Human influence on River Regimes of Western Europe

"AN ASSESSMENT OF HUMAN INFLUENCE ON THE RIVER FLOW AND WATER QUALITY REGIMES OF WESTERN EUROPE"

A research proposal by the United Kingdom
for

IHP III THEME 6. METHODS FOR ASSESSING THE CHANGES IN THE HYDROLOGICAL REGIME DUE TO MAN'S INFLUENCE

PROJECT 6.1 The use of representative and experimental basins (including benchmark and vigil basins) for monitoring natural and man made changes in the various hydrological regimes.

(a) To assemble, review and report on the results of existing representative and experimental basins on a national and international basis.

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INTRODUCTION

1.1 Aim

This project will use data from representative and experimental drainage basins in western Europe to study natural and man-made changes in various hydrological regimes.

1.2 Objectives

(i) To assess the effects of land use change (land drainage, afforestation etc) on
flood frequency
low flow frequency
storage-yield relationships
water quality regimes
water balance

(ii) To assess long term trends in acidification and nitrification

(iii) To identify regions or catchment types that are prone to acidification and nitrification

(iv) To develop a methodology for the transfer of results from representative or experimental basins to ungauged sites

1.3 Methods

A variety of statistical techiques will be used to analyse flow and water quality data and basin characteristic data. Distributed basin runoff models will be used to simulate basin response to land use change. Full details of proposed analytical procedures are given in section 3.

1.4 Background

This project has been initiated under the International Hydrological Programme (IHP) of UNESCO with the intention that it should use representative and experimental basin data to monitor natural and man-made changes in various hydrological regimes. A representative or experimental basin differs from the standard gauged basin of the hydrometric network in being more intensively monitored and is normally carefully sited so as to be representative of a wider region.

The planning and establishment of representative and experimental basins and the collection of records from them was a major and valuable initiative of the International Hydrological Programme. Numerous isolated basin studies have resulted from this but there have been few attempts to generalise or extrapolate research results beyond individual basin boundaries.

This study seeks to overcome this deficiency by collecting together data from many representative basins in Western Europe. Statistical analyses and modelling techniques will be applied to these data in an attempt to identify human influences on runoff quantity and quality. The results of the study will not only be of scientific interest but will also be of use in water resource and water quality planning, in flood design and in national planning of land use and pollution control.

1.5 Implementation

A six-person team of scientists is to be established at the Institute of Hydrology at Wallingford in England for a period of three years, 1985-1988. The Institute is providing three members of the team and three scientists are being seconded from countries within the study area.

Within the UK funding has been obtained from the Department of the Environment and the Natural Environment Research Council. The Overseas Development Administration is to sponsor a training post and it is hoped that the European Community will also contribute towards the project. All countries in the study region are invited to participate as they would in any IHP project. Details of the study programme, costings and international participation are given in Appendix 1.

1.6 Extent of the study area

The study area will in the first instance include the area of Western

Europe shown on Figure 1 and the countries listed in Table 1. If initial enquiries indicate problems in the availability or transfer of data from particular countries or organisations then it may be necessary to revise the study area.

TABLE 1 Potential geographical extent of study

Ireland	Denmark	Belgium
UK	F R Germany	France
Norway	Luxembourg	Switzerland
Sweden	Netherlands	Austria
Finland		

