1991/050

Institute of Hydrology

Natural Environment Research Council

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Modelling Climate Change Impacts on Biochemical and Ecological Systems: Core Model Project

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A progress report for the year to November 1991.

The Institute of Hydrology

Under contract to DoE (Global Atmosphere Division).

(contract number:PECD 7/12/69)

Executive Summary

A number of models are being developed, some from existing models, for the study. Two demonstration studies are reported; (i) utilises an existing distributed model for nitrate modelling on a catchment scale and (ii) a simple general linear model for modelling soil moisture deficit (SMD) on a UK scale. The two demonstration studies were initiated to demonstrate the feasibility of linking a GIS, database and model. A lumped catchment hydrochemical model is being developed to link with a vegetation model. Two vegetation models have been developed, one a simple Penman-Monteith type simulation and the other a model which includes feedback processes between the grassland, soil water content and soil chemistry. The simple grassland model has been successfully linked to a hydrochemical model. All of the models developed to date can be run with equilibrium or transitional climate data and run on a daily time scale.

Table of Contents

1.0) Introduction

With the current concern regarding possible climate change, a research programme has been initiated to assess the likely impact on biogeochemical systems. The Impacts of Climate Change on Ecosystems (ICE) project has three main objectives;

1) To provide core models for predicting impacts of climate change on biogeochemical and ecological systems.

2) To provide models which run for both equilibrium and transitional climates.

3) To couple the models with a GIS to examine the impacts spatially across the UK.

A number of climate scenarios have been proposed for the UK climate over the next 40 years. Using the 'Business-as-usual' scenario of greenhouse gas emissions (Climate change impacts review group, 1991) the average UK summer season temperature will rise by 1.4°C, the mean winter season temperature will rise between 1.5°C and 2.1°C, precipitation in the UK during the winter will be on average 5% greater and global sea-level is estimated to be 20 cm higher.

Obviously the 'Business-as-usual' climate scenario could have a large impact on the flora and fauna of the UK as well as agriculture, horticulture, aquiculture and forestry. The ICE programme is concerned with modelling the effects of changes in climate on biochemical and ecological systems across the UK. Geographical Information systems (GIS) will assist in the management and communication of this study.

The ITE will focus on modelling climate change effects on natural and semi-natural ecosystems, while IH will be modelling impacts on biochemical and ecological systems. The work of the two laboratories is closely linked and these links will be demonstrated in all aspects of the research programme, for example, UK SMD calculated from general linear models applied across the UK under different rainfall and temperature scenarios might be used by ITE as an input variable in the ecological models.

2.0) **Datasets**

Six datasets are presently employed on the ICE project; Land Classification, Hydrology of Soil Types (HOST), Digital Terrain Model (DTM), Meteorological office rainfall and evaporation calculation system (MORECS), Hydrological boundaries of UK rivers and UK boundary. The Land Classification and DTM datasets were supplied by the Institute of Terrestrial Ecology (ITE) and the remaining datasets were supplied from within the Institute of Hydrology (IH). The Land Classification and DTM datasets are on a 1 Km^2 grid covering the whole of the UK, spatially referenced by Eastings and Northings of the lower left hand corner of each grid square. The MORECS data is on the same reference system, but set on a 40 Km^2 grid across the UK. The hydrological boundaries and UK coastline again used the same reference system, to a resolution of 100 m.

2.1) **The Land Classification Dataset**

The Land Classification dataset (Figure 1) was derived from a land classification scheme, produced by ITE (1978). There are 32 land classes in the scheme and each UK 1 Km^2 grid square is assigned to a class. Each land class is statistically derived from cartographic and environmental sources and represents a distribution of land use, rather than actual land use within the square. Thus, each land class has a percentage coverage of each of 11 land classes, including; Built Up, coniferous woodland, broadleaf woodland, miscellaneous natural, moorland, bog, heath/shrub, upland grass, permanent grass, leys and cultivated land.

2.2) **The HOST Dataset**

The HOST dataset (Figure 2) is based on an analysis of the important parameters of a soil with relation to water movement (Boorman and Hollis, 1991). There are 29 soil classes. A given soil is classified using; Soil hydrogeology, depth to aquifer or groundwater, presence of a peaty top soil, depth to a slowly permeable layer, depth to gleyed layer and integrated air capacity.

Figure 1

Figure 1 shows the distribution of land classes across the UK. There are 32 classes. Overlaid are the hydrological boundaries.

Figure 2

Figure 2 shows the distribution of soil classes (HOST) across the UK. Overlaid are the hydrological boundaries.

2.3) The DTM Dataset

The DTM dataset (Figure 3) provides a range of information about a given 1 Km^2 grid square including; Height of nearest hill, height of nearest valley, distance to nearest hill, distance to nearest valley, calculated gradient, northerly aspect, easterly aspect, calculated slope and mean altitude of square.

2.4) The MORECS Dataset

The MORECS dataset (Figures 4 and 5) consists of 9 meteorological parameters for a given month, averaged over 27 years from 1961 to 1988. Each 40 Km^2 grid square is assigned a MORECS square number from 1 to 190 over the UK. The dataset consists of; month, square, potential evaporation, actual evaporation, soil moisture deficit, penman evaporation, rainfall, sunlight, temperature, vapour pressure and wind speed.

2.5) The Hydrological Boundaries and UK Coastline Datasets

The Hydrological boundaries and UK coastline (Figures 1-5) include all of the hydrological boundaries of the main UK rivers as described in the Hydrological registrar. Each hydrological area is define by a unique number from 1 to 106. The boundary of each area was denoted as a sequential list of Eastings and Northings, to a resolution of 100 metres.

Figure 3

Figure 3 shows the UK altitude map from the DTM dataset. Overlaid are the hydrological boundaries.

