the GIS presentation capability giving a false accuracy to the underlying data and model limitations. GIS cannot solve the fundamental problems of data availability, accuracy and translation, and model inaccuracy and inapplicability.

Problems of data availability, accuracy and translation were all encountered in this study. Information was often not available, of unrelated time frames, not intended for the purpose required, or of a predictive nature rather than observed. To derive model input data further, often subjective assumptions had to be made. In addition the applicability of a U.S. related model a U.K. situation should be considered. However these issues were not unexpected, as the main objective was to achieve an application with data readily available.

Having achieved the application, the main priority of future research related to the application, should be to increase source data accuracy, focusing on curve number related parameters and fertiliser application and availability estimates. Further work is justified by the benefits of integrating the model and GIS, which has been demonstrated to be a powerful combination in the communication of NPS pollution related issues of increasing concern.

The benefits demonstrated in this successful case study can also be realised more generally in the Impact of Climate on Ecosystems (ICE) research programme. Indeed the nature of the research suggests that there should be even greater benefits.

The ICE research programme is concerned with modelling complex ecological processes, and the possible effects of climate change on these processes within the U.K., over a long timescale, and in relation to various climate change scenarios. The exploration and communication of complexity and uncertainty is therefore a major features of the research, and this is where the major benefits of a GIS approach have been demonstrated.

In addition to the communication benefits, the GIS approach has significant advantages in efficiently exploring the scenarios and managing the data volumes involved. However further consideration should be given to the data volumes and computer processing power required, as these will be substantially greater in the main ICE programme than those encountered in this case study. An example of the increase required was indicated by a test to load the U,K. catchment outline into PC ARC/INFO which took a few hours. Clearly a PC based application would therefore be untenable, and in this regard an ARC/INFO version for the SUN workstation is on order.

A more powerful version should also have other benefits, for example the full hardware colour range can be used for presentation, which is virtually impossible in the PC version. In addition the SUN ARC/INFO version has greater capability, for example in digital terrain modelling. These extra features, combined with greater familiarity with ARC/INFO learned during the case study, may mean that ARC/INFO could be used more widely in the analyses required in the programme.

In conclusion the ICE research programme should benefit significantly from a GIS approach demonstrated in this case study. The ICE programme is characterised by complexity, and GIS has the potential to manage, analyze, and above all communicate this complexity very effectively. Integrating a powerful version of the GIS ARC/INFO, with the models under development, should provide greater insight into the study of the serious issue of climate change impacts on ecosystems.

6. REFERENCES AND BIBLIOGRAPHY

Airola, T.M. and Kossen, D.S. (1989). Digital Analysis of Hazardous Waste Site Aerial Photographs. J. Water Pollut. Control Fed. 61 2.

AGNPS (1991) AGNPS Newsletter. A Quarterly Report - April, 1991. USDA-ARS, NCSCRL. North Iowa Avenue, Morris, MN 56267.

AGNPS (1990) AGNPS Newsletter. A Quarterly Report - July, 1990. USDA-ARS, NCSCRL. North Iowa Avenue, Morris, MN 56267.

Alm, A.L. (1990). Non-Point Sources of Water Pollution. Environ. Sci. Technol.. 24 (7) p.967.

Bagnold, R.A. (1966). An Approach to the Sediment Transport Problem from General Physics. Prof. Paper 422-J. US Geol. Surv.,. Reston, Va.

Barker, P. (1991). Agricultural Pollution: Control and Abatement in the Upper Thames Region. J. IWEM. 5 p.318.

BBC (1991). Co-op Initiative to Reduce Pesticides in Food. The Food Programme. BBC Radio 4 29/4/91.

Beck, M.B. (1991). Principles of Modelling. Water Science and Technology. 2 pp.1-8.

Beck, M.B. and Finney, B.A. (1987). Operational Water Quality Management: Problem Context and Evaluation of a Model for River Quality. Wat. Res. Res.. 23 11 pp.2030-2042.

Boorman, D.B. and Hollis, J.M. (1991). Hydrology of Soil Types: A Hydrologically-Based Classification of the Soils of England and Wales. Internal Paper. Institute of Hydrology, Wallingford, UK.

