CHAPTER 24

Regional Palaeoflood Databases Applied to Flood Hazards and Palaeoclimate Analysis

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INTRODUCTION

The aim of palaeohydrological flood analysis is to provide information on extraordinary events which are outside the timescale covered by systematic gauge records (Baker, 1989). This includes the study of past floods, both those for which historical records exist, and those which took place in prehistoric times or in areas remote from human observation. The study of spatial and temporal flood distribution and the palaeohydrological analysis of flood magnitude and frequency, based on stratigraphic and historical records, provides a highly effective tool for risk analysis and long-term planning (Baker, 1989; Ely and Enzel, 1992; Benito et al., 1996a) and for defining periods with a high frequency of climatic conditions favourable to flood generation (Hirschboeck, 1988; Ely et al., 1993). Owing to the close interaction between climate and the hydrological cycle, the study of the spatial and temporal variability of extraordinary events is essential for identifying anomalous patterns of atmospheric circulation on different scales. The organisation and systematisation of hydrological information on past floods enables a detailed regional analysis to be made of extraordinary events and their related hydroclimatic scenarios.

Since the beginning of the 20th century, hydrological services in most countries have compiled systematic hydrological databases based on discharge records. Advances in information technology have undoubtedly contributed to the development of hydrological databases which can manage considerable amounts of information in a simple,

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immediate and reliable manner within a system which may include tools for hydrological calculation and modelling (Quintas, 1996). Palaeohydrological databases, however, are a new development, hitherto limited by the scarcity of palaeohydrological data. This information is restricted to certain regions, and its main drawback is the considerable diversity of the methods used in hydrological reconstruction and the chronological uncertainties which hinder analysis and comparison. It is therefore necessary to define the type of data to be used in palaeohydrological analysis and the temporal and spatial scale which will enable us to provide databases whose degree of development and usefulness is comparable with that of contemporary hydrological databases.

GLOBAL PALAEOHYDROLOGICAL DATABASES

Differences in the amount of data and the methods used to calculate the hydrological parameters of hydrological and palaeohydrological databases has meant that the two types of database have been conceived and developed very differently. Contemporary hydrological databases are based on regions, with the drainage basin (catchment) as the superunit. The main palaeohydrological databases developed to date are global in nature and were chiefly designed for global analysis in terms of the calibration, validation and interpretation of models such as the general circulation models, and for predicting future hydrological changes. At present, different databases dealing with palaeodata information such as palaeoenvironmental data (WDC-A, 1992) and palaeolake level data (Street-Perrott and Harrison, 1982) have been implemented. In terms of specifically global fluvial palaeohydrological data sets, two comprehensive databases have been designed in recent years: (1) the Global Continental Palaeohydrology (GLOCOPH) database, and (2) the Global Palaeoflood Database.

(1) The GLOCOPH database is managed by the GeoData Institute at Southampton University (UK) and was developed to facilitate the compilation and distribution of fluvial palaeohydrological data compiled prior to, during and after the Global Continental Palaeohydrology Project (Branson, 1995; Branson et al., 1995). The aim of this database is to provide a resource for the study of palaeohydrological change in the long term, improving access to datasets on primary and secondary environmental parameters of interest for modelling fluvial palaeohydrological processes and their controls. The data include details of channel morphology, drainage basin features, sedimentology, and the calculation of hydraulic and hydrological parameters such as discharge, flow velocity, sediment load and groundwater flow, derived from the primary data (Branson, 1995). In the GLOCOPH database the data are stored hierarchically and have first been grouped in sets of individual records relating to data for an individual site provided by a researcher or taken from publications relating to the same author (researcher's table, bibliography table). Metadata about each dataset are provided in the dataset table which gives information on the spatial and temporal coverage of the records in the datasets, the techniques used during compilation, a brief description and related key words. The raw data tables contain primary field information and the hydrological reconstruction is presented in the derived data table. The data can be modelled and analysed using a model table, which provides routines for applying several hydrological models to the data for calculating discharges, flow velocity, etc. using the primary data.

(2) The Global Paleoflood Database (Hirschboeck et al., 1996) is designed to compile

different types of information on palaeofloods and include them in a flexible but structured database allowing analysis and regional and global comparisons. The ultimate aim of the project is to supply a forum for communication and storage in order to foster and stimulate research into hydrological matters through the growing demand for information on palaeofloods. The project originated at the Arizona Laboratory for Paleohydrological and Hydroclimatological Analysis (ALPHA), which for several decades has been compiling information on palaeofloods in the southwest of the USA, an area which has become a pilot region due to the numerous palaeoflood hydrology studies conducted using various techniques. The records specify the nature of the flood (rain, snow, dam break, etc.), the techniques used to define the palaeoflood (through palaeostage indicators, flow competence, hydraulic geometry, historical observations and botanical data), the methods for calculating the discharge (slope–area, Manning equation, step-backwater modelling, empirical regression, etc.). In addition, a form is included for a description of the site, with data on the geometry of the drainage basin, the nearest gauge and precipitation stations and the characteristics of the maximum likely discharge and precipitation.

