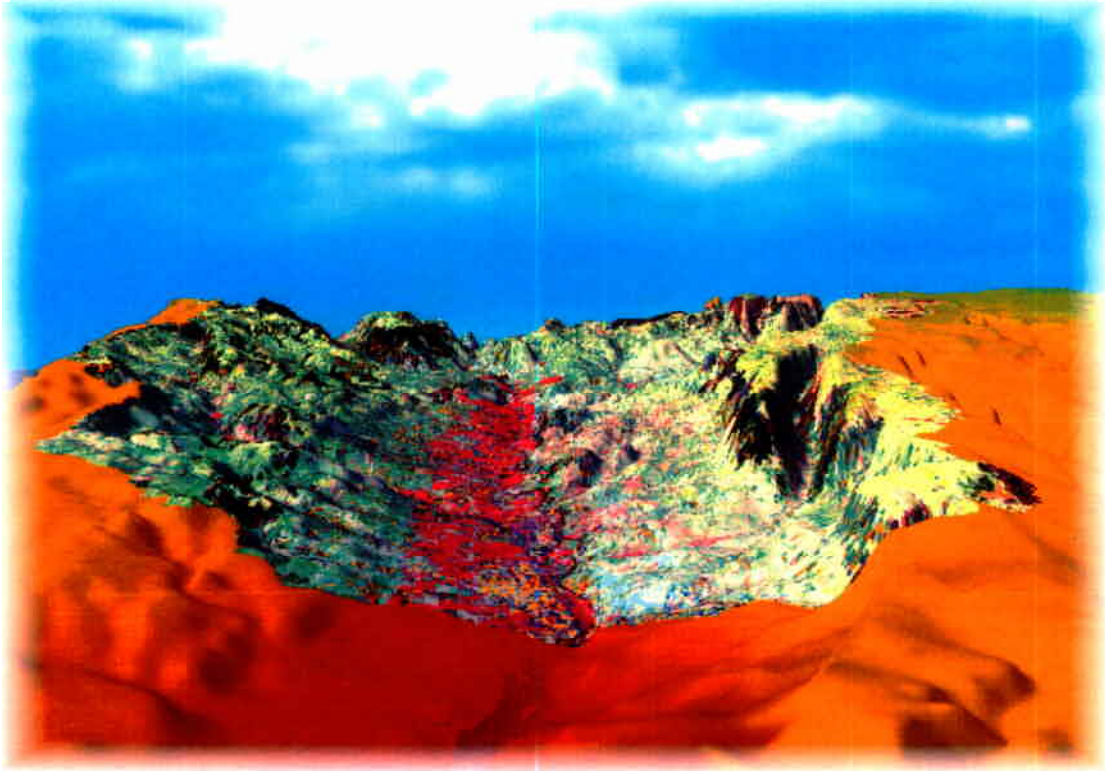
A EUROPEAN FLOW NETWORK AND CATCHMENT DATA SET



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EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