Bouwer, H. (1989). Agricultural Contamination: Problems and Solutions. Water Environment and Technology. Oct. 89 p.292.

Bouwer, H. (1990a). Agricultural Chemicals and Groundwater Quality - Issues and Challenges. Groundwater Monitoring Review. Winter. pp.71-79.

Bouwer, H. (1990b). Agricultural Chemicals and Groundwater Quality JSWC. 45 2 pp.184-189.

Buck, W. and Plate, E. (1990). A Basin Study for Pollution Transport. In: Hooghart, J.C., Posthumus, C.W.S. and Warmerdam, P.M.M. (eds) Proc. Hydrological Research Basins and the Environment. Neth. Org. for Appl. Sci. Res. No. 44.

Bunce, R.G.H., Barr, C.J. and Whittaker, H.A. (1981). Land Classes in Great Britain: Preliminary Descriptions for Users of the Merlewood Method of Land Classification. Merlewood Research and Development Paper No. 86. ITE (Merlewood).

Burrough, P.A. (1986). Principles of Geographical Information Systems for Land Resources Assessment. Oxford University Press, New York.

Ciesla, W. (1991). Ethics in Photogrammetry and Remote Sensing: A Perspective from a Natural Resource Specialist. Photogrammetric Engineering and Remote Sensing. 57 3 p.281.

Couillard, D. (1988). Development of a Water Quality Planning Model Using UTM Square Grid Equipment. J. Environ. Manage.. 26 p.95.

Cowen, D. (1988). GIS vs CAD vs DBMS. What are the Differences? Photogrammetric Engineering & Remote Sensing. 54 11 pp.1551-1555.

Davies, R. (1990). Be N Sensitive or Court Tougher EC Regulations. Farmers Weekly, 9/11/90.

Decoursey, D. (1990). Proceedings of the International Symposium on Water Quality Modeling of Agricultural Non-Point Sources, Parts 1 and 2. ARS-81. (June 19-23, 1988; Utah State University, Logan, Utah.

Deizman, M. and Saied, M. (1991). A Model for Evaluating the Impacts of Land Application of Organic Waste on Runoff Water Quality. Res. J. Water Pollut. Control Fed.. 63 1 p.17.

DelRegno, K.J. and Atkinson, S.E. (1988). Nonpoint Pollution and Watershed Management: A Remote Sensing and GIS Approach. Lake Reservoir Manage. 4 17.

Dickinson, W.T., Rudra, R.P. and Wall, G.J. (1990). Targeting Remedial Measures to Control Nonpoint Source Pollution. Wat. Res. Bull.. 26 3 p.499.

Dunn, R., Harisson, A.R. and Turton, P.J. (1991). Rural to Urban Land-Use Change: Approaches to Monitoring & Planning Using GIS. Mapping Awareness and GIS Europe. 5 4 p.26.

ESRI (1990). Understanding GIS. The ARC/INFO Method. Environmental Systems Research Institute. Redlands, CA.

Evans, B.M. and Myers, W.L., (1990). A GIS-Based Approach to Evaluating Regional Groundwater Pollution Potential with DRASTIC. J. Water Cons.. 45 2.

Evans, B.M. and Miller D.A. Modelling Nonpoint Pollution at the Watershed Level with the aid of a GIS. In: Nonpoint Pollution:1988 - Policy, Economy, Management and Application Technology V Novotny (ed.). Tech. Publ. Series TPS-88-4 Am. Water Resour. Assoc., Bethesda, Md.

Fawcett, A. (1975). A Management Model for River Water Quality. The Bedford Ouse Study. Symposium Proceedings. Anglian Water Authority. pp.29-49.

Fisher, P.F. and Lindenberg, R.E., 1989. On Distinctions Among Cartography, Remote Sensing and GIS. Photogrammetric Engineering & Remote Sensing. 55 10 pp.1431-1434.

Foster, G.R., Lane, L.J., Nowlin, J.D. Laflen, J.M. and Young, R.A. (1981). Estimating Erosion and Sediment Yield on Field-Sized Areas. Trans., ASAE 24 5 pp.1253-1262.