These global databases are well established although further development may be increased by integrating reference and access to regional database systems. A regional database allows different resolutions of information as well as independent collation and management at a regional level. This could equally well be maintained within a global system, although the updating and maintenance may be best handled by the data generators; the custodial and wider access and exchange role of global databases suggests a cooperative link between regional and global systems. It is therefore proposed to increase the use of regional palaeohydrological databases, using standard palaeohydrological reconstruction techniques enabling comparison and global analysis of the data in the databases referred to above. The main advantages and contributions of regional databases are detailed below.

(1) The palaeohydrological data generated by small research groups are compiled, analysed and interpreted at the regional level, providing results in the short term due to their application to risk analysis and hydrological planning.
(2) In view of the intrinsic spatial component of palaeohydrological data, the use of geographical information systems (GIS) is justified at the regional level to acquire and analyse information and present results. This GIS makes it possible to include maps and derived data by means of topologic relations, the application of filters and algebraic operations with the information coverages.
(3) Quantitative and qualitative studies of palaeohydrological data and their connection with graphic applications and numerical analysis tools allow the calibration of hydrological models and the simulation of hydrological variations for different climatic and environmental scenarios.

IMPLEMENTATION OF REGIONAL PALAEOHYDROLOGICAL DATABASES: THE PALAEOTAGUS DATABASE

One of the first proposals for the creation of a database to compile palaeohydrological information at regional level was made by Gregory and Lewin (1987) for the Severn and Wye river basins (UK). In view of the huge amount of palaeohydrological data generated in prior studies and collected in a complete work (Gregory et al., 1987), they decided to structure them in several figures and tables. The main objective was to provide the basis of present-day river management and allow secular climatic and runoff trends to be identified. In addition, there are relevant examples of compilations of data of past floods, chiefly historical, which in the case of the People's Republic of China was part of a national survey of historical flood marks (Chen et al., 1974; Hua, 1985). In other European countries, for example in Spain, an inventory was made of the main historical floods (Spanish Civil Protection; Comisión Técnica de Inundaciones, 1985) to determine the main points of conflict for the purpose of risk analysis.

In all these cases, it remains necessary to systematise palaeohydrological information using computerised databases which efficiently organise data and link them with both graphic data with a geographical reference (thematic maps), and with hydrological models for the regional analysis of different hydroclimatic scenarios in the past.

The Palaeotagus database was established in 1996 to compile, analyse and interpret the palaeohydrological data generated within a geographical region (the Tagus river basin, central Spain) by the National Climate Programme research project CLI95-1748. This relational database is supported by a standardised and compatible database management system which not only allows information to be stored but enables it to be studied quantitatively and qualitatively using graphic applications and numerical analysis tools.

AIMS AND STRUCTURE

The general aims of the regional Palaeotagus database are diverse and relate to both its immediate regional application and its future integration with global databases:

(1) to compile and store effectively all the diverse palaeohydrological information in the bibliography or generated in subsequent studies;
(2) to analyse palaeohydrological data, using their spatial and temporal variability and the quantitative values of certain parameters (discharge, flood stage, etc.);
(3) to interpret the results of the analysis from a twofold viewpoint: the understanding of regional hydroclimatic development and the definition of parameters applied to flood study;
(4) to facilitate the integration of this palaeoclimatic information and these palaeoclimatic interpretations into the most commonly used databases worldwide.

To achieve these aims, the structure of the Palaeotagus database is based on storage using information tables and a hierarchy of data. Since there are two different palaeohydrological datasets (historic floods and palaeostage-based discharge data using slackwater deposits), two independent but interrelated databases have been created (Historic and Geologic).