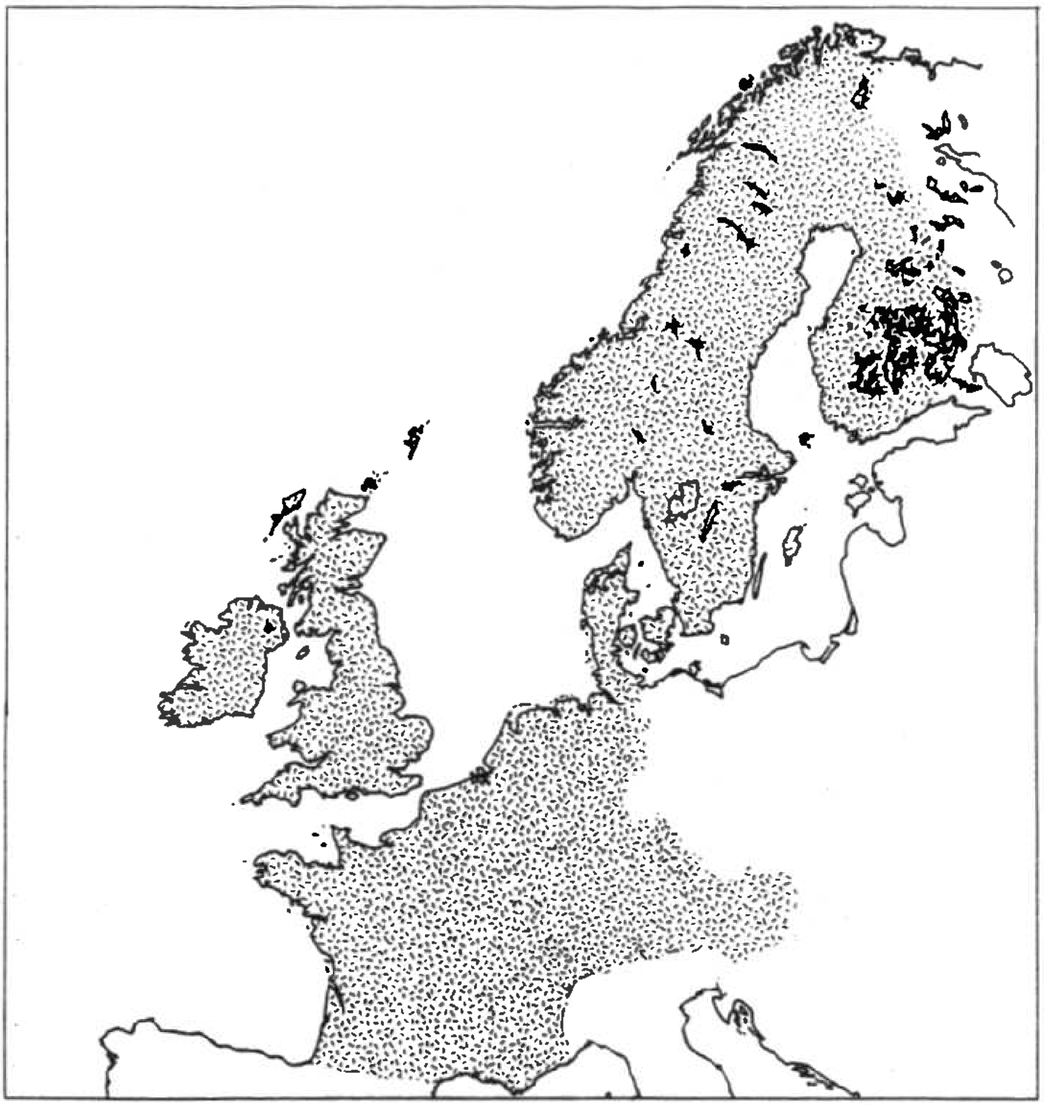

Figure 1. Potential Extent of the Study Area.

2. PROGRAMME OF WORK

The main tasks of the project will be:

Selection of basins

2. The collection and archiving of daily discharge, flood flow, rainfall and water quality data

The derivation of basin characteristics from published maps and where necessary the derivation of new maps

The analysis of these data to quantify human influence on river flow and water quality.

2.1 Selection of basins

In countries where representative and experimental basins have been identified the task of catchment selection will be relatively simple and will involve checking that all primary parameters have been monitored and that data are available. Elsewhere it will be necessary to select homogeneous, well instrumented basins from the hydrometric network ensuring that a range of climates, soil types, land uses and topography are represented.

The success of a statistical approach to regional hydrology depends heavily on the quality of the hydrometric data that comprise the raw material for analysis. In general, long records of continuous and accurate data are required. It will therefore be necessary to assess the quality of data that are available and to identify the extent of the artificial control of rivers by reservoir regulation, groundwater pumping, sewage and industrial effluent. Where possible a member of the project team will visit agencies within the study area to discuss the quality of data.

2.2 Collection and archival of hydrometric and water quality data

The study will add to existing archives of flood, daily flow and water quality data held at the Institute of Hydrology. Annual maximum floods and mean daily flows will be archived, and water quality data will be collected from small catchments (typically less than 100 km^2) which have requisite monitoring programmes. Priority will be given to transferring both flow and quality data which are available in computer compatible form. Section 4 gives complete details of the types of data required by the project.