Figure 4

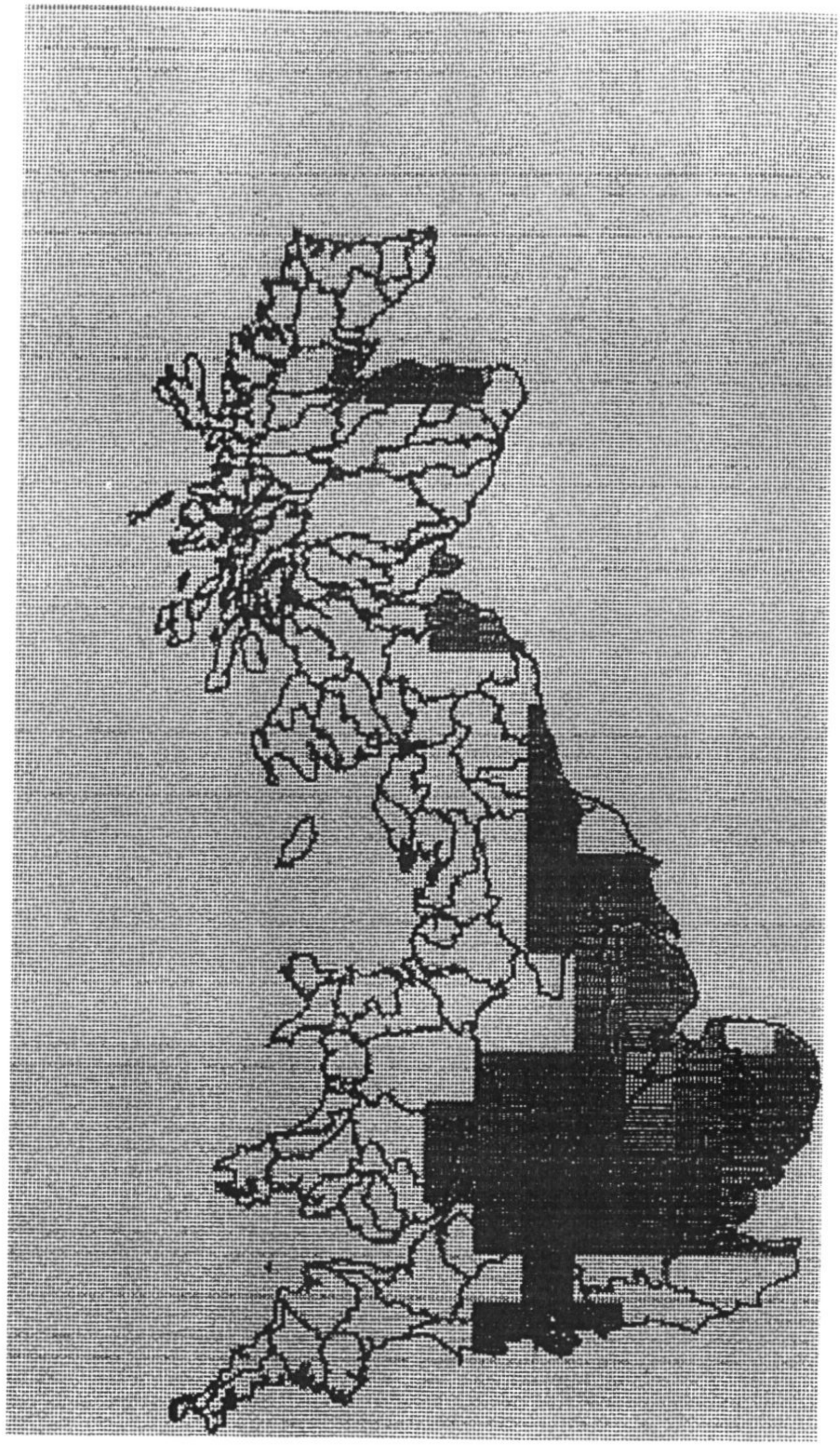


Figure 4 shows the distribution of SMD across the UK, for January. Overlaid are the hydrological boundaries. The colour scale represents; grey (0 mm SMD) to green, to brown, to yellow (9.5 mm SMD).

Figure 5

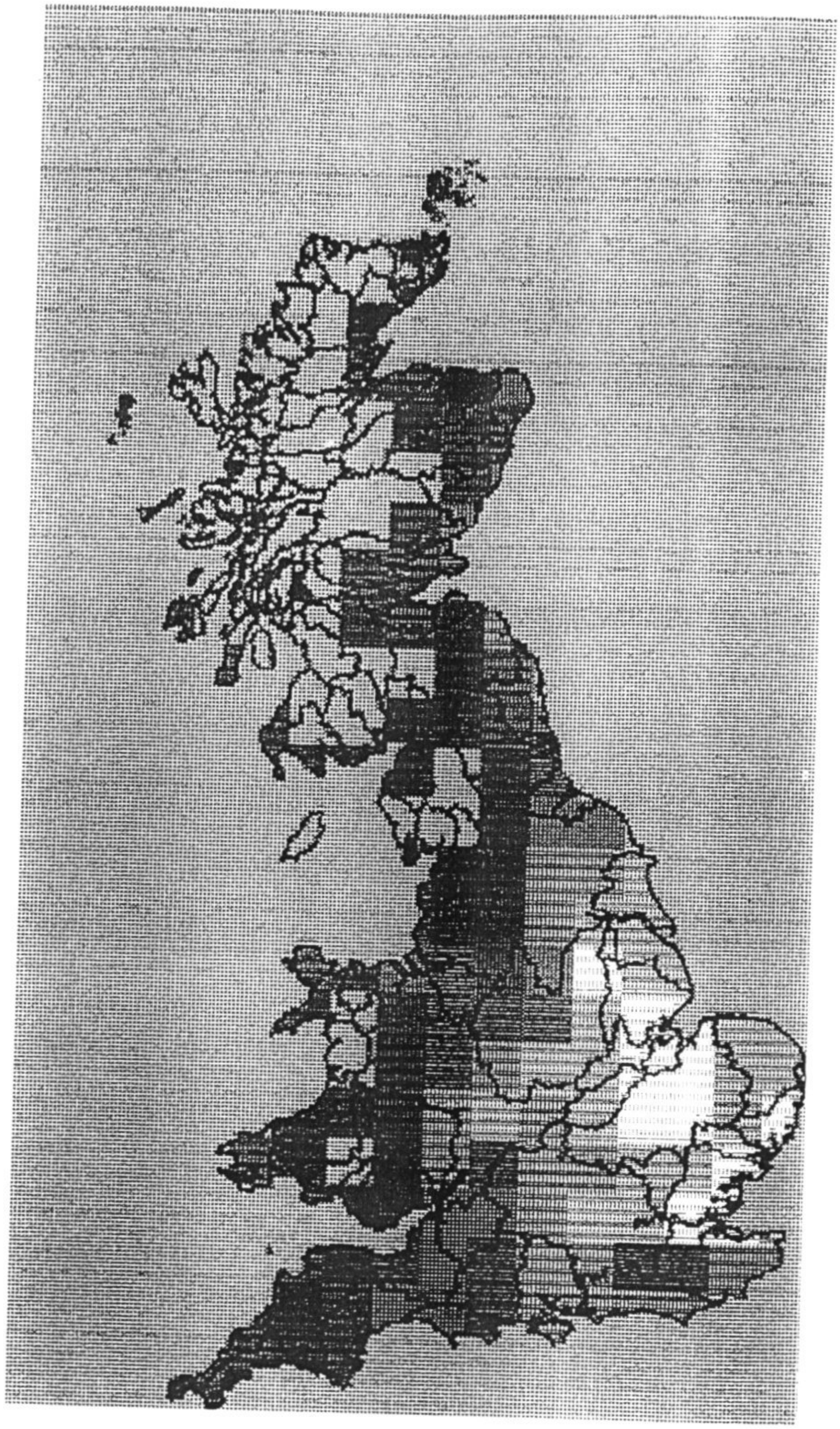


Figure 5 shows the distribution of SMD across the UK, for September. Overlaid are the hydrological boundaries. The colour scale represents; grey (0 mm SMD), to green, to brown, to yellow (295 mm SMD).

2.6) The ORACLE Database

The Land classification, HOST and DTM datasets were loaded into the ORACLE database, running on an IBM 4381 mainframe and indexed by Eastings and Northings. Only the Easting, Northing and dominant Soil Class for a given grid square, were loaded from the HOST dataset, in order to simplify the database and reduce storage.

2.7) Scaling

The MORECS dataset at a 40 Km^2 scale had to be converted to a 1 Km^2 grid scale. To this end a FORTRAN program was written to convert each MORECS square number (1 - 190) into 1600 1 Km^2 grid squares (each 40 Km^2 grid square consists of 1600 1 Km^2 grid squares), referenced by Eastings and Northings. No interpolation, of data, between grid squares was carried out during this process so the data in each of the 1600 1 Km^2 grid squares was identical to the data in the equivalent 40 Km^2 grid square. The 1 Km^2 grid square MORECS dataset was then loaded into ORACLE and indexed by Eastings and Northings.

3.0) Geographical Information Systems

A Geographical Information System (GIS) is a tool kit for the manipulation and interrogation of geographical entities and their associated attributes. A typical GIS dataset consists of a number of 'coverages'. Each coverage is a set of geographical features with common attributes. A geographical feature could be for example; streets, soil type, vegetation type, etc. Features can be stored as points, arcs (lines) or polygons (areas), for example streets would be stored as arcs.

The GIS currently in use is Horizon running on a VAX workstation. This is being succeeded by ARC/INFO loaded on a SUN workstation.

The spatial datasets; HOST class, Land class, DTM and MORECS (see above), have been set up on Horizon. This system was used to verify the datasets and a variety of errors and inconsistencies have been removed. At present the datasets are stored in raster format, with the exception of the hydrological areas and UK coastline which has been stored in vector format as polygons.

With the installation of ARC/INFO the datasets will be transferred to the SUN workstation. This will allow the models currently running on the workstation (see below) to be linked to the GIS. Horizon is not presently available on a UNIX platform.

4.0) Demonstration Studies

Two demonstration studies have been carried out on the linkage of a GIS, model and database. In both cases the studies spanned different computer hardware and software applications. The first study utilises a non-point source pollution (NPS) model and ARC/INFO, while the second study utilises a simple linear regression model and Horizon. Below is a summary of each study.

For further details of the NPS pollution study refer to 'Environmental Analysis Using Modelling and Geographical Systems - A Case Study.', Morse, G., Eatherall, A., Jenkins, A. and Finch, J., Institute of Hydrology, Nov. 1991'.

4.1) <u>Non-point Source Pollution Modelling using a GIS - A Case Study</u>

The ICE programme is concerned with modelling large-scale complex issues, and it is intended to use Geographical 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.

Modelling 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 processed easily, 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 watershed management purposes. In this study the model was integrated with the ARC/INFO GIS 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 further used for presentation purposes. The model was run under various scenarios, including scenarios representing the most likely situation, incorporating reasonable data input uncertainty, and representing changes in management practices.

The most likely scenario over-predicted agricultural pollution, but this may be because of 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.