2003

EUR 20703 EN

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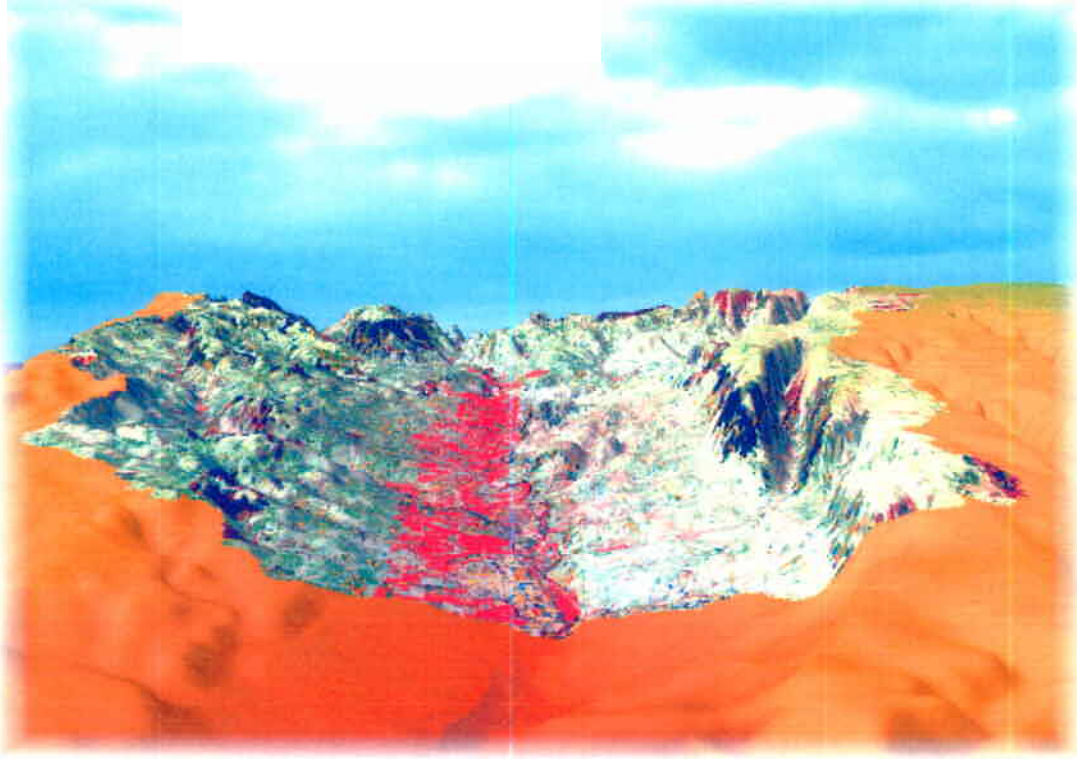

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Abstract

In 1998 the JRC, Ispra initiated a specific research activity to design and implement a Catchment-based Information System (CIS). The purpose of the CIS is to provide a quantitative response to agri-environmental topics in the framework of an operational activity, using catchments as management units and covering the area of the European Union.

For the delineation of catchments and sub-catchments a "stream burning" method was applied. This necessitated the development of a European river network. The network was built starting with a commercially available data set. The river data was further developed to ensure connectivity of rivers within a river system, separation of different systems in the raster representation and a single defined outlet. As elevation data the 1km DEM of the Eurostat GISCO database was used. The land/sea definition was based on the SABE administrative data.

The flow network generated by the stream burning procedure was then used to delineate 10 catchments layers through repeated sub-division. The catchment layers are arranged in a hierarchical system. The highest level in the hierarchy contains primary catchments (outlet into the sea) and aggregated coastal catchment units. All other levels comprise of sub-catchments, i.e. sub-divided primary catchments.

The areas of the thus identified catchments were compared with figures from other sources. In general, the CIS catchments compare favourable with other data. Differences could be traced to routing in flat areas and the degree to which coastal areas are added to the river basin.

The catchment data were used in combination with additional data layers of the CIS to calculate a nitrogen balance for agriculture in EU15. The application included the development of a methodology for transferring administrative data to catchments by spatial disaggregation.

The 1km gridded flow network forms an essential element in the development of catchment-scale and European-wide flood simulation and forecasting models. For example, it is used for the feasibility study for the European Flood Forecasting System.

Table of Content

List of Tables

List of Figures

1 INTRODUCTION

Within recent years mounting pressure on natural resources has become an increasing concern to a wider public. One of the essential resources for any population is water. The processes determining water availability, quality and threats from extreme events are governed by the hydrologic cycle and the factors acting thereupon. Those factors are physical parameters, like climate, soil, topography, and vegetation. To various degrees the factors are influenced by human intervention, either indirectly, e.g. by changes in land use, application of agricultural practices, or directly by changes to the river systems, in form of canals or alterations to river beds.

The European flow network and the catchment boundaries derived there from form a vital component in activities related to monitoring, analysing and modelling the status of water in the hydrological cycle. Following the role of water in ecosystems, adequate supplies of water of good quality are seen as a fundamental factor in promoting sustainable development, which builds on economic and social advancement and environmental protection (United Nations Environment Programme, 1992).