In the historic floods database (Historic), the primary data table contains information on the year, month and day(s) of the flood, stream, site, discharge, causes and damage inflicted by the flood (Figure 24.1). The information about the damage provides an indication of the severity of the flood for events for which water stage data are not available. Damage has been categorised into four groups: (1) loss of human lives; (2) infrastructures; (3) irrigation and drainage networks; (4) river bed floodplains and

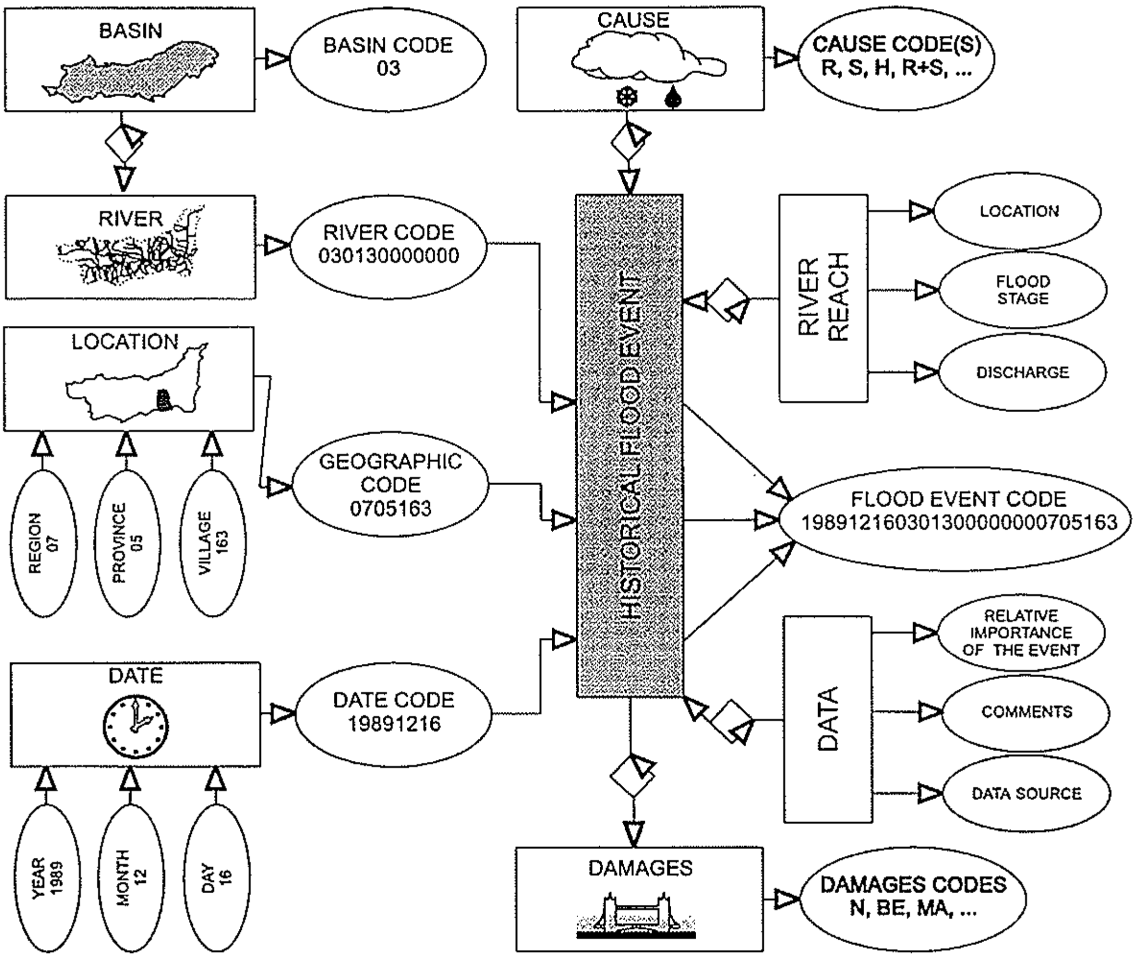


Figure 24.1 Diagrammatic representation of the conceptual model and the formal structure of the historic floods database (Historic) included in the Palaeotagus database. The rectangular boxes, ellipses and rhombuses represent the entities, attributes and relations among the associations, respectively

geomorphological changes. For each type of damage, three categories have been considered: no damage, minor damage and severe damage. These fields have been used in combination to generate other fields which will be used as coders in the database, such as *flood event* (year, month, day, stream and location) and *date* (year, month, day). To facilitate subsequent spatial and temporal flood analysis, events which affected different locations and streams on the same date have been considered as different events. In addition, the primary data have been used to generate a series of reference tables relating to locations, streams, causes and damages. The location and stream codes are linked to georeferenced points, arcs and polygons in the graphic coverages (Table 24.1).

Flood data obtained from palaeostage indicators (Geologic) have been stored in a hierarchical structure, similar to that of GLOCOPH (Branson, 1995). This makes it possible to group together datasets in subdrainage basins and subdivide them progressively into specific locations, places and records. By way of an example, we can cite the set of individual data provided by Benito et al. (1996b) in their study of palaeofloods using slackwater flood deposits (Figure 24.2), in the Tagus basin, located at the El Puente del Arzobispo gorge with several stratigraphic profiles and multiple flood units.