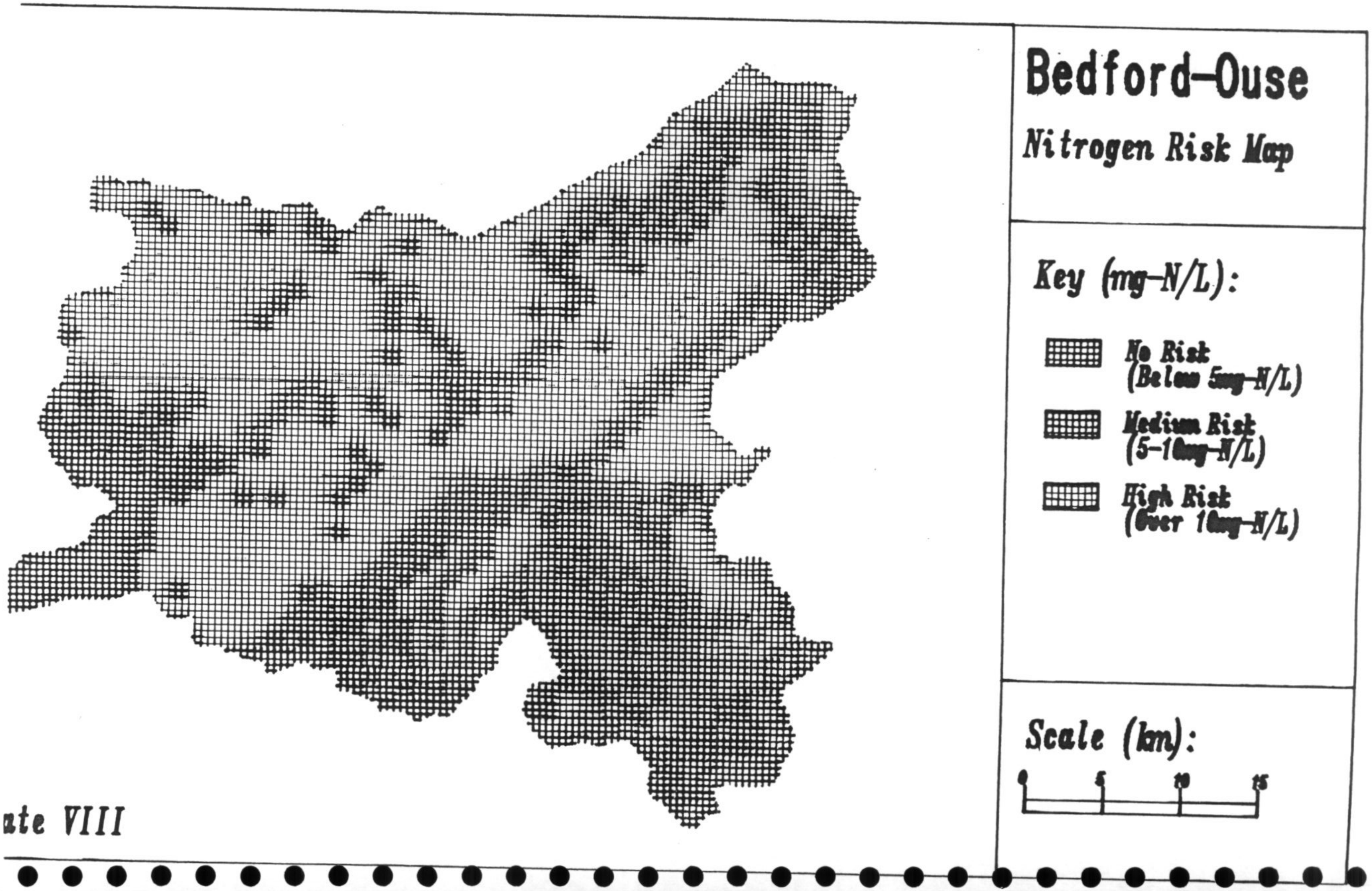
Scenarios to evaluate model data input sensitivity identified the U.S. Soil Conservation Service (SCS) curve number equation as the input parameter dominating model prediction. SCS curve number relates to the runoff or sediment yield of a catchment (Mockus, 1972).

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.

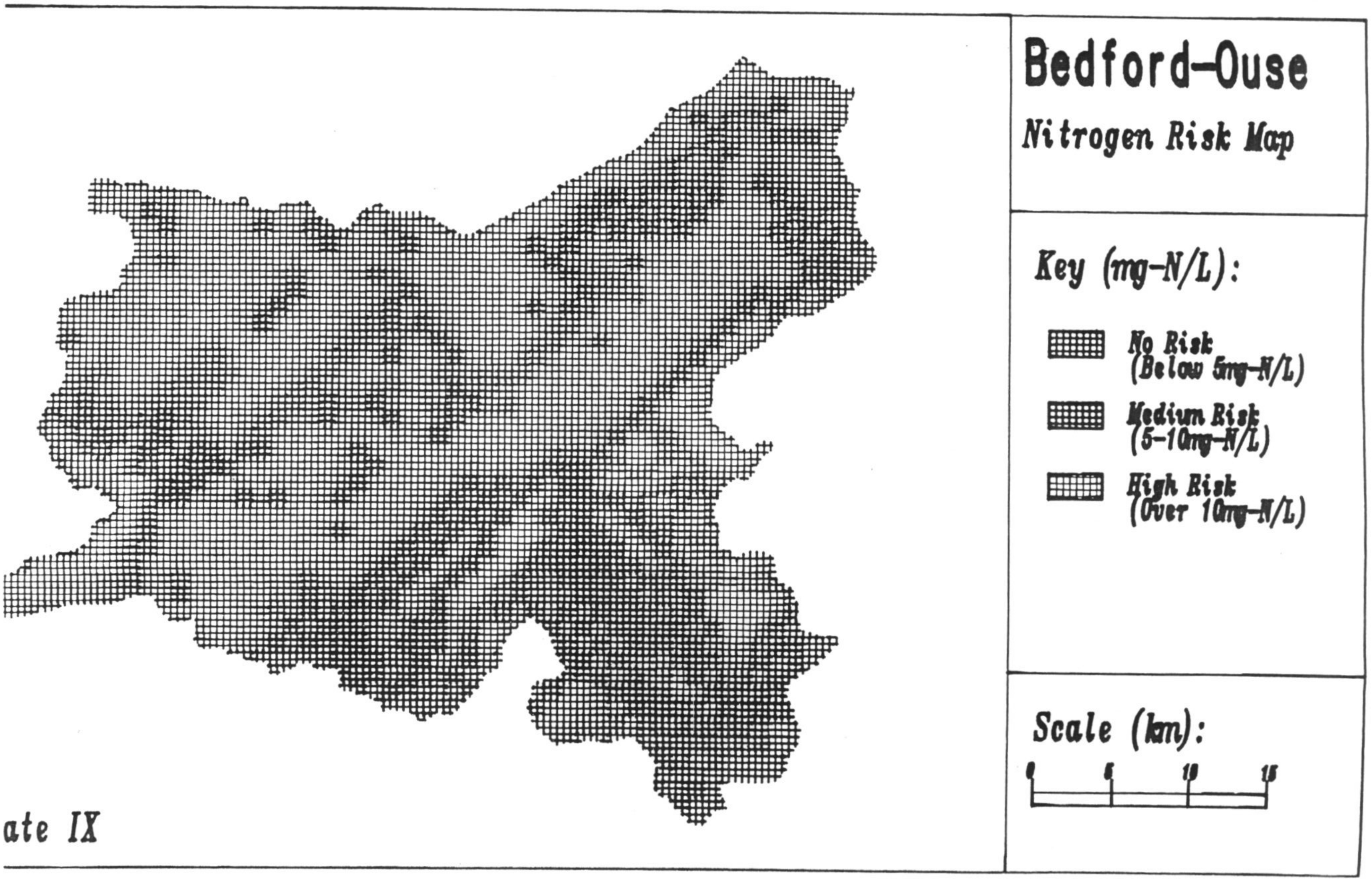
The use of GIS in the application demonstrated the benefits identified in the literature, although other computing aspects, notably FORTRAN, must take substantial credit for adding the flexibility to integrate software components. Although it would have been almost impossible to do some analyses without the GIS. 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 (Plate VIII shows the nitrogen risk map for the Bedford Ouse. Plate IX shows the low fertilizer input nitrogen risk map). 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 model developed


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

ate VIII


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
ate IX

in the US to 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.