2.3 Derivation of basin characteristics

To predict parameters of flow and water quality regimes from basin characteristics all relevant physical and climatic properties of a basin must be described by numerical indices. Practical limitations permit the enumeration of only a limited number of catchment characteristics, which in the first instance will include the following:

- Basin area
- Annual average rainfall
- 10 year return period, 2 day duration rainfall
- Stream frequency
- Channel slope
- Forest cover
- Lake cover
- Urban cover
- Soil type

The traditional method of deriving a basin characteristic is to overlay the catchment boundary onto the thematic map of interest and, by planimetering or square counting, derive the basin average value of the mapped quantity. This method has been replaced at the Institute of Hydrology by an automated system which combines digitised basin boundaries with gridded thematic data. A data archive already in existence holds gridded rainfall, forest, lake, urban and stream frequency data at 1.25 km or 2.5 km resolution for much of the study area. This will be extended to cover new territories and new thematic data types. The gridded nature of data storage allows basin characteristics to be derived which take account of the spatial distribution of the data type within the basin and these may lead to more powerful equations for estimating flow or quality parameters.

3. RESEARCH PROCEDURES

There are five general areas of research that will be pursued during the project. These are listed below and described more fully in the following subsections.

(i) Analysis of time series of flow and quality data for trends and jumps. Investigate relation of non-stationary effects to drainage basin history which may involve afforestation or deforestation, agricultural land drainage, terracing, agricultural land use change or water resource development.

(ii) Use of techniques of multivariate analysis to identify basin characteristics which explain the natural variability of flow and quality regimes. Development of basin characteristics which index aspects of human influence and the relation of regime parameters to these indices.

(iii) The application of black box, empirical and distributed models to selected representative and experimental basins. Experiments with basin models provide a further means of assessing the effect of human influences on basin outputs.

(iv) Identification of areas of western Europe liable to acidification and nitrification by relating water quality parameters to basin characteristics.

(v) Development of statistical procedures to allow the transfer of research results to ungauged catchments. This requires the identification of homogeneous regions of the basin characteristic dataspace within which a single transfer function is operable.

The effects of urbanisation on river flow and water quality will not be considered in this project although a review of the extensive literature on urbanised catchments will be presented. Water quality studies will be confined to basins upstream of major industrial effluent and sewage outfalls as the impact of these inputs on water quality is site specific.

3.1 Time series analysis

The three changes in a basin most likely to alter river regimes are afforestation or deforestation, agricultural land drainage and urbanisation. It is hoped that flow and water quality data from basins having a documented history of such land use changes will be available. It is expected that in some instances experimental basins will have been established precisely to monitor such effects: data from these basins is of particular interest to the project. Series of peak flows, monthly flows and daily flows will be collected for suitable basins together with series of water quality measurements. At least 30 years of data are required for time series analyses, and these data should be very reliable.

A number of parameters will be derived for each series as a whole and for a succession of 10 year 'windows' in the series. These will include means, standard deviations, coefficients of skew and kurtosis, autocorrelation coefficients of first order differences etc. The analysis of variability of these parameters will be conducted both in time and in space:

(a) in time - plotting each time series, both in its entirety and for each window period. Further plotting of values of calculated parameters through time may highlight trends, jumps and perodicities in the series

(b) in space - plotting parameters of common periods in geographical space should reveal clusters of similar values if climate variability rather than human influence is the dominant control of the time series.

3.2 Multivariate analysis

Indices of flow and quality regimes can be empirically related to basin characteristics using techniques such as multiple regression analysis. These studies will concentrate on the following regime parameters:

Average annual losses calculated from the difference between mean catchment rainfall and average runoff

2. Frequency distribution of daily mean flows

3. Seasonal variability of daily flows
4. Annual minimum low flow discharges for different duration
5. Storage yield relationships for reservoir design
6. Flood frequency distribution
7. Mean and variance of water quality parameters
8. Total load for different water quality parameters.

For each analysis single number indices will be calculated, such as the 95 percentile low flow discharge or the ratio of the 50 year return period flood to the mean annual flood. Basin characteristics will be derived which describe the degree to which the basin is grassland, forested, urbanised or artificially drained. Relationships will be derived between the hydrological indices and these and other basin characteristics using data analysis facilities for variable selection, transformation, correlation and regression.