The importance of water to sustainable development make it a multi-sectoral commodity. Depending on local circumstances it can be supportive (drinking water, irrigation) or detrimental (flood, drought) to development. As a consequence, its interaction with the environment is increasingly seen as being dynamic and reciprocative and studying fresh water properties at various stages in the hydrological cycle demands a holistic view. This has lead to demands for an integrated approach to the development, use, management and protection of fresh water resources in form of a management plan (United Nations, 1998).

To be effective, the management plan should completely cover the area, which influences the fate of fresh water the hydrological cycle. Subsequently, the catchments were identified as the management unit, at which integrated water resource management should be performed[1]. Furthermore, for larger river basins and sub-basins an integrated management plan of catchments is inherently trans-boundary and requires multi-national co-operation (Wolf *et al*, 1999).

The use of catchments as management units for an integrated planning approach has been generally accepted and is now actively supported by policy makers in Europe and elsewhere (United Nations, 1998; European Commission, 1999). In the UNEP Agenda 21 it was put forward to design and initiate national action programmes by the year 2000[2]. For the European Union the application of integrated management practices on the basis of a hydrological system was put forward in several Council Directives.

The "*Convention on the protection and use of transboundary watercourses and international lakes Declaration by the Community pursuant to Article 25 (4) of the Convention*" promotes the application of the ecosystems approach (European Communities, 1995).

The use of catchments or river basin as a management unit and the implementation of an integrated management plan based on river basins was stipulated by the "*Directive2000/60/EC of the European Parliament and the Council of 23 October2000 establishing a framework for Community action in the field of water policy*" (European Communities, 2000). The text puts forward that diverse conditions in various regions of the Community "...should be taken into account in the

[1] UNEP Agenda 21, Chapter 18, Paragraph 18.9.

[2] UNEP Agenda 21, Chapter 18, Paragraph 18.11(a).

planning and execution of measures to ensure protection and sustainable use of water in the framework of the river basin." For the purpose of the Directive Member States are required to identify individual river basins and assign them to individual river basin districts.

2 CREATING EUROPEAN DATA SETS

While the need for an integrated management plan using the catchment as the working unit is generally accepted, its implementation requires a uniform and homogeneous dataset of European catchments at a suitable scale. To create such a dataset one could either mosaic existing pieces of catchment data from divergent sources or generate a uniform dataset from base data with European cover.

For the first approach it would appear reasonable to use catchment boundaries as defined by national institutions. Yet, this leads to problems of intra-layer consistency (same thematic layer) and inter-layer compatibility (divergent thematic layer). For once, the limits of the river basin boundaries do not always coincide between the various sources. In addition, different standards and methods are applied in the identification of catchments and data are present at divergent scales. Problems of inter-layer integration occur, because additional base data corresponding the catchment boundaries is needed for further analysis. An example is rivers flowing across catchment boundaries. This renders the task of integrating existing national data into a European data set rather impractical. Thus, most attempts of defining continental catchment layers are derived from corresponding base data layers.

A currently available European data set on catchment boundaries exists as part of the "Geographic Information System for the European Commission" (GISCO) database of Eurostat (Kleinberg and Jakob, 1996). The layer contains major river basins, with coastal areas presented as aggregated basin units. At the scale of 1:3mio. a total of 240 drainage basins were defined[3] by integrating information from various sources (GISCO, 2001).

An attempt to delineate the largest 1000 European catchments was made by the project "European Rivers and Catchments" (ERICA) (Flavin *et al*, 1998). In the course of the project the originally proposed method of combining a commercially available river network of scale 1:1,000,000 with elevation data was abandoned in favour of an automated-Sekulin method. The method relies on river network data and an allocation algorithm for a grid with 500m cells. Elevation data is not required to delineate the catchments.