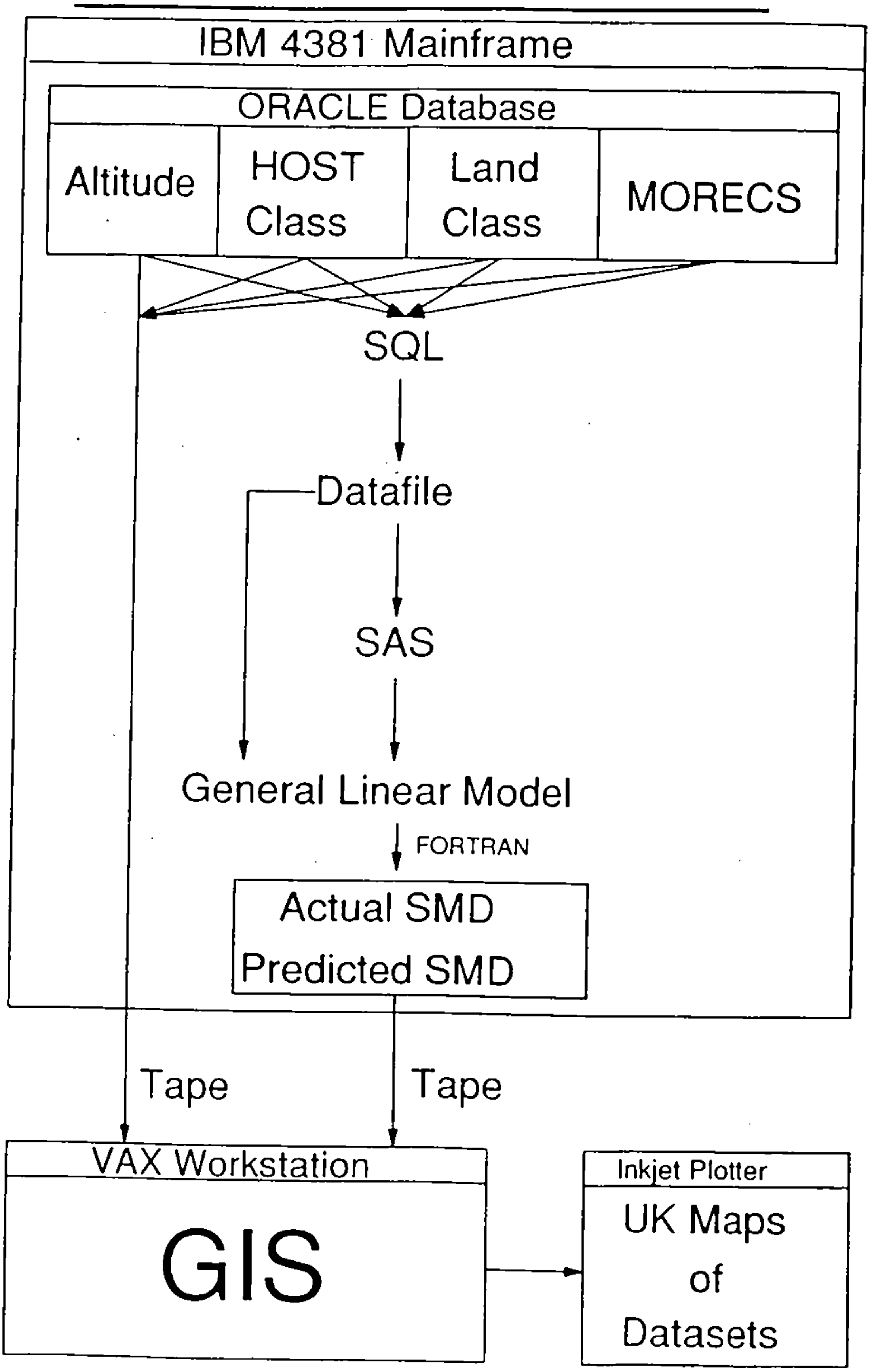
The benefits of this case study to the ICE research programme lie in the need for exploration and communication of complexity and uncertainty and this is where the major benefits of a GIS approach have been demonstrated. In addition to the communication benefits, the GIS approach has significant advantages in efficiently exploring scenarios and managing the data volumes involved.

4.2) Demonstration of Linked GIS, Database and Model

In order to test whether a GIS, database and model could be linked on a UK scale and to see how difficult the problem was, a further demonstration study was undertaken. The aim of the study was to link the datasets on ORACLE (on the IBM mainframe) with Horizon, the GIS (on the VAX workstation), with a model to predict soil moisture deficit (SMD) across the UK, in January and September. Figure 6 shows the flow of information through the systems. The model formulation is necessarily crude, a general linear model (GLM) using multiple predictors, since the aim of the demonstration study is to determine the problems of dealing with large datasets in terms of data transformation, graphical output and data overlay.

Information Flow

Figure 6



4.2.1) SQL

To produce the model a data file was required containing values for SMD, rain, slope, land class and HOST class for each grid square across the UK. Since the datasets on ORACLE were from different sources, a number of grid squares only had a subset of the variables required for producing the model. Thus it was necessary to use only the grid squares where a full set of data existed. This was achieved using the ORACLE Structured Query Language (SQL). The result was a data file consisting of UK grid squares where all of the dataset required for building the GLM was present. This data file was then used as input to a statistical package SAS which produced the GLM and coefficients.

4.2.2) The SMD Model

Since this was only a demonstration study a simplified model was developed to predict SMD from rainfall, land class, HOST class and slope for each 1 Km^2 grid square across the UK. The GLM procedure uses the method of least squares to fit a general linear model to a dataset. In this case multiple regression analysis was utilised. The model constructed had the form;

$$\log(SMD) = \log(Rain) \times \alpha + Slope \times \beta + Landclass + HOSTclass + Intercept$$

Rain, SMD and slope were continuous data, whereas land class and HOST class were entered as classes in the GLM *i.e.* discrete non-continuous data. α and ß are coefficients of the model. The log function was added to the GLM to increase the 'goodness of fit'. An r^2 value of 0.81 was attained for the January dataset and 0.95

for the September dataset. No attempt has been made to validate this model, it is simply a tool to demonstrate linking a model to a GIS and database.

4.2.3) **Predictions of SMD**

The GLM and coefficients were then used in a FORTRAN program to produce two datasets; one a prediction of the SMD across the UK in September and one a prediction of the SMD across the UK in January. The final datasets created were transferred from the IBM mainframe to the VAX workstation via magnetic tape and converted into a file format suitable for input to the GIS.

4.2.4) **Results**

Figures 1, 2 and 3 show three of the original datasets used in the model. Overlaid on each dataset are the hydrological areas of the UK mainland. . Figures 4,5,7,8 show the actual and predicted SMDs for both months. The predicted SMD for January and September show variation within each 40 Km^2 grid square, because of the differing HOST class, land class and slope. All four Figures demonstrate the typical Northwest to Southeast trend across the UK of decreasing SMD. This is because of the similar trend across the UK in rainfall pattern, with high rainfall in the North and West and low rainfall in the South and East. As expected, the SMDs were smaller in January than in September since the majority of yearly rainfall occurs during the winter months. The model predicts SMD quite well across the UK, though