This analysis should enable the identification of the natural basin controls on flow and quality parameters and should quantify the extent to which human influences can alter the natural hydrological response of a basin.

3.3 Modelling studies

Distributed basin models provide the framework for the application of an accumulation of knowledge of hydrolgical processes.

The Système Hydrologique Européen is a physically-based, distributed model in which the major hydrological processes of water movement are modelled by the theoretical equations of mass and energy conservation or by empirical equations derived from independent experimental research. Variations in conditions and processes across the catchment are simulated using a grid network. The model is designed for use particularly with ungauged catchments and in the prediction of the effects of land use change. It's use of physically measurable parameters means that calibration can be based on representative field measurements and does not require a lengthy historical record of hydrological events.

Inclusion of the SHE model in this project will be based on a programme of tests and calibrations for several different catchments, investigating the ability of the SHE to simulate the effects of land use change. Catchments will be required in which land use changes have occurred in the past (preferably with a hydrological record before and after the change) or ones in which changes were planned for the near future. Such land use changes might include deforestation, afforestation, agricultural changes and urbanisation.

Of particular importance to such a model is information on the soil moisture tension/content relationshps for the unsaturated zone, values of conductivity and moisture content for saturated vertical flow in the unsaturated zone and levels of the phreatic surface. Measured values of the other parameters (eg vegetation and channel flow coefficients) are desirable but can also be estimated from the literature. Input data (meteorological data) are required, preferably at hourly intervals and for the larger catchments the distribution of rainfall may have to be specified.

If resources permit other recognised catchment models contributed from participating agencies will be included in the study. It is hoped that a comparison of the performance of different types of model (empirical, lumped, distributed etc) will be possible on selected representative basins under varying assumptions of calibration data availability.

A further application of distributed basin modelling is to assess the sensitivity of outputs to simulated changes in a basin. For example, is deforestation as important in the steep headwaters compared with deforestation on low lying areas near the basin outfall? Answers to such questions are of direct interest, but would also provide guidance for the definition of catchment characteristics from the gridded thematic database described in section 2.3. These in turn will be of use in multivariate statistical modelling of drainage basin runoff regimes.

3.4 Acidification and Nitrification

Regions of the study area which are susceptible to acidification and which show high levels of nitrate contamination are to be identified. Two approaches are envisaged:

The first will be a statistical approach of the type described in Section 3.2 above in which parameters descriptive of acidity and nitrate concentration will be related to the characteristics of basins such as climate, land use, soils and geology. The formulation of these relationships will draw from the results of process studies of water quality systems which indicate the conditions under which different hydrochemical processes are dominant.

The second approach will be to study trends and changes in acidity and nitrate parameters in a collection of long term water quality records. These should come from different regions of Europe and should represent different types of drainage basin. Analytical techniques will be largely those described in Section 3.1 above.

3.5 <u>The transfer of research results to ungauged sites</u>

A common problem in hydrology is the estimation of flow characteristics at ungauged locations. The most frequently used techniques to solve such problems are based on the transfer of flow characteristics of interest and one or more basin characteristics, the relations being calibrated by data on gauged basins.

Transfer techniques such as this can be expected to be effective only if the region encompassed by the analysis is reasonably homogeneous, ie the same basin characteristics have the same relation with the flow statistic throughout. Most regionalisation studies define geographical regions within the study area and assume these to be homogeneous. However, geographic proximity is seldom a guarantee of similarity of basins, either in terms of their physiography and geology or their hydrologic response, and consequently geographic regionalisation is likely to be inefficient.

An alternative approach is to transfer hydrologic data within regions of the basin characteristic data space rather than with geographic space. If data regions can be defined which are homogeneous and significantly different from one another then a framework will be established for the extrapolation of results from representative and experimental basins. Two distinct schemes for forming these groups are to be developed. The first of these consists of an iterative search through the data space. At each iteration a number of groups or regions are formed by partitioning the set of basins according to threshold values of basin characteristics. Significance tests will be used to examine the homogeneity of each group and the differences between groups based on certain regime statistics. The search converges on a division of the data space that optimises distinction between groups and the homogeneity within groups.

The second scheme will employ techniques of cluster analysis, a process whereby basins having similar basin characteristics are lumped together independently of the flow data. Basins may be exchanged between the resulting clusters to maximise prerequisite statistical criteria.