The project "Flow Regimes from International Experimental and Network Data" (FRIEND) was an international collaboration study, which has lead to the creation of the "European Water Archive" (Gustard, 1995). The archive contains data from small experimental catchments, but also from national hydrometric networks. As such, the FRIEND research programme does not generate a coherent data set of European catchment, but concentrates on applying consistent methods of analysis to the catchments of the database.

An effort of mapping catchments and sub-catchments at global scale was made by the US Geological Survey (USGS, 1999). It used elevation data from the GTOPO30 data set to generate a hydrologically correct DEM. The DEM was then used to identify and delineate catchments at 6 levels. Also drawn from the DEM were ancillary data sets at continental scale, such as flow direction, flow accumulation or streams[4]. However, the delineation process used runs into

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3 Eurostat GISCO database, layer WSEU3M.
Eurostat, Directorate E: Social and Regional Statistics and Geographical Information System
Unit E-4: Regional Indicators and accounts, population and Geographical Information System, sector GISCO, D3/706- Bech Building, 5, rue Alphonse Weicker - L- 2721 Luxembourg

4 The European data set can be downloaded from http://edcdaac.usgs.gov/gtopo30/hydro/europe.html

difficulties in flat areas and the final product contains significant inconsistencies. In those areas of planes and river deltas the elevation data is not accurate enough to determine flow direction, in particular because it has been altered by human intervention.

In view of the lack of a coherent European catchment dataset the Directorate General Joint Research Centre, Ispra, initiated in 1998 the creation of a suitable layer as part of a Catchment-based Information System (CIS). The layer should cover completely the area of the Member States of the European Union, including those regions, where only part of a catchment lies within the boundaries of the EU. The first complete catchment layer was produced in 2000 and from 2001 onwards the data were included in the Eurostat GISCO dataset. The method applied to generate the European catchment data layer at scale 1:1mio. and the results obtained are presented in the following chapters.

3 METHODOLOGY AND DATA

A river basin can be defined as "...the area of land from which all surface run-off flows through a sequence of streams, rivers and, possibly, lakes into the sea at a single river mouth, estuary or delta." (European Communities, 2000). In its description the WFD follows the definition of river basins by its outlet (Wolf *et al*, 1999).

The area thus covered can be large, e.g. there are 14 river basins exceeding 50,000km^2, which are within or partially covered by the area of the 15 EU Member States. A more manageable unit for specific studies can be a catchment. Within the project the catchment is defined as a *logical unit covering the land area, which drains water to a specific surface water body*. The area is defined by a single point (the outlet), which is generally located at the land/sea boundary for catchments and at a stream or river crossing for sub-catchments.

For the European catchment dataset the catchment boundaries are determined by the flow direction of surface water. The flow direction is modelled by a river routing network (RRN). The RRN defines neighbourhood relations of all elements in a gridded data set. A catchment is then determined by the array of all cells, which are connected by an uninterrupted thread of neighbouring cells. This approach was used successfully for individual river basins, but also to develop a global RRN (Renssen and Knoop, 2000).

The process of generating the RRN combines elevation data with data on river positions by a method referred to as "stream burning" (Maidment, 1996) to ensure flow towards and along surface water bodies. The method uses as input data a digital elevation model (DEM), a river network and a land/sea mask. Suitable sources were identified following a survey on the availability pan-Europe datasets (Hiederer, 2000a). A description of the data and their characteristics is given hereafter.

3.1 Elevation Data

Only one original data set with pan-European coverage could be identified, the GTOPO30 product, which is distributed by the USGS EROS Data Centre[5]. The accuracy of the data varies depending on the source used to compile the product. For most of Europe the Digital Terrain Elevation Data (DTED) was used. For the U.K. and Ireland and some regions along the German and Polish coast of the Baltic Sea, the Digital Chart of the World (DCW) data was used. The vertical accuracy of the DTED data is given as 18m RMSE, and as 97m RMSE for the DCW (EROS Data Center, 2000). For many derived products the original spacing of 30" is resampled to 1km nominal resolution, as in the elevation data from the Geographic Information System of the European Commission (GISCO, 2001). Other elevation data set with higher resolution could be identified, but none with pan-European coverage.