At present, the degree of developement of the Historic and Geologic databases is uneven. The Historic database has actually been developed and the data set comprises

Table 24.1 Example of a card extracted from the historic floods database (Historic) integrated in the regional Palaeotagus database. The data table, reference table (for code transfer) and the code combination table are shown

* DATA TABLE

FIELD	CONTENTS
YEAR	1876
MONTH	12
DAY	06
RIVER CODE	030100000000
GEOGRAPHIC CODE	1010008
RIVER REACH LOCATION	Roman Bridge
FLOOD STAGE	33.37 m
DISCHARGE	15,800 m^3/s
RELATIVE IMPORTANCE OF THE EVENT	The Tagus river reached a flood stage of 33.37 m above the base level. This stage was 1 m higher than the one reached in 1856, and only 5 m below the uppermost brick portion of the Alcántara Roman Bridge. A discharge of 15,800 m^3/s was estimated by Water Resource Office. The hydraulic computations made by G. Benito show us values of the peak discharge near to 18,000 m^3/s.
CAUSES	R
DAMAGES A	I2
DAMAGES B1	NH
DAMAGES B2	
DAMAGES B3	UH
DAMAGES C1	
DAMAGES C2	AH
DAMAGES C3	IH
DAMAGES D	BE
COMMENTS	On 7 December 1876, the hydrograph recorded in the Villa Velha de Rodão gauge station (Portugal) shows a peak discharge of 15,000 m^3/s.
DATA SOURCE	Comisión Técnica de Inundaciones, 1985

* REFERENCE TABLES

* TABLE R1 (INE).

FIELD	CONTENTS
GEOGRAPHIC CODE	1010008
GEOGRAPHIC NAME	Alcántara

* TABLE R2 (CDR).

FIELD	CONTENTS
RIVER CODE	030100000000
RIVER NAME	Tagus River

* TABLE R3.

FIELD	CONTENTS
CAUSE CODE	R
CAUSE DESCRIPTION	River flood by rain

* COMBINATION TABLE

FIELD NAME	CONTENTS
FLOOD EVENT	18761206030100000000 1010008
DATE	18761206

* TABLE R4.

RECORD NUMBER	FIELD CONTENTS	
	DAMAGE CODE	DAMAGE
1	I2	Injuries/1–2 casualties
2	NH	Destruction of bridge/road/railway
3	UH	Damage to buildings
4	AH	Major damage to agricultural fields and cattle
5	IH	Major damage to industries
6	BE	Bank erosion/channel incision