Frere, M.H., Ross, J.D. and Lane, L.J. (1980). The Nutrient Submodel. In: CREAMS, A Field Scale Model for Chemicals, Runoff and Erosion from Agricultural Management Systems. Cons. Res. Rpt. No. 26. USDA-ARS, Washington D.C. pp.65-85.

Hedges, P.D. (1991). Evaluation of the Effects of Groundwater Drawdown on Vegetation using GIS. In: Proc. of Conference. Atmospheres, Hydrospheres and Space Sciences XVI General Assembly Wiesbaden 22-26/4/91. Supplement to Vol. 9.

Hession, W.C. (1990). Geographic Information System Technology and Water Quality Modelling: An Interface. In: Proc. Application of Geographic Information Systems, Simulation Models, and Knowledge-Based Systems for Landuse Management. Nov 12-14. Virginia Polytechnic Institute and State University.

Hession, W.C. and Huber, K.L. (1989). BMP Effectiveness Using AGNPS and a GIS. American Society of Agricultural Engineers, 1989 International Winter Meeting. Paper No. 89-2566.

Hession, W.C. and Shanholtz, V.O. (1988). A GIS for Targeting NPS Agricultural Pollution. J. Soil Water Conserv.. 43 p.264.

HoL. (1989). Nitrate In Water. Report of the Select Committee on the European Communities. Session 1988-89, 16th report. HMSO.

Howard, M. (1989). Water Issues in the United Kingdom. Res. J. Water Pollut. Control Fed.. 61 (1) p.26.

ITE (1991). ITE Land Classification: Classification of all 1km Squares in GB. DoE/NERC Contract - PECD 7/2/88. ITE (Merlewood).

ITE (1990). ITE Land Classification and its Application to Survey: An Internal Appraisal. Institute of Terrestrial Ecology (Merlewood), 18/2/90.

Jamieson, C.A. and Clausen, J.C. (1988). Tests of the CREAMS Model on Agricultural Fields in Vermont. Wat. Res. Bull.. 24 6 p.1219.

Knisel, W.G. (1980). CREAMS. A Field Scale Model fo Chemicals, Runoff, and Erosion From Agricultural Management Systems. USDA Cons. Res. Rep. No. 26.

Koelliker, J.K., and Humbert, C.E. (1990). Application of AGNPS Model to Watersheds in Northeast Kansas. Final Report on Joint Agreement Number 65-6215-8-1 between USDA-SCS, Kansas Office, and Kansas State University.

Leavesley, G.H., Beaseley, D.B., Pionke, H.B. and Leonard, R.A. (1990). Modeling of Agricultural Nonpoint-Source Surface Runoff and Sediment Yield - A Review From The Modeler's Perspective. In: Proceedings of the International Symposium on Water Quality Modeling of Agricultural Non-Point Sources, Part 1. USDA ARS. ARS-91. p.171.

Lee, M.T. and Camacho, R. (1989). Geographic Data Base and Watershed Modeling for Evaluation of the Rural Clean Water Program in the Highland Silver Lake Watershed. Illinois State Water Survey Division, Surface Water Section. SWS Contract Report 421. Champaign, Illinois.

Lee, M.T., Kao, J.J. and Ke, Y. (1990). Integration of GIS/Remote Sensing/Digital Elevation Data for the AGNPS Model. Paper presented at the National Symposium on "Remote Sensing and GIS Applications to Nonpoint Source Pollution", sponsored by USEPA, held in Chicago, IL.

Lee, M.T. and Terstriep, M.L. (1991). Integration of GIS Databases and Water Quality Modeling for Agricultural and Urban Watersheds. Unpublished.

Lees, M.L. (1985). Inland Water Surveying in the United Kingdom - A Short History. Hydrological Data UK. 1985 Yearbook. Institute of Hydrology, Wallingford,UK.

Mason, L.A. (1991). A Long Hard Look at Nitrogen is Needed. Farmers Weekly. 18/1/91 p.52.

Mockus, J. (1972). Estimation of Direct Runoff from Storm Rainfall. In: National Engineering Handbook, Sec.4 Hydrology. US Conservation Service, Washington, D.C.

Nachtnebel, H.P., Furst, J., Girstmair, G. and Holzmann, H. (1991). Integration of a GIS with a Groundwater Model to Assist in Regional Water Management. In: Proc. of Conference. Atmospheres, Hydrospheres and Space Sciences XVI General Assembly Wiesbaden 22-26/4/91. Supplement to Vol. 9.