Figure 7

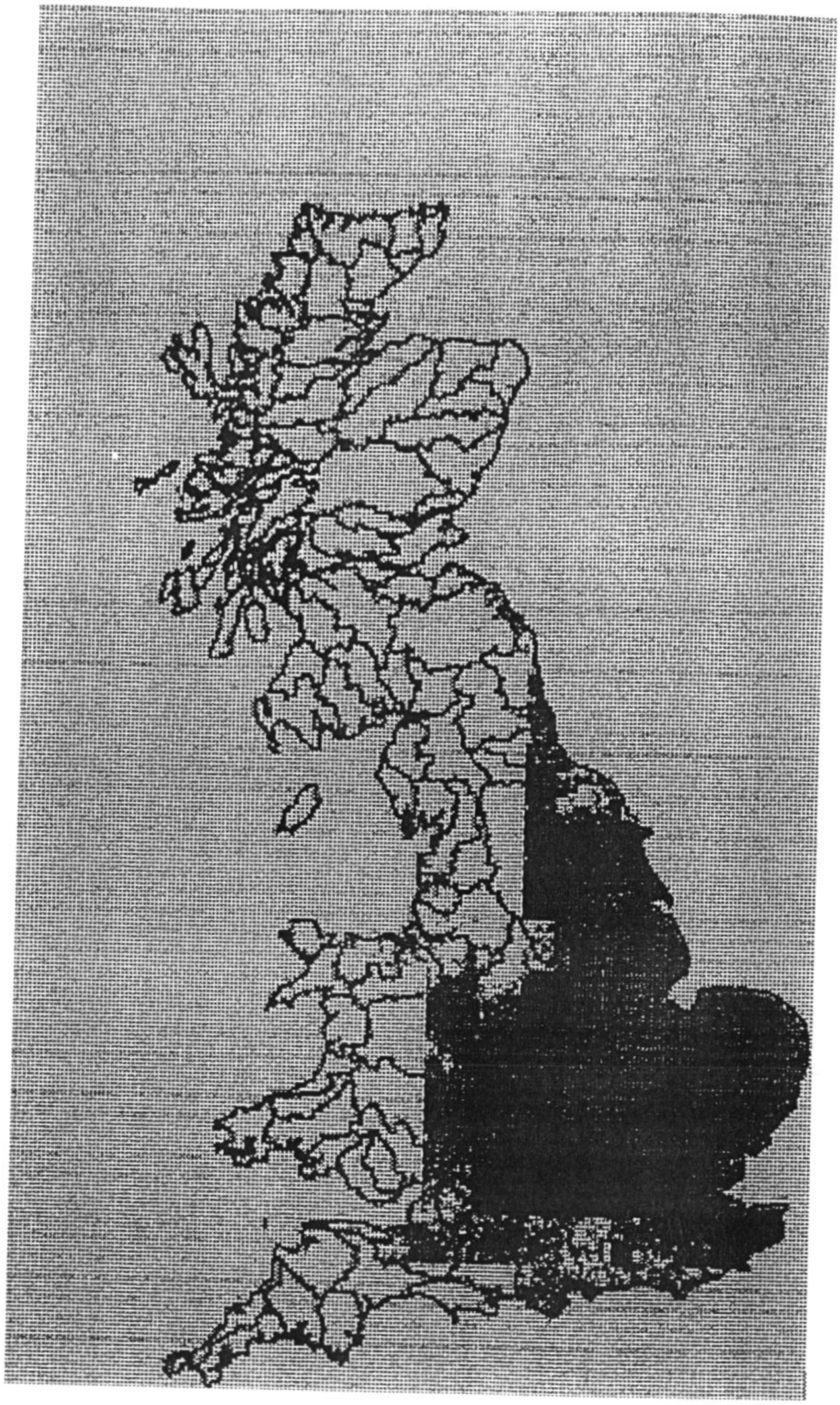


Figure 7 shows the predicted distribution of SMD for January, across the UK. Overlaid are the hydrological boundaries. The colour scale represents; grey (0 mm SMD), to green, to brown, to yellow (9.5 mm SMD).

Figure 8

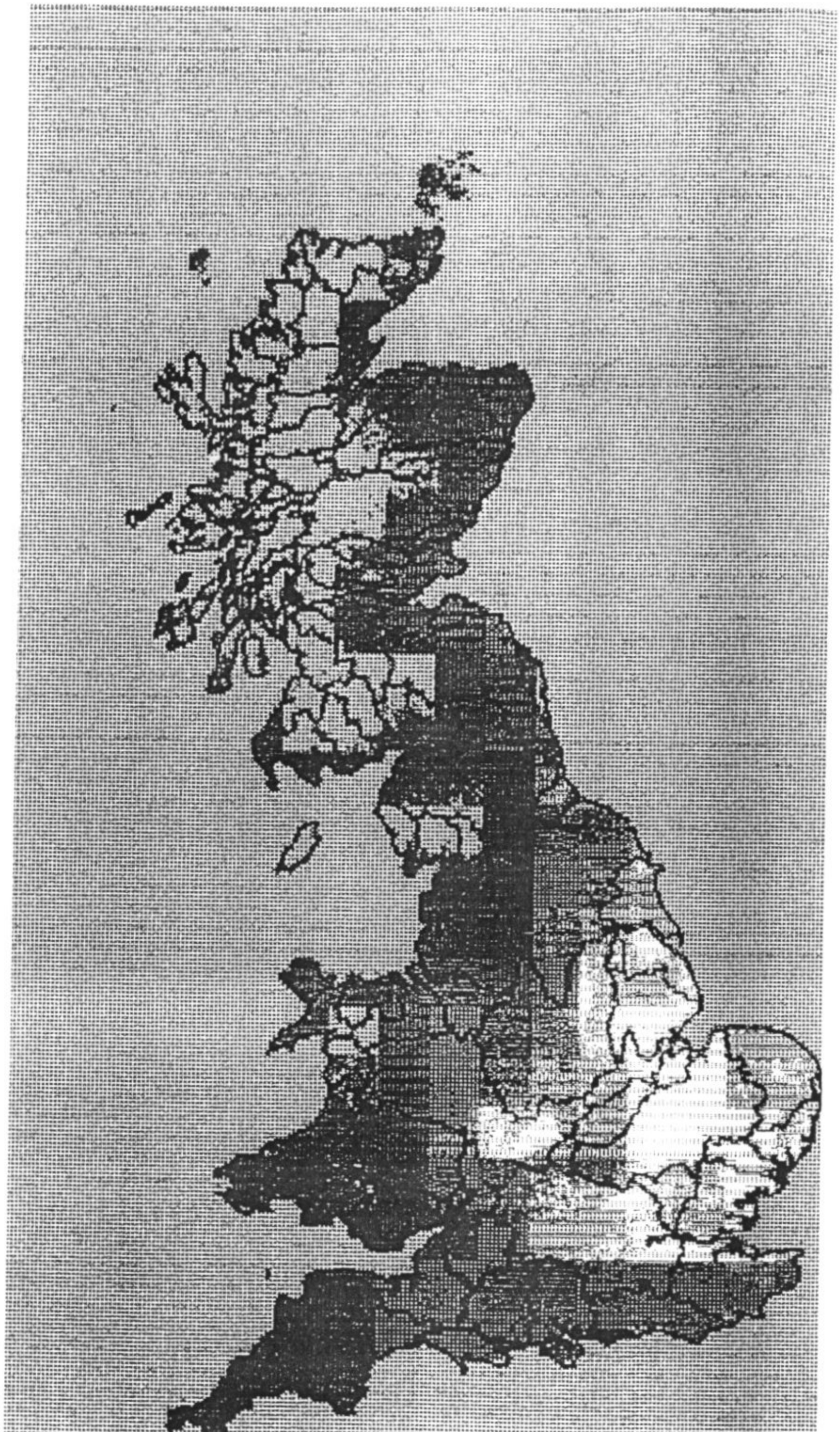


Figure 8 shows the predicted September SMD distribution over the UK. Overlaid are the hydrological boundaries. The colour scale represents; grey (0 mm SMD), to green, to brown, to yellow (295 mm SMD).

this was to be expected given the datasets used.

4.2.5) Conclusions

The study has succeeded in linking a GIS, database and model. The linkage mechanisms in this case were simply data files used to transfer from one format or application to another. Magnetic tape was used to link data files between the VAX workstation and IBM mainframe. This method of linkage was time consuming and there was difficulty in changing data file formats, between applications and computers, however the problems were not insurmountable.

The GIS was used here only as a presentation tool and although this was very useful it only utilised a small part of the GIS. However with the transfer of the GIS and datasets onto the same hardware platform (Sun workstation running UNIX) the GIS will be linked directly to the database and used to select hydrological areas of interest for modelling.

Future aims for this demonstration include dynamically linking the GIS, database and model, so that the model can be run for a 'user' chosen hydrological area. This would utilise the 'overlay' functions of the GIS by determining the subset of variables for each dataset which lie in the given hydrological area i.e. spatial analysis. This demonstration can also be used for assessing SMD under differing climate scenarios following the validation of the model. Subsequently predicted SMD maps of the

UK can be supplied to ITE for Ecological modelling.