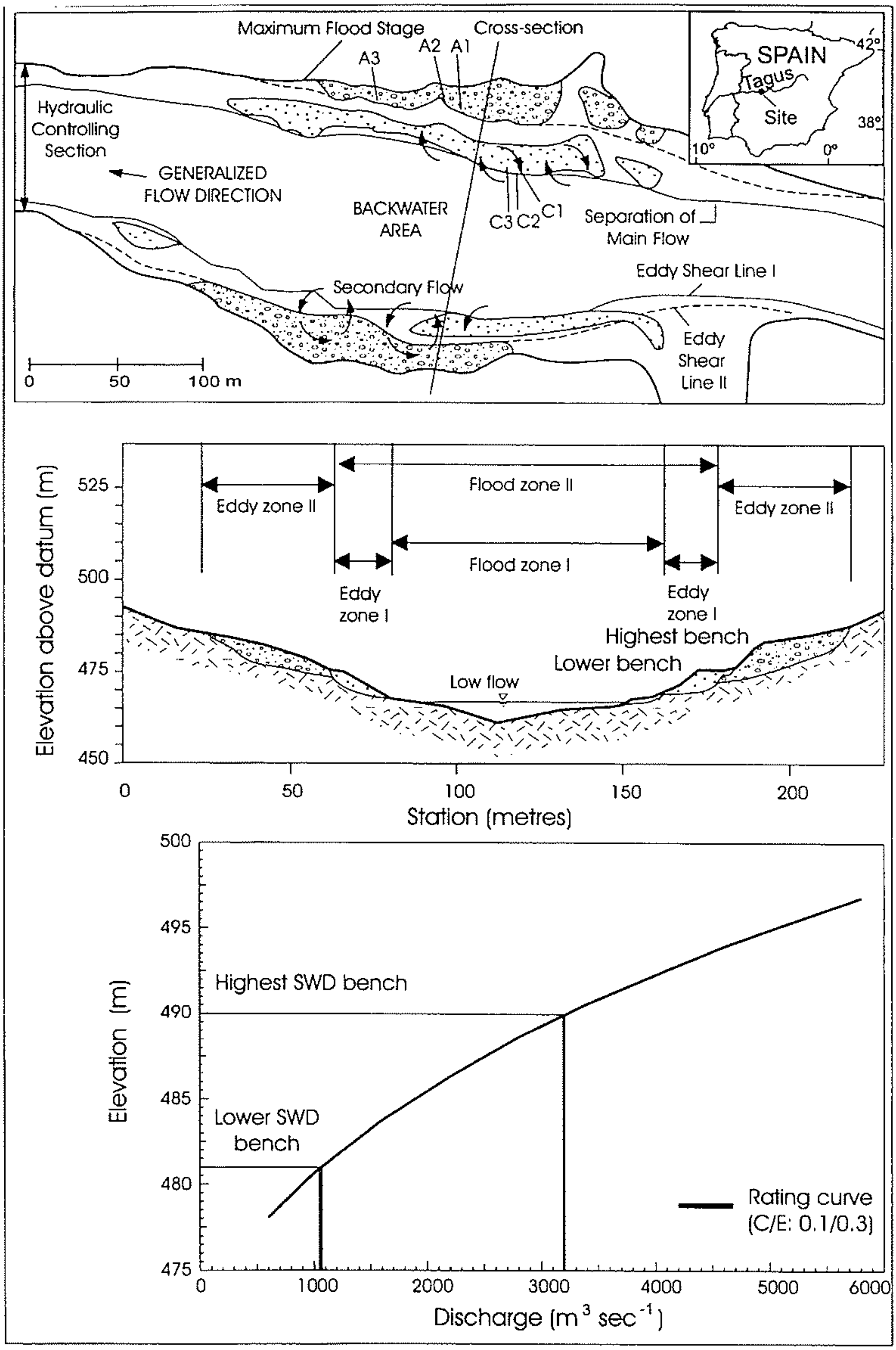


Figure 24.2 Output of a slackwater deposit (SWD) site at the El Puente del Arzobispo gorge included in the geologic flood record (Geologic) of the Palaeotagus database. A1–A3 and C1–C3 refer to the location of stratigraphic profiles

about 400 records. The Geologic database will be developed eventually when the number of flood deposit sites along the Tagus river basin increases in the near future.

DATA INTEGRATION AND ANALYSIS ON GIS

A significant feature of Palaeotagus is that the database is connected to a GIS installed on ARC/INFO v. 7.03 for Workstation (ESRI) software which is widely used worldwide. The vector coverages incorporated in the GIS are:

- boundary of the Tagus basin;
- autonomous community, provincial and municipal boundaries; polygons labelled with the Spanish National Statistics Institute (Instituto Nacional de Estadística, INE) numbers;
- isohypses from provincial scale 1:200 000 maps published by the National Geographical Institute (Instituto Geográfico Nacional, IGN); arcs encoded with their related altimetric values in metres above sea level;
- main drainage network of the Tagus basin; arcs encoded with the Decimal River Code (Código Decimal de Ríos, CDR) numbers;
- network of meteorological stations of the National Weather Institute (Instituto Nacional de Meteorología, INM); points encoded with their related numbers;
- network of gauge stations of Tagus River Water Resources Authority (Confederación Hidrográfica del Tajo, CHT); points encoded with their related number;
- geological map reclassified according to the hydrogeological properties of the lithology;
- soil map, with classes distributed according to hydrological parameters;
- land use map, reclassified according to the proposal of the Soil Conservation Service (SCS, 1972);
- potential vegetation map (vegetation series);
- isomaxima of precipitation in 24 h for different return periods;
- detailed maps including isohypses and siting of deposits (polygons) or landmarks (arcs and/or points).

The raster information incorporated in the GIS is:

- digital terrain model of the Tagus basin; pixel size 80 × 80 m (Centro de Estudios y Experimentación de Obras Públicas, CEDEX).
- images (photographs, diagrams and/or drawings of locations, sites or records of interest).

The alphanumeric information in the data tables was imported to the Arc/Info system from the Access database. In addition, it was necessary to integrate new reference tables relating to the alphanumeric equivalents of the encoding of the vector coverages (CEDEX, INE and CDR codes), and tables with supplementary information (statistical parameters of INM and CHT stations). Other graphic material to be integrated in the GIS are the graphics, functions and representations obtained from the analysis of the individual datasets and contained in the publications.