Schemes such as these offer great potential for the transfer of results from representative and experimental basins to locations lacking locally measured data but which require environmental or engineering judgements.

4. DATA REQUIREMENTS

4.1 Flow data

Extensive archives of peak flows and daily mean flows are already held at the Institute of Hydrology for much of the study area. Where necessary and where possible these will be supplemented by the following:

(i) peaks-over-threshold and annual maximum flood data in series of at least 10 years length.

(ii) rainfall-runoff data for flood event and water balance studies for at least 20 basins in the study area.

(iii) series of mean daily flow data of at least 3 years length and preferably much longer

(iv) data for distributed modelling studies

4.2 Water quality data

The following parameters are relevant to acidification and nitrification and will be collected at all possible sites:

Aluminium	(Al)	Sulphate	(SO_4)
Magnesium	(Mg)	Ammonia	(NH_3)
Phosphorus	(P)	Nitrate	(NO_3)
Potassium	(K)	Carbonate	(CO_3)
Sodium	(Na)	Chloride	(Cl)
Calcium	(Ca)	pH	(H)

For the regional time series analysis water quality data should have a minimum sampling frequency of 12 samples per annum. For time series analysis, about 30 records of at least 20 years length are required. The regional analysis will require data from about 250 sites which are upstream of industrial or sewage effluent discharges and records should contain at least 5 years of data. For more detailed studies hourly or daily water quality data will be required.

4.3 Site and basin data

Detailed information is required for sites which are to be subjected to time series analysis. This should consist of the following:

(i) history of change in instrumentation, site relocation or changes in site condition. Details of any changes in operating policy during the period of record.

(ii) history of change in the drainage basin such as urbanisation, land use, deforestation/afforestation, industrial development, and drainage or water resource developments. Details of any extreme events affecting flows or water quality.

(iii) details of any corrections applied to the record to 'naturalise' the data.

(iv) details of rating curve stability and extent of extrapolation to high and low flows.

5. APPLICATIONS

The results of the study will not only be of scientific interest but will also be used in water resource and water quality planning, in flood design and in national planning of land use and pollution control. It is anticipated that the results of the study will be used to resolve a number of problems for different hydrological regimes of Western Europe including the following:

The change in yield of water supply reservoirs as a result of change in land use.

The influence of land use change on direct river abstraction schemes and the dilution of sewage effluent including changes in the seasonal distribution and range of flows.

The sensitivity of flood frequency relationships to changes in land use.

The loss of hydro electric power production as a result of change in land use.

The influence of reservoir regulation on downstream flow regimes.

Identification of relationship between acid rainfall and river water quality for different geological and land use regions of Western Europe.

APPENDIX 1 - STAFF AND FUNDING.

A team of at least six scientists are being established to work at the Institute of Hydrology for a period of 3 years. In the UK financial support has been obtained from the Department of the Environment, the Institute of Hydrology (Natural Environment Research Council) and the Overseas Development Administration to fund three scientists and establish a training post attached to the project. Secondments of staff from Norway, Germany, Netherlands and Belgium are currently under discussion. In addition to salaries and scientific staff the project will require additional funds to cover travel, subsistence and costs of support staff. An estimated 12K per annum is required for each scientist attached to the project. These costs are expected to be covered by the seconding country together with assistance from the European Communities. Applications for research grants will be made to the Stimulation Programme of the European Communities which is designed to encourage scientific and technical cooperation. Computing costs will be supported by the Natural Environment Research Council and UNESCO may provide funds to cover the costs of a project steering committee. A provisional programme of work is given in Table 2.

Activity	Scientific Staff	Support Staff
Liaison with hydrological organisation in study area	6	—
Selection of representative basins	12	3
Collection and archiving of hydrological data	12	24
Collating maps of land use, climate, soils etc.	2	3
Digitising catchment boundaries, thematic maps and calculating catchment characteristics	12	42
Analysis of water quality and quantity time series	24	6
Developing relationships between hydrological indices and basin characteristics	24	6
Identification of homogeneous hydrological regions	12	
Review of experimental basin investigations	12	
Completion of annual reports	4	
Final report and workshop	6	3
	126	90
	10½ man years	7½ man years

10/84 10/85 10/86 10/87

TABLE 2 Provisional Study Programme