5.0) **Deterministic Catchment Modelling**

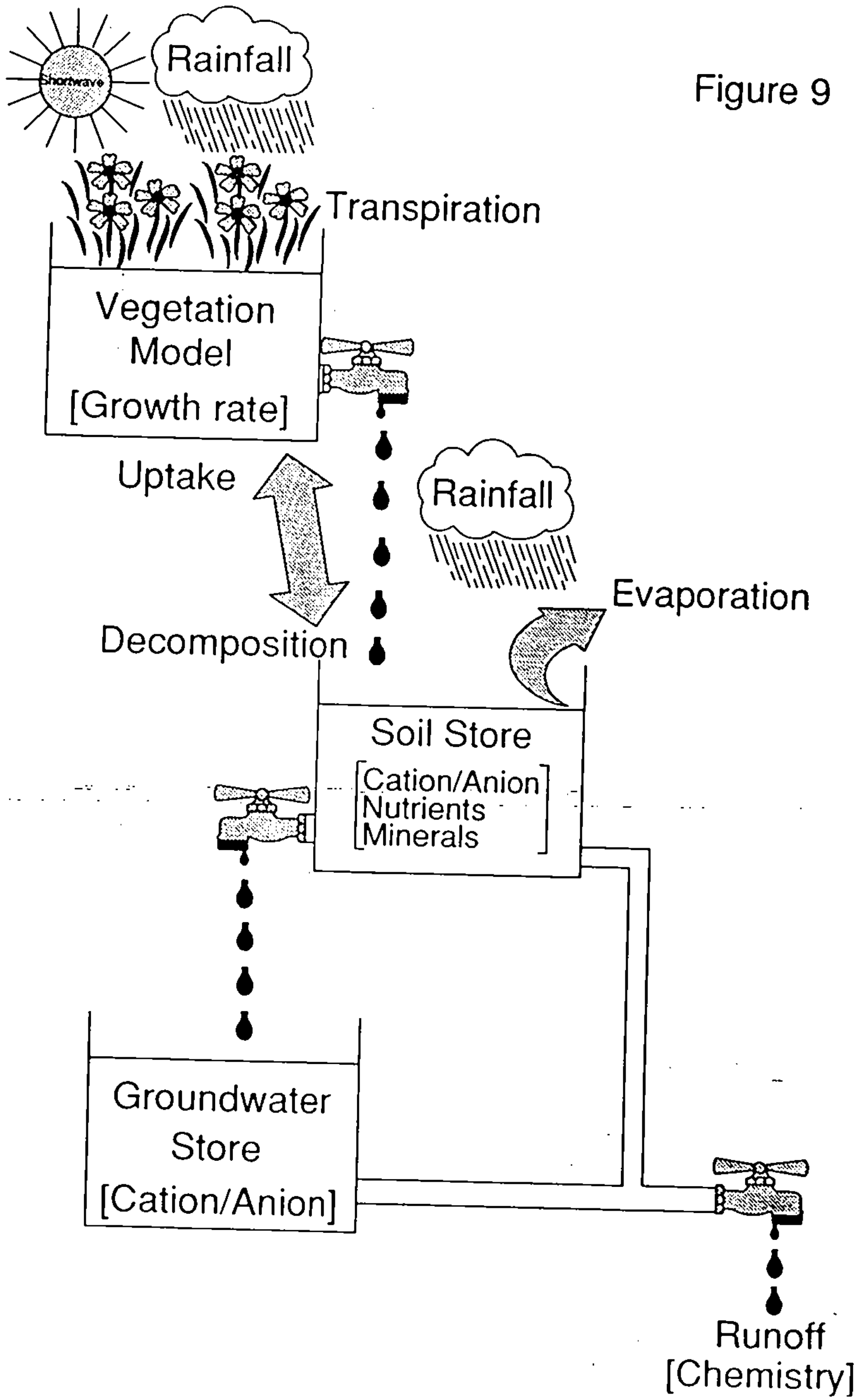
A major objective of the ICE programme is to develop core models with which to assess the impacts of climate change on the biogeochemistry of catchment ecosystems in the UK. The complexity of such ecosystems demands the development of deterministic, process-based models. That is, models that describe the processes in question through the interaction of physically meaningful and measurable parameters and constants. A number of models describing various compartments of natural ecosystems currently exist, *e.g.* soil-soil solution chemistry, hydrology and plant growth. A first stage in this modelling programme has been to attempt to link available models to incorporate important feedbacks and mass transfers.

5.1) **Linkage of Hydrology, Chemistry and Simple Vegetation Models**

The first linked model developed utilised a soil chemistry and hydrology model (an amended version of the Birkenes model (Christopherson *et al*, 1982)) and a simple vegetation model based on the Penman-Monteith model (Penman, 1948). In this version of the linked model there was no feedback between the vegetation model and the hydrochemical model.

Figure 9 illustrates how the vegetation, soil chemistry and hydrology models are linked. Precipitation contributes to the

Figure 9


Shortwave
Rainfall
Transpiration
Vegetation Model [Growth rate]
Uptake
Decomposition
Rainfall
Evaporation
Soil Store
[Cation/Anion Nutrients Minerals]
Groundwater Store [Cation/Anion]
Runoff [Chemistry]

mass balance of the upper soil horizon, along with snowmelt if present. Output from the horizon is dependant upon the saturation state. There are three possible routes from the upper soil horizon; overland flow to the stream, evapotranspiration and flux through and out of the soil horizon. The flow out of the upper soil horizon is partitioned into flow entering the lower soil horizon and flow travelling directly to the stream. Outputs from the lower soil horizon include; evapotranspiration, rapid flow to the stream as the layer saturates and flow from the lower reservoir to the stream.

The amount of precipitation falling as snow is dependant upon the temperature. A temperature of 0°C or lower designates all of the precipitation as snow. Between 0°C and 1.6°C there is a linear relationship describing the ratio of snow to rain and above 1.6°C all precipitation is rain. Once snow falls a snow reservoir is present. The snowmelt is dependant upon temperature, with no snowmelt below 0°C. The snowmelt either enters the upper soil horizon or the stream directly along preferential flow paths.

The soil chemistry in both horizons is treated in similar ways. Water flowing into the soil horizons changes the concentration of cations and anions. The anion model takes into account dry deposition of SO_2 and SO_4^{2-}, calculates the $[SO_4^{2-}]$ and $[Cl^-]$ in the snow and meltwater, calculates SO_4^{2-} reduction in the upper soil horizon when the horizon is wet, calculates SO_4^{2-} mineralisation when the upper horizon is dry and calculates the proportion of SO_4^{2-} in soluble or fixed form in the lower horizon (SO_4^{2-} is only present in soluble form in the upper horizon).

The cation model calculates; $[H^+]$, $[HCO_3^-]$, $[Mg^{2+}]$, $[Na^+]$, $[Ca^{2+}]$ and $[Al^{3+}]$ in snow, meltwater and upper and lower reservoirs. Na^+ is treated as conservative in the upper soil horizon and cation concentrations are adjusted until a charge balance is reached by adjusting $[H^+]$. Consumption of H^+ through weathering and chloride adsorption onto the solid phase are also included.

The vegetation model is based on a Penman-Monteith growth efficiency concept. For a given latitude in the UK a value for radiation is calculated for each day of the year. Transmission through the atmosphere is dependant upon the cloud cover and the degree of air pollution. One half of the radiation is in an active form and 85% of this is absorbed. Photosynthetic efficiency takes into account the energy content of light and the heat stored in one molecule of CH_2O. A Monteith architecture factor for the position of the leaf is included as well as leaf area index and from these factors shaded and sunny areas of the crop are calculated. The diffusion efficiency and interception efficiency are calculated and the respiration efficiency of the crop is allowed for. The overall efficiency of the crop is then derived along with the dry matter content, transpiration rate and ion uptake.

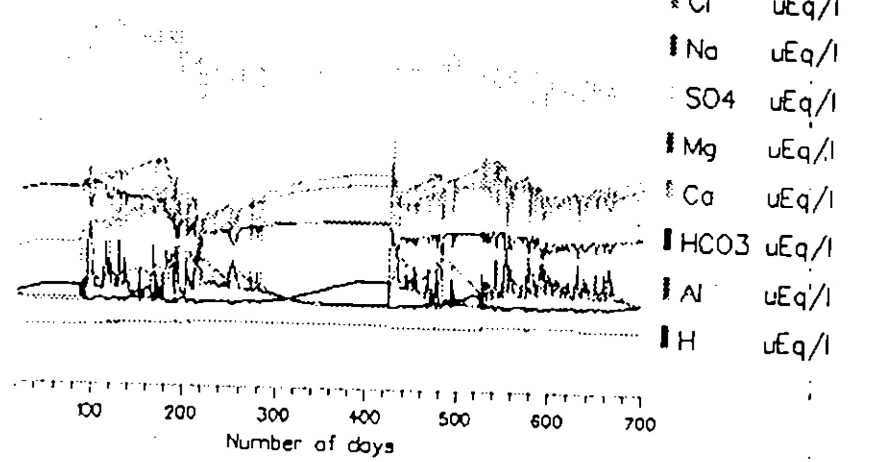
The transpiration rate of the vegetation model is considered equal to the uptake of water from the soil horizon. If the upper soil horizon is sufficiently saturated all of the water required by the crop is removed from here. When the saturation level of the upper soil horizon is lower than a predetermined level, but higher than the minimum; evapotranspiration is proportioned between the upper and lower soil horizons, so that as the proportion of water in the upper reservoir decreases an increasing amount is removed from the lower horizon. Below an arbitrarily selected minimum all evapotranspiration is removed from the lower reservoir. If the temperature is below 1.0°C no evapotranspiration occurs. It is assumed all ion uptake, by the crop, is by solute transport and thus ion uptake is dependent upon the transpiration rate.