Once the information has been entered in the GIS, the first uses of the system focus on visualisation and selective searches for information (Figure 24.3). It is thus possible to

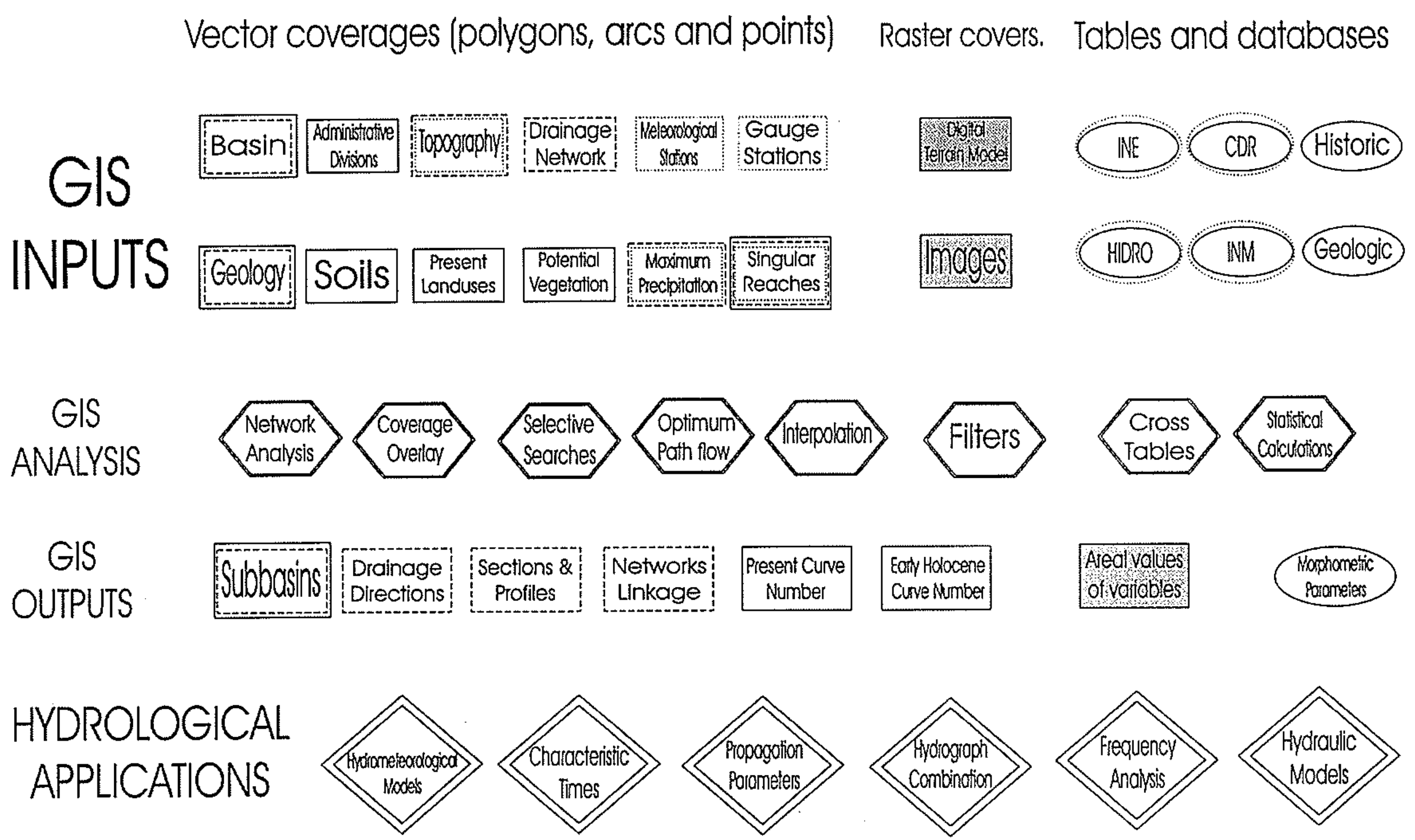


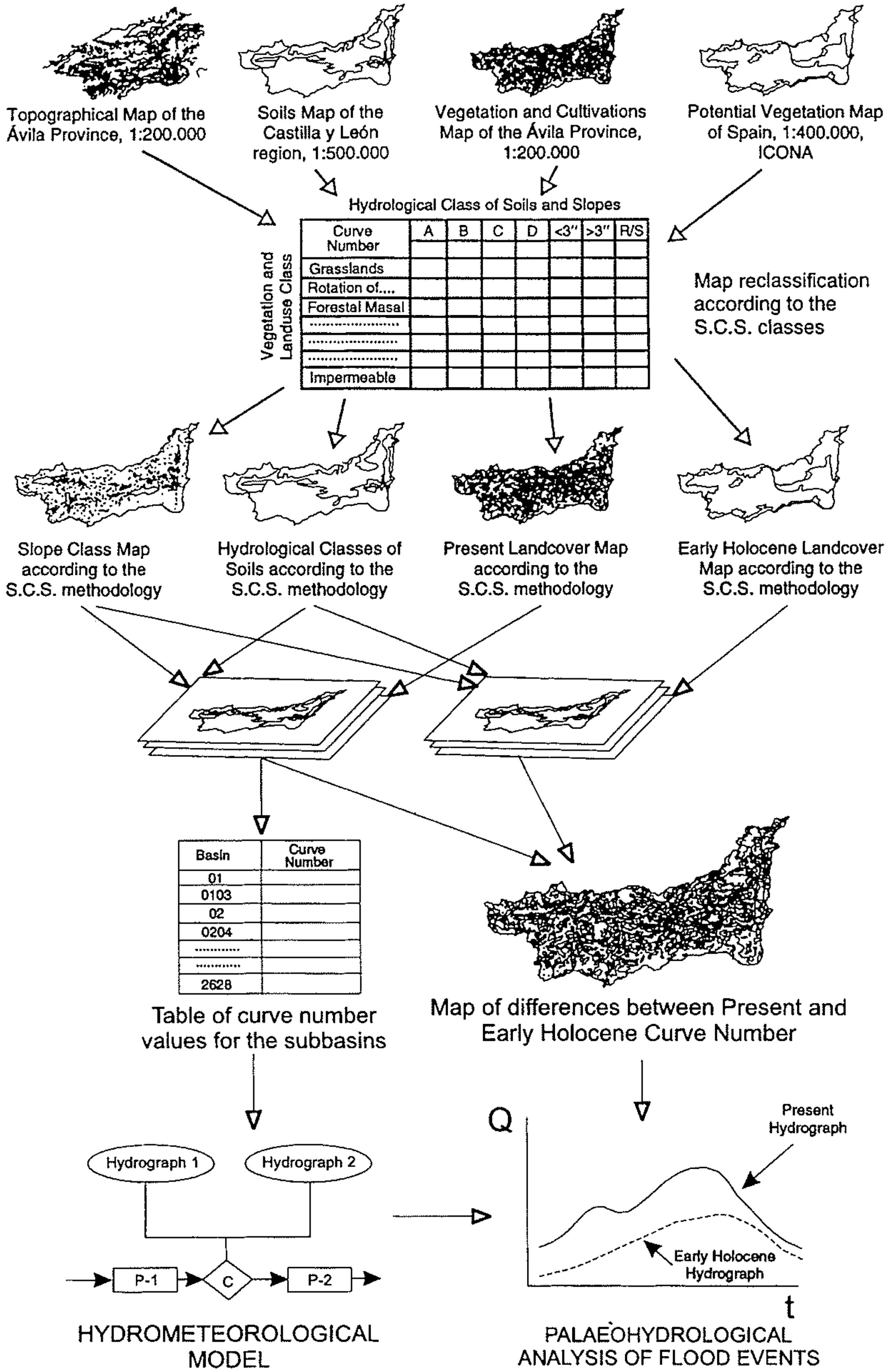
Figure 24.3 Organisation of the graphic coverages available in the Palaeotagus database and functions of the geographical information system applied to the palaeohydrological analysis

obtain different synthesis maps, detailed maps and compositions of the mapping with other study diagrams and graphics; selective searches can be used to obtain areal distributions of indicators according to their characteristics at different time intervals, or by geographical situation. Both types of analysis make it possible to draw conclusions regarding the spatial and temporal distribution of the flood events and the establishment of groups of streams or sub-basins with uniform behaviour, and to calculate the classic statistical parameters for each group according to different database variables.

At a more advanced level, the GIS makes it possible to obtain mapping and data through topologic relations, the application of filters and algebraic operations with the information coverages. The following techniques are noteworthy due to their application to the study of flood parameters.