Neill, M. (1989). Nitrate Concentrations in River Waters in the South-East of Ireland and their Relationship with Agricultural Practice. Water Research. 23 11 pp.1339-1355.

Newson, M. (1991). Catchment Control and Planning: Emerging Patterns of Definition, Policy and Legislation in UK Water Management. In Land Use Policy. Butterworth-Heinamann Ltd.

Novotny, V. and Chesters, (1981). Handbook of Nonpoint Pollution - Sources and Management. Von Nostrand Rheinhold Company, New York, N.Y.

Novotny, V. and Bendoricchio, G. (1989). Linking Nonpoint Pollution and Deterioration. Water Environment and Technology.. Nov. p.407.

Nyhan, J.W. (1990) Calibration of the CREAMS Model for Landfill Cover Designs Limiting Infiltration of Precipitation at Waste Depositories. Hazardous Waste & Hazardous Materials. 7 2 pp.169-184.

OECD (1986). Water Pollution by Fertilisers and Pesticides. OECD, Paris.

Oliver, G., Burt, J. and Solomon, R. (1990). The Use of Surface Runoff Models For Water Quality Decisions - A User's Perspective. In: Proceedings of the International Symposium on Water Quality Modeling of Agricultural Non-Point Sources, Part 1. USDA ARS. ARS-91. p.197.

O'Neil, W.B., Raucher, R.S. (1990). The Costs of Groundwater Contamination JSWC 45 2 pp.180-183.

Parker, H.D. (1988). The Unique Qualities of a Geographic Information System: A Commentary. Photogrammetric Engineering & Remote Sensing. 54 11 pp.1547-1549.

Potter, W.B., Gilliland, M.W., Long, M.D. (1986). A Geographic Information System for Prediction of Runoff and Non-point source Pollution Potential. Hydrologic Applications of Space Technology. IAHS Publ. No. 160.

Prato, T. et. al., 1989. Soil Erosion and Nonpoint Source Pollution Control in an Idaho Watershed. J. Soil Water Cons.. 44 pp.323-328.

Pringle-Baker, C. and Panciera, E.C. (1990). A GIS For Groundwater Protection Planning. JSWC. 42 2 p.247.

Richardson, C.W. and Wright, D.A. (1984). WGEN: A Model For Generating Daily Weather Variables. ARS-8, USDA ARS.

Roberts, G. (1987). Nitrogen Inputs and Outputs in a Small Agricultural Catchment in the Eastern Part of the United Kingdom. Soil Use & Management. 2 4 pp.148-154.

Roberts, G., and Marsh, T. (1987). The Effects of Agricultural Practices on the Nitrate Concentrations in the Surface Water Domestic Supply Sources of Western Europe. Water for the Future: Hydrology in Perspective. IAHS Publ. no. 164.

Roka, F.M., Lessley, B.V. and Magette, W.L. (1989). Economic Effects of Soil Conditions on Farm Strategies to Reduce Agricultural Pollution. Wat. Res. Bull.. 25 4 pp.821-827.

Rose, C.W., Parlange, J.Y., Sander, G.C. and others (1983). Kinematic Flow Approximations to Runoff on a Plane: An Approximate Analytical Solution. J. Hydrol.. 62 pp.363-369.

Rose, C.W., Dickenson, W.T., Ghadiri, H. and Jorgenson, S.E. (1990). Agricultural Nonpoint-Source Runoff and Sediment Yield Water Quality (NPSWQ) Models: Modeler's Perspective. In: Proceedings of the International Symposium on Water Quality Modeling of Agricultural Non-Point Sources, Part 1. USDA ARS. ARS-91. p.145.

Ryerson, R. (1989). Image Interpretation Concerns for the 1990s and Lesson From the Past. Photogrammetric Engineering & Remote Sensing. 55 10 pp.1427-1430.

Smith, R.E. and Williams, J.R. (1980). Simulation of Surface Water Hydrology. In: CREAMS. A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. Cons. Res. Rpt. 26. USDA-ARS, Washington, D.C.