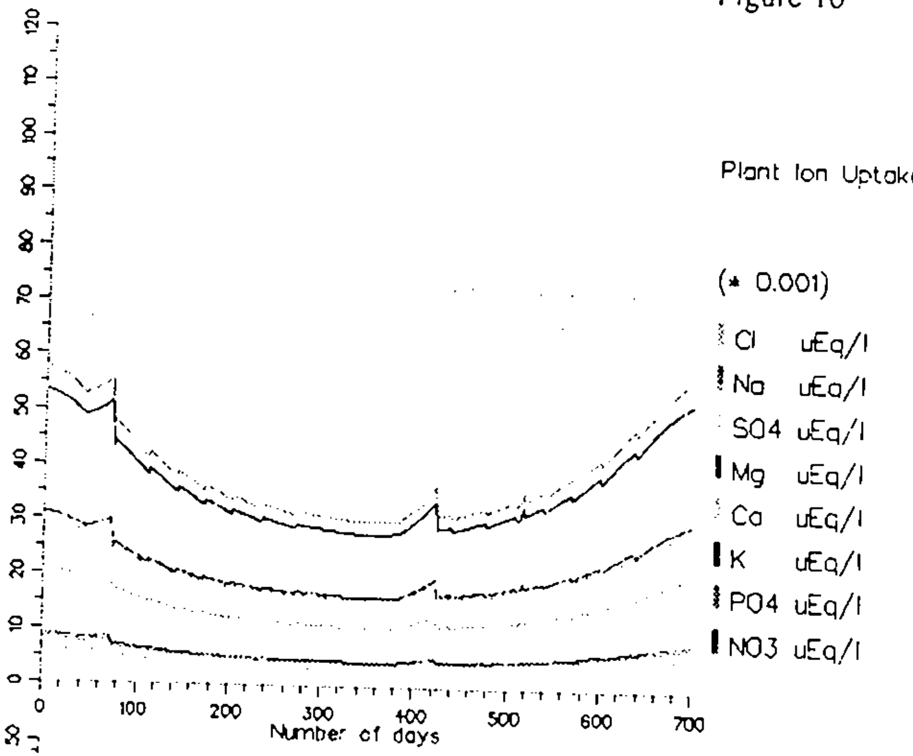
Figure 10 shows an example of the output for the linked model, for the Birkenes catchment over two years.

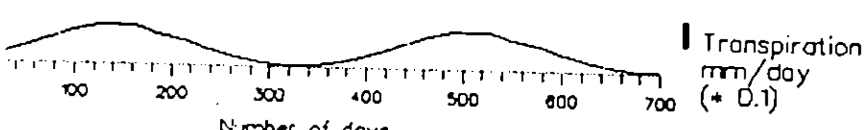
5.2) Grassland model

An improved version of the linked model is now being generated which utilises a newly developed grassland model. Figure 11 shows a schematic diagram of the simulation. The model is driven by light and temperature and requires water and nitrate inputs from the soil. Assimilate production is calculated from photosynthesis, respiration and transpiration. The assimilate is then partitioned to the leaf, stem or root, new growth rates are calculated and the leaves, stems and roots expand accordingly. Routines are included for leaf area index, new leaf growth, ageing of leaves and death. Feedback to the hydrochemical model is incorporated via water and nitrate supply,

Figure 10


Stream Chemistry
O18 mm/l
Cl uEq/l
Na uEq/l
SO4 uEq/l
Mg uEq/l
Ca uEq/l
HCO3 uEq/l
Al uEq/l
H uEq/l
100 200 300 400 500 600 700
Number of days


Plant Ion Uptake
(* 0.001)
Cl uEq/l
Na uEq/l
SO4 uEq/l
Mg uEq/l
Ca uEq/l
K uEq/l
PO4 uEq/l
NO3 uEq/l
0 10 20 30 40 50 60 70 80 90 100 110 120
0 100 200 300 400 500 600 700
Number of days


Transpiration
mm/day
(* 0.1)
100 200 300 400 500 600 700
Number of days

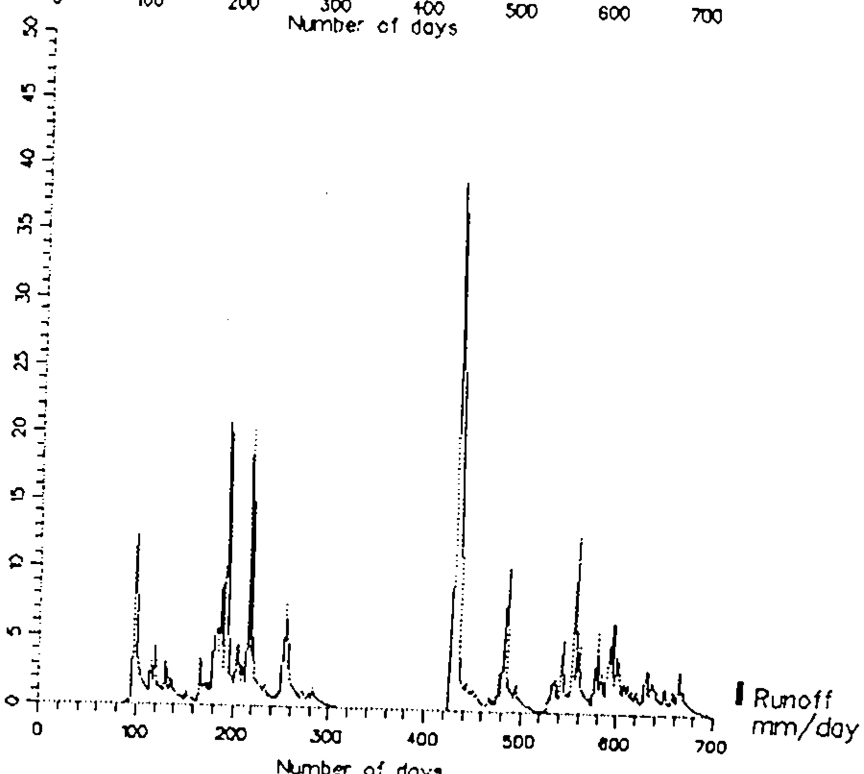
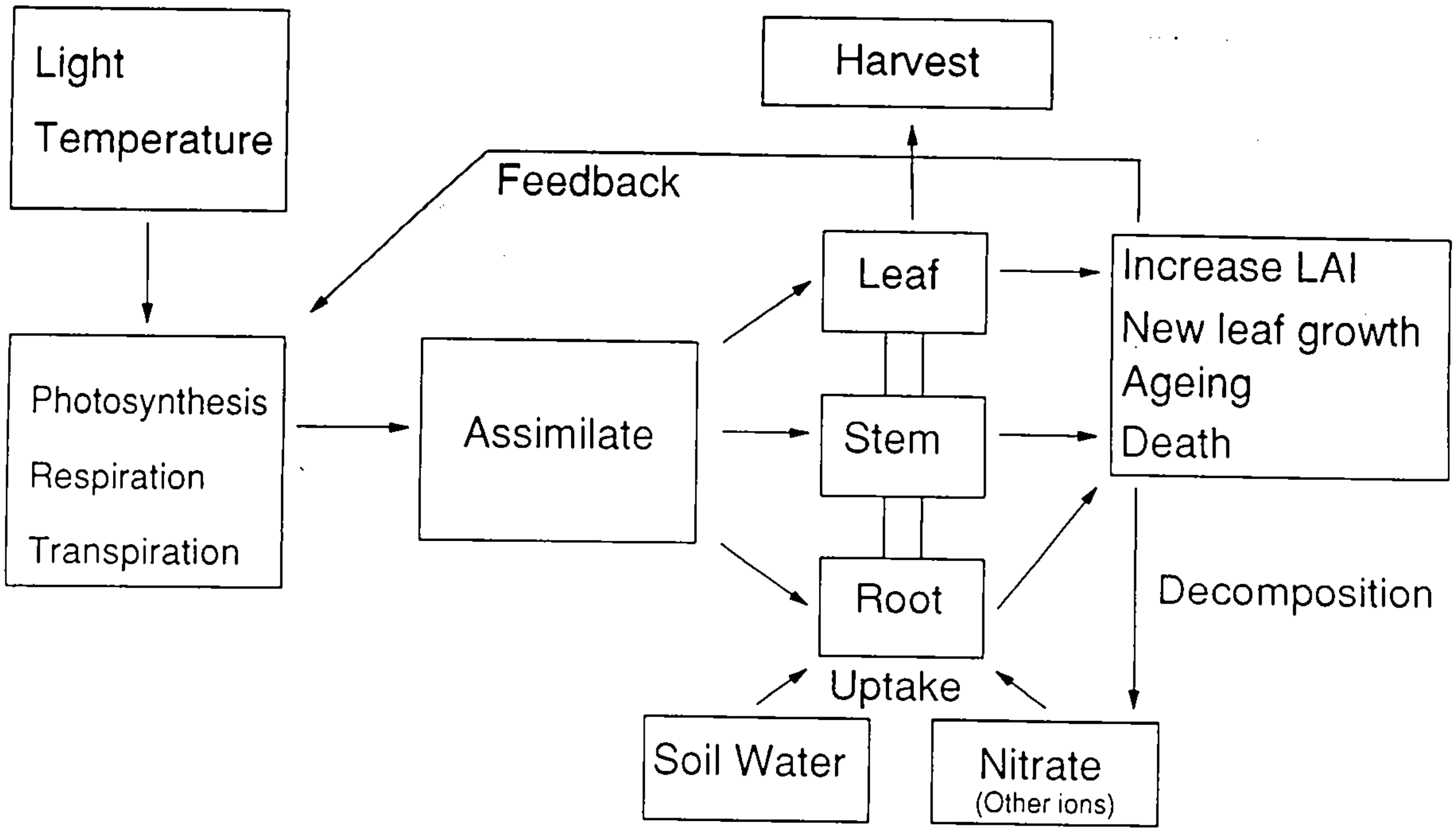