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[5] EDC DAAC User Services
U.S. Geological Survey
EROS Data Center
47914 252nd Street
Sioux Falls, SD 57198-0001
http://edcdaac.usgs.gov/main.html
For GTOPO30: http://edcdaac.usgs.gov/gtopo30/gtopo30.html

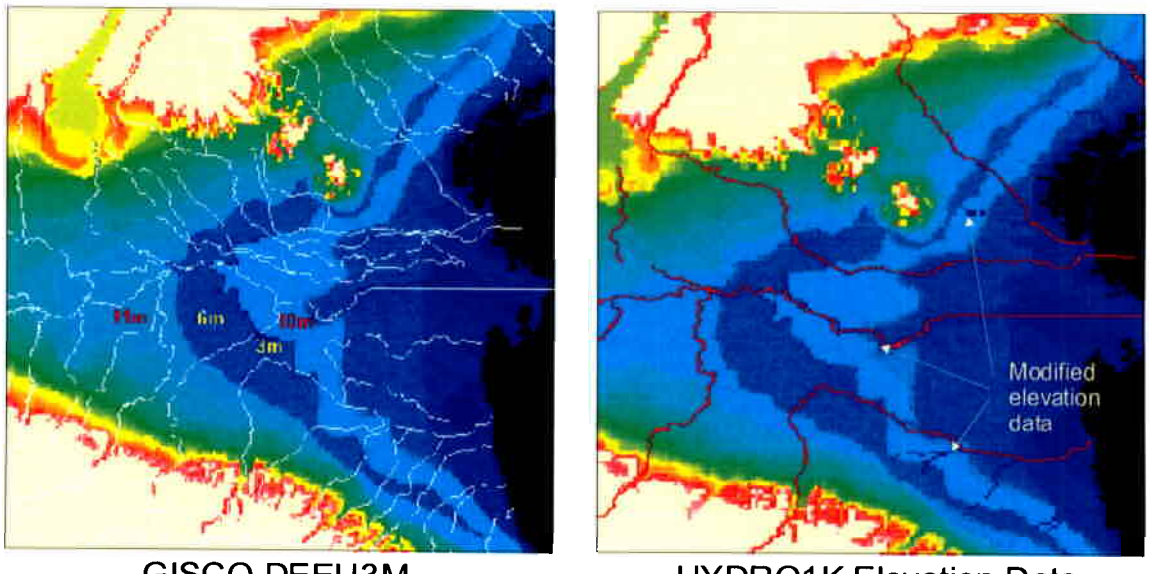
An obvious choice of a 1km elevation data set is the layer "Digital Elevation model for Pan Europe 3 Million scale" (DEEU3M) of the Eurostat GISCO database and the hydrologically correct elevation data from the HYDRO1k project[6] (USGS, 1999). The latter was specifically modified to be used for generating a river network and delineating catchments. To identify the more suitable product the properties of the two data sets were, therefore, investigated.

The DEEU3M layer was created from the source data by projecting the geographic co-ordinates to the GISCO projection ((Lambert Azimuthal Equal Area) and resampling the data to a square grid cell size of 1km spacing. The elevation values represent averages over an area of $1km^2$. Sea values are coded as "no data" values (GISCO, 2001).

The HYDRO1k elevation data was derived form the same source as the GISCO data used in this project, namely the GTOPO30 data. To obtain a hydrologically correct elevation data set the original was processed to identify natural sinks and to fill other artificial areas. In an iterative procedure stream lines and basin boundaries were generated from the elevation data. The results were then checked against drainage cover from the Digital Chart of the World (DCW) and from maps. Features in the elevation data, which lead to errors in the stream lines and basin boundaries were then corrected. The procedure was repeated until the stream lines and basin boundaries generated from the elevation data matched those derived from the ancillary information.