Spooner, J., Wyatt, L., Coffey, S.W., Brichfield, S.L., Arnold, J.A., Smolen, M.D., Jennings, G.D., Gale, J.A. (1990) Fates and Effects of Pollutants: Non-Point Sources. JWPCF. June 1990, Literature Review.

Streng, J.M.A. (1991). An Integrated Hydrological Modelling Framework as a Decision Support System. In: Atmospheres, Hydrospheres and Space Sciences XVI General Assembly Wiesbaden 22-26/4/91. Supplement to Vol. 9.

Stuebe, M.M. and Johnston, D.M. (1990). Runoff Volume Estimation Using GIS Techniques. Wat. Res. Bull. 26 4 pp.611-619.

Terstriep, M.L. and Lee M.T. (1989). Regional Stormwater Modeling Q-ILLUDAS and ARC/INFO. In: Proc. Computing in Civil Engineering. Sixth Conference, TCCP/ASCE, Atlanta, GA. September 1989.

USEPA (1985a). EPA National Water Quality - 1984 Report to Congress. USEPA Office Water Reg. Stand., Washington DC.

USEPA (1985b). Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Groundwater (Vols 1 & 2). EPA/600/6-85/002a. Environmental Research Laboratory, Athens GA 30613. 1985.

Vachaud, G., Vauclin, M. and Addiscott, T.M. (1990). Solute Transport in the Vadose Zone: A Review of Models. In: Proceedings of the International Symposium on Water Quality Modeling of Agricultural Non-Point Sources, Part 1. USDA ARS. ARS-91. p.81.

Van Mullen, J.A. (1990). Application of the CREAMS model at a Contaminated Industrial Site. JSWC. 45 5 p.577.

Vinney, V.L. (1990). AGNPS: How do I know when I have enough data? Presented at the SCS, WEST NTC Water Quality Worksop, July 18-20, 1990. Reno, Nevada.

Walker, J.F., Pickard, S.A. and Sonzogni, W.C. (1989) Spreadsheet Watershed Modelling for Nonpoint Source Pollution Management in a Wisconsin Basin. Wat. Res. Bull.. 25 1 pp.139-147.

Walsh, S.J. (1985). Geographic Information Systems for Natural Resource Management. J. Soil and Water Cons.. 40 2 pp.202-205.
Wan, M.T. (1990) Railway Right of Way Contamination in the Lower Mainland of British Colombia. Jnl. Env. Quality. 20 1 p.228-234.

Water Bulletin (1991a). Nitrate Directive Adopted. Water Bulletin. 21/6/91. p.4.

Whitehead, P.G. (1975). A Dynamic Stochastic Model for Non-Tidal Rivers. The Bedford Ouse Study. Symposium Proceedings. Anglian Water Authority. pp.49-76.

Whitehead, P.G., Beck, M.B. and O'Connell, E. (1981). A Systems Model of Streamflow and Water Quality in the Bedford Ouse River System - II. Water Quality Modelling. Water Research. 15 10 pp.1157-1172.

Wischmeier, W.H. and Smith, D.D. (1978). Predicting Rainfall Erosion Losses. Agriculture Handbook 5371. USDA-SEA.

Witt, R. (1989). An Overview of GRID. A Working Global Database - Global Resource Information Database. In: Int. Symp. on Remote Sensing of Environment Abidjan, Ivory Coast, Oct. 20-26 1988 Proc. Vol. 1 (A90-31776 13-43). Env. Res. Inst. Michigan, Ann Arbour, Michigan USA pp29-38.

Woodcock, C.E., Sham, C.H. and Shaw, B. (1991). Comments on Selecting a Geographic Information Systems for Environmental Management. J. Env. Mgt.. 14 3 pp.307-315.

Young, R.A., Onstad, C.A., Bosch, D.D., and Anderson, W.P. (1991). AGNPS User's Guide. Version 3.65 (Draft). USDA-ARS, Morris, Minnesota.

Young, R.A., Onstad, C.A., Bosch, D.D., and Anderson, W.P. (1990). AGNPS User's Guide. Version 3.51 - January 1990. USDA-ARS, Morris, Minnesota.