Runoff
mm/day
0 5 10 15 20 25 30 35 40 45 50
0 100 200 300 400 500 600 700
Number of days

Figure 11

Grassland Model



deficiency in either results in diminished growth rates and if severe enough, leaf and root area will decrease. A harvesting routine is also included.

Figure 12 shows a schematic diagram of the proposed linkage between the new grassland model and the existing hydrochemical model. The grassland simulation will be linked to the soil water compartment providing feedback between the grassland model and soil water content. The grassland model will also be linked via the nitrate content of the soil chemistry forming another feedback pathway. Thus there will be uptake of water, nitrate and other ions (in proportion to nitrate) from the soil and if supplies are insufficient to support maintenance or growth, the growth rate of the crop will decrease and if severely stressed leaf and root area will decrease. The soil water chemistry and stream water chemistry will change appropriately to plant uptake. A nitrate soil chemistry compartment will also be added, based on the Addiscott model (Addiscott and Whitmore, 1987).

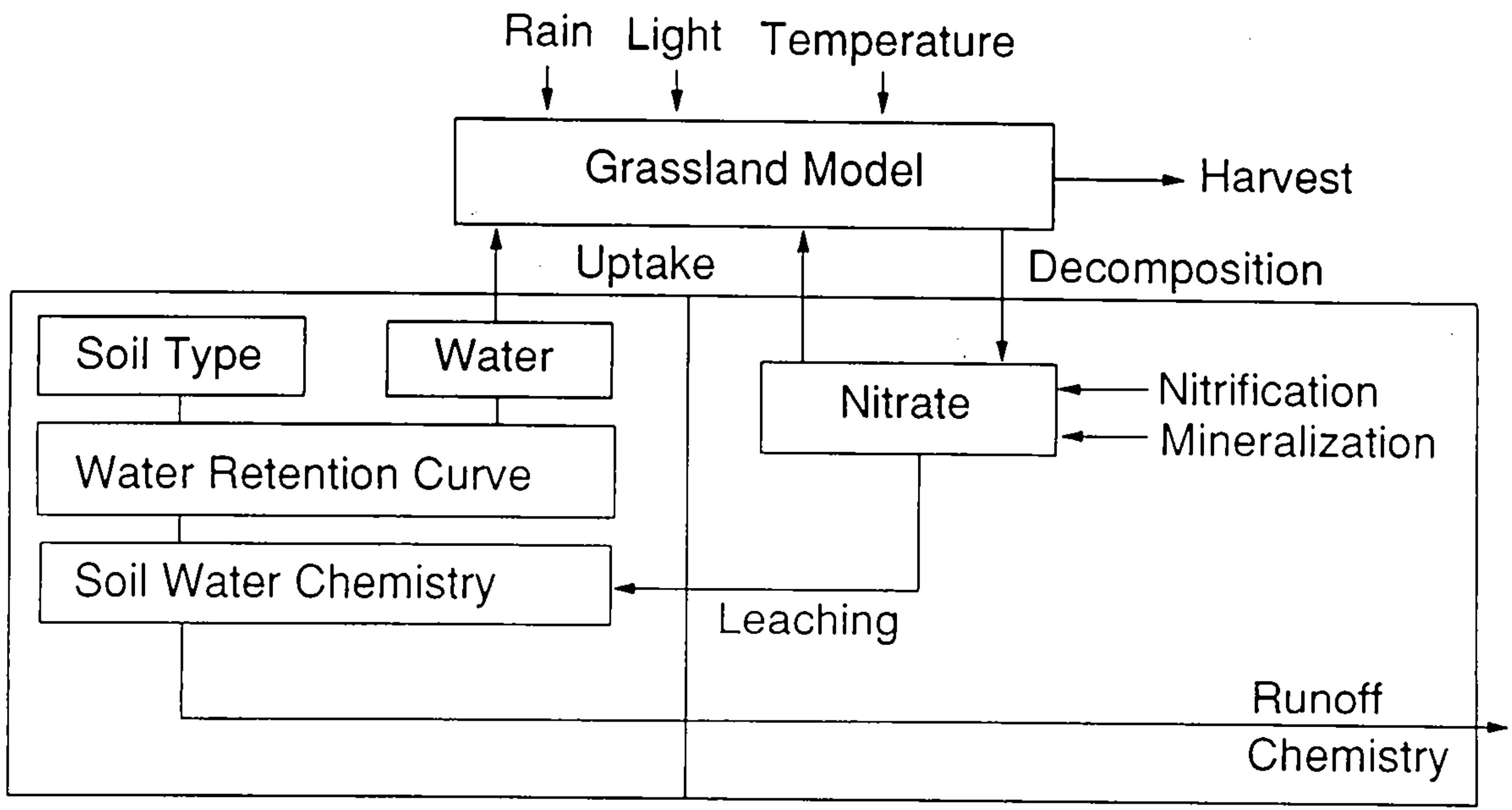
6.0) **Future Developments**

Future work will focus on;

1) The completion of the linking of the grassland model with the existing hydrochemical model, incorporating feedback paths via water and nitrate supply resulting in an integrated lumped catchment model.

Figure 12

Linked Model



2) The possible simplification of the hydrochemical sub-model of the lumped catchment model, by replacing the routing parameters in the existing model, which in any case, cannot be determined on a grid basis cross the UK since the model is catchment based and requires parameterisation against an observed flow record. An alternative formulation is now being explored utilising IHAcres, a time series analysis model, to generate proportions of quick and slow flow. These may then be related to catchment physical characteristics.

3) The validation of the grassland model will be investigated, using data collected from lysimeter studies in the Balquhidder catchment.

4) The dynamic linking of models to the GIS and databases on the SUN workstation will be undertaken, so that the lumped catchment models can be applied to hydrological areas as well across large areas of the UK.

5) The development of equilibrium and transitional climate scenarios with the Hadley Centre for Climate Research for use with the linked models, GIS and databases.

6) The development of long term models for use with the GIS and databases.

7) Investigation of the use of catchment based semi-distributed hydrological model (TOPMODEL, Beven and Kirkby, 1979) to predict

changes in soil saturation within catchments. Links between this approach and ITE plant species distribution models will be explored.

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