The hydrologically correct elevation data of the HYDRO1k project would thus appear to be a suitable data set to replace the GISCO 1km elevation data for compiling a European River Network. However similar the two DEMs may seem, a comparison of the data revealed some differences other than those caused by the processing applied.

In the HYDRO1k DEM errors in flow direction were corrected for by modifying the elevation values. Increased elevations of areas can be found, for example, at Lake Geneva (form 372m to 466m), the area of the Rhine basin before Bingen (from 81m to 92m, since the outlet is at 91m) or Lake Ladoga in Russia (from 5m to 56m). Other modifications to the elevation values are digitising channels through closed areas, of which an example is given in Figure 1.



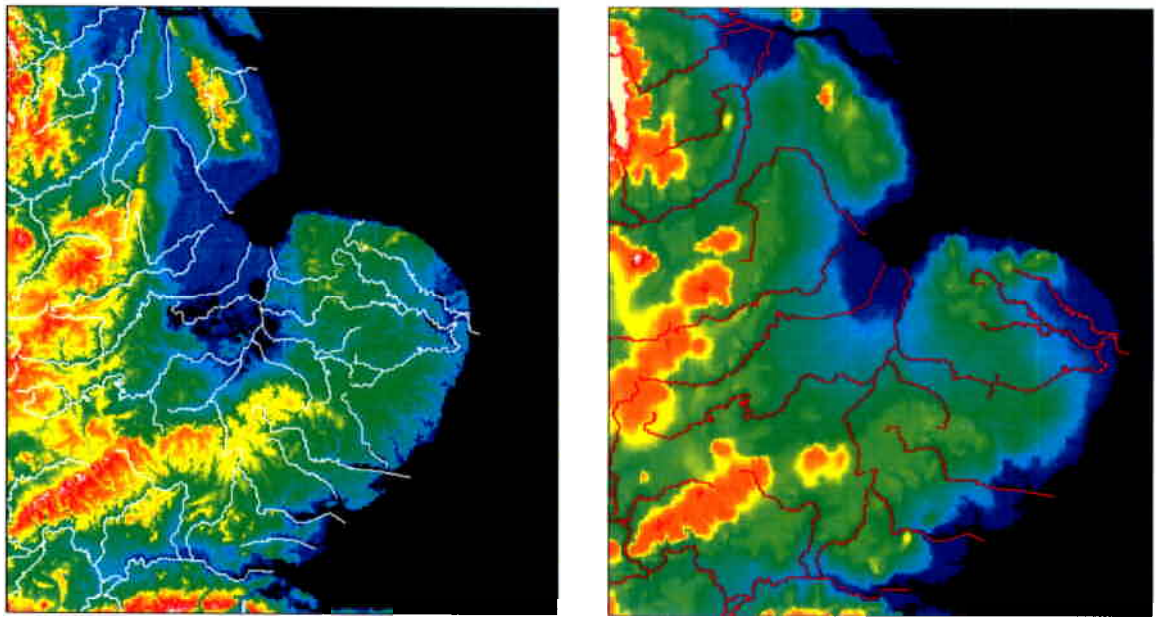
GISCO DEEU3M HYDRO1K Elevation Data

Figure 1: GISCO and HYDRO1k Elevation Data in the Po Valley, Italy

[6] EROS Data Center
http://edcdaac.usgs.gov/gtopo30/hydro/index.html

Problems in DEMs used for hydrological purposes become most evident in flat areas. A suitable study site is the lower Po valley in Italy, where the flow of surface water is also regulated by human intervention. For the lower part of the Po valley both elevation data sets show a depression of 6m elevation (dark blue), sitting between areas of 11m up-stream and 10m downstream (both light blue). On the downstream borderline the elevation data in the GISCO data set drops to 3m before rising to 10m. By comparison, the drop in the Hydro1k data goes down to 5m. For an automatic procedure solely based on elevation data it would probably be difficult to determine the drainage direction in the area. This problem seems to have been dealt with in the HYDRO1k elevation data by locally lowering the elevation data based on the location of rivers (see right graph of Figure 1). The introduction of the artificial data in the elevation data set can potentially interfere with the "stream burning" methodology used in this project.