Young, R.A., Onstad, C.A., Bosch, D.D., and Anderson, W.P. (1989). AGNPS: A Nonpoint Source Pollution Model for Evaluating Agricultural Watersheds. Journal of Soil & Water Conservation. 44 2.

Young, R.A., Onstad, C.A., Bosch, D.D., and Anderson, W.P. (1987). AGNPS, Agricultural Non-Point-Source Pollution Model. A Watershed Analysis Tool. USDA-ARS. Conservation Research Report 35.

Younos, T.M. and Metz, C.D. (1988). Site Selection for Land Application of Sludge Using a GIS. Appl. Eng. Agric.. 4 56.
Younos, T.M., and Weigmann, D.L. (1988). Pesticides: A Continuing Dilema. J. WPCF.. 60 p.1199.

APPENDIX A: GLOSSARY OF ACRONYMS

ACRONYM	FULL EXPANSION
ACTMO	Agricultural Chemical Transport Model.
ADAS	Agricultural Development Advice Service.
AFRC	Agriculture & Food Research Council.
AGNPS	Agricultural Non-Point Source (Model).
ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation.
ARC/INFO	A proprietary GIS.
ARM	Agricultural Management Model.
BAA	British Agrochemicals Association.
BFI	Base Flow Index.
BOD	Biochemical Oxygen Demand.
BMP	Best Management Practice.
BR	British Rail.
CEC	Council of the European Communities.
CLA	Country Landowner's Association
CN	Curve Number.
COD	Chemical Oxygen Demand.
COPA	Control of Pollution Act.
CMIS	Chemical Movement In Soils.
CREAMS	Chemicals, Runoff and Erosion from Agricultural Management Systems.
DBMS	Data Base Management System.
EC	European Community.
EI	Energy Intensity (value).
EPA	(See USEPA).
ESRI	Environmental Science Research Institute.
FoE	Friends of the Earth.
GAMES	Guilph Model for Evaluating the Effects of Agricultural Management Systems on Erosion and Sedimentation.
GIS	Geographical Information Systems.
GLEAMS	Ground Water Loading Effects of Agricultural Management.
HMIP	Her Majesty's Inspectorate of Pollution.
HMSO	Her Majesty's Stationery Office.
HoL	House of Lords.
HSPF	Hydrologic Simulation Program - FORTRAN.
IBM	International Business Machines.
IH	Institute of Hydrology.
ITE	Institute of Terrestrial Ecology.
IWEM	Institute of Water and Environmental Management.
JSWC	Journal of Soil and Water Conservation.
LANDRUN	Overland Flow and Pollution Generation Model.
LEACHMP	Leaching Estimation and Chemistry Model - Pesticides.

MAC	Maximum Admissable Concentration.
MAFF	Ministry of Agriculture, Fisheries and Food.
MCPA	A Pesticide.
MOUSE	Method of Underground Solute Evaluation.
MRC	Medical Research Council.
NCC	Nature Conservancy Council.
NPS	Non-Point Source. (also Nonpoint Simulation Model).
NRA	National Rivers Authority.
NS	New Scientist.
NSA	Nitrate Sensitive Areas.
OECD	Organisation of Economic Communities and Development.
PAH	Poly Aromatic Hydrocarbon.
PC	Personal Computer.
PCB	Poly Chloro-Biphenyl.
PESTAN	Pesticide Analytical Model.
PPM	Parts per million.
PRZM	Pesticide Root Zone Model.
PTR	Pesticide, Transport, & Runoff (model).
RCWP	Regional Clean Water Program.
SERC	Science and Engineering Research Council.
SML	Standard Macro Language (of ARC/INFO).
SPR	Standard Percentage Runoff.
SQL	Standard Query Language.
USDA	United States Department of Agriculture.
USDA-ARS	United States Department of Agriculture - Agricultural Research Service.
USEPA	United States Environmental Protection Agency.
USLE	Universal Soil Loss Equation.
UTM-TOX	Unified Transport Model For Toxics.
VM/CMS	An IBM operating system.
SCC	Surface Condition Constant.
VOC	Volatile Organic Carbon.
WB	Water Bulletin.
WHO	World Health Organisation.
WIS	Water Information System.
WPCF	Water Pollution Control Federation.

Natural
Environment
Research
Council