(1) Boundary of drainage basins and sub-basins and preferential directions of drainage or of surface runoff concentration can be determined using the digital terrain model.
(2) Automatic estimation of different morphometric parameters of the basin (surface area, elongation, etc.) or of the streams (length, gradient, etc.); determination of timing parameters (concentration, time to peak, etc.) using classic formulae (US Corps of Engineers, etc.), and the necessary parameters in the flood wave propagation studies (Muskingum or Puls methods).
(3) Delineation of longitudinal and transverse profiles based on different directions or following the course of a particular fluvial stream, which can be used to reconstruct the extent of flooded areas during the peak flood discharge.
(4) Visualisation of the interconnections between streams and related analyses with regard to flood routing applicable to the propagation and combination of flood hydrographs.
(5) Interpolation of specific hydrological parameters based on a calculation of the spatial distribution of meteorological data from weather stations (precipitation in 24 h) and their statistics (means, rates of variation, etc.).
(6) Solution of the curve number or runoff threshold (mm) of an area (complete basin or sub-basin) by superimposing the gradient map (obtained from the digital terrain model), the land use map and the soil map, all reclassified according to the proposal of the Soil Conservation Service (SCS, 1972). By overlaying these maps (see Ferrer et al., 1995; Díez and Pedraza, 1997) and applying the SCS tables, we obtain a new raster mapping with the spatial distribution of the curve number which is essential in hydrometeorological flood calculations. This value, which refers to the current situation, can be modified towards hypothetical past situations (e.g. runoff threshold 10 000 years ago) by applying the potential vegetation map instead of the land use map (Figure 24.4).
(7) Integration of hydraulic models into the GIS, making it possible to supply directly to the database important parameters such as the circulating flood and velocity, using the digital terrain model. Two effective applications in this field were the integration

Figure 24.4 (opposite) Case study of the Palaeotagus GIS implementation applied to the determination of the curve number for the El Burguillo sub-basin (Alberche river, Tagus basin) both for the present vegetation and land use conditions and for a scenario previous to the land use change (Early Holocene). The rainfall–runoff models (e.g. HEC-1) account for palaeohydrological conclusions as a result of the analysis of the hydrographs obtained for present and past scenarios


Topographical Map of the Ávila Province, 1:200.000
Soils Map of the Castilla y León region, 1:500.000
Vegetation and Cultivations Map of the Ávila Province, 1:200.000
Potential Vegetation Map of Spain, 1:400.000, ICONA
Hydrological Class of Soils and Slopes
Vegetation and Landuse Class
Curve Number
A
B
C
D
<3''
>3''
R/S
Grasslands
Rotation of....
Forestal Masal
Impermeable
Map reclassification according to the S.C.S. classes
Slope Class Map according to the S.C.S. methodology
Hydrological Classes of Soils according to the S.C.S. methodology
Present Landcover Map according to the S.C.S. methodology
Early Holocene Landcover Map according to the S.C.S. methodology
Basin
Curve Number
01
0103
02
0204
2628
Table of curve number values for the subbasins
Map of differences between Present and Early Holocene Curve Number
Hydrograph 1
Hydrograph 2
P-1
C
P-2
HYDROMETEOROLOGICAL MODEL
Q
t
Present Hydrograph
Early Holocene Hydrograph
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of Arc/Info with the HEC-2 model, and of Grass with two-dimensional flow models in the floodplain.

(8) Integration of the discharge data on historical floods and palaeofloods into the flood frequency analyses, using maximum likelihood estimates (Stedinger and Cohn, 1986).

The original maps and information or those derived from the GIS analysis can be visualised or printed using multiple final editing tools. An application with a menu system (user-friendly interface) could be intalled on Visual Basic or similar, which, through the use of an ArcView (ESRI) medium, would make handling of the spatial database easier for users not familiar with GIS.

CONNECTION TO GLOBAL DATABASES

The integration of the information contained in Palaeotagus into global databases requires a similar degree of hierarchical structure of the information and the compatibility of the management systems of the two databases.

The structure and nomenclature of the GLOCOPH fields, with their multiple tables, ensure a high degree of division of the information, which is ideal both for compiling and organising information and for carrying out selective searches. The structure of the flood database in the Palaeotagus geological record takes over the GLOCOPH tables whose techniques and methodologies (slackwater deposits) or results (hydroclimatic, discharges and stages) are common to both. A simple computer application extracts the necessary information in the fields common to GLOCOPH and, after adapting it to the Global Paleoflood Database codes, fills in the related record in the global database.

Also with the aim of integrating the information, the Access Database Management System, which is widely used and compatible with other systems (including GLOCOPH's Oracle) has been selected for the computerised implementation of Palaeotagus.

CONCLUSION

The design and development of palaeohydrological databases at regional level enables information to be organised and analysed prior to its integration into global databases, facilitating the standardisation and validation of results. Furthermore, coupling such databases with tools such as geographical information systems considerably increases the possibilities of spatial and temporal analysis, implementation of hydrological models and graphic output, facilitating palaeohydrological interpretation.

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