Another problem with the HYDRO1k elevation data as compared to the GISCO data is the actual resolution of the data for the UK. It would appear that the actual resolution is coarser than the stated 1km. The point is illustrated in Figure 2.



GISCO 1km Elevation Data Hydro1k 1km Elevation Data

Figure 2: GISCO and Hydro1k Elevation Data for England

A visual comparison of the GISCO data indicates the elevation data for the UK is comparable to other regions. This is not the case the HYDRO1k data set. The information is significantly reduced and important details are lost. One cause of this discrepancy could be that the GTOPO30 source of the GISCO DEM uses DCW data for the UK and Ireland.

In the end it was decided against using the HYDRO1k elevation data in favour of the GISCO data. The main reason for the decision were the need to control the effect of the elevation data on the results, for which a less processed product than the HYDRO1k data set was required, and the uniformity of the resolution.

3.2 Qualified Accuracy of Eurostat GISCO DEM

For an appraisal of the information content the 1km DEM was compared to more detailed elevation data from different sources. One of the DEMs originated from the project "Monitoring Agriculture with Remote Sensing - Rapid Area Estimates" (MARS STAT[7].). For the action the DEMs were specifically digitised for the project using Russian maps at scale 1:200,000. The quoted accuracy in plain areas is 10m vertical and 60 to 80m horizontal, 40m horizontal accuracy for geodetic benchmarks and grid points, 40m contour intervals (generally) and 20m contour intervals in flat plain areas (SCOT Conseil, 1996).

Within each of the 60 sample sites 3 reference points were selected, at which horizontal position and height were recorded in both data sets. To facilitate the identification of reference points, and to allow for the marked difference in spatial resolution, all MARS data were aggregated to the same geographic position as the GISCO elevation data. Both data sets were then vectorized for the identification of the reference points.

The average difference between the MARS elevation data and the GISCO data was found to be 430m in longitude and 40m in latitude (i.e. the GISCO reference points are 430m to the west and 40m to the south of the MARS reference points). The average vertical difference was 3.5m. With a standard deviation of 440m the variation in longitude around the average is considerable. Also, no spatial dependence in the difference was found, rather the differences seemed to be distributed at random across the area covered by the MARS sites. By comparison, the variation in the latitude difference is small. Still, with 398m the standard deviation in latitude is comparable to the one in longitude.

The findings suggest that the GISCO elevation data could be shifted by half a pixel position in longitude to the east, while the position in latitude could remain unchanged.

The vertical difference in elevation was within 10m for 75% of all reference data point, with a standard error in vertical direction of 20m. Mainly responsible for the diverging values were comparatively few values found for the tops of steep hills or mountains. In the evaluation of the results one should consider that the higher resolution elevation data is not always the more correct source of information. A comparison to topographic maps revealed that in some cases the 1km data set better presents the topography than the 50m data (Hiederer, 2000a). Hence, a difference in the data is not necessarily an error.

As a medium resolution DEM the 250m MONA Pro Europe[8] data was used. It covers most part of Europe below 56deg. N, The Netherlands with 81% and Greece with 54%. The vertical accuracy is stated as 3.5m RMS in flat terrain and 12.5m in areas with high relief for the 75m product. The 250m dataset is derived from the 75m data by resampling (Carl and Bätz,1999).

As higher-resolution data the MARS-STAT DEM for the sample site "Essen" in Germany (centre at lat 7.112deg, lon 51.768deg) was used. In addition to this resolution used, the 75m resolution data were simulated by resampling the 50m MARS DEM.

A graphical overview of the DEMs used in the evaluation is given in Figure 3.

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[7] Monitoring Agriculture with Remote Sensing, http://mars.aris.sai.jrc.it/

[8] GEOSYS
20, impasse René Couzinet
Parc d'activité de la Plaine
BP 5815
31505 TOULOUSE cedex 5
FRANCE
http://www.geosys-inc.com/francais/sommaire/frsommai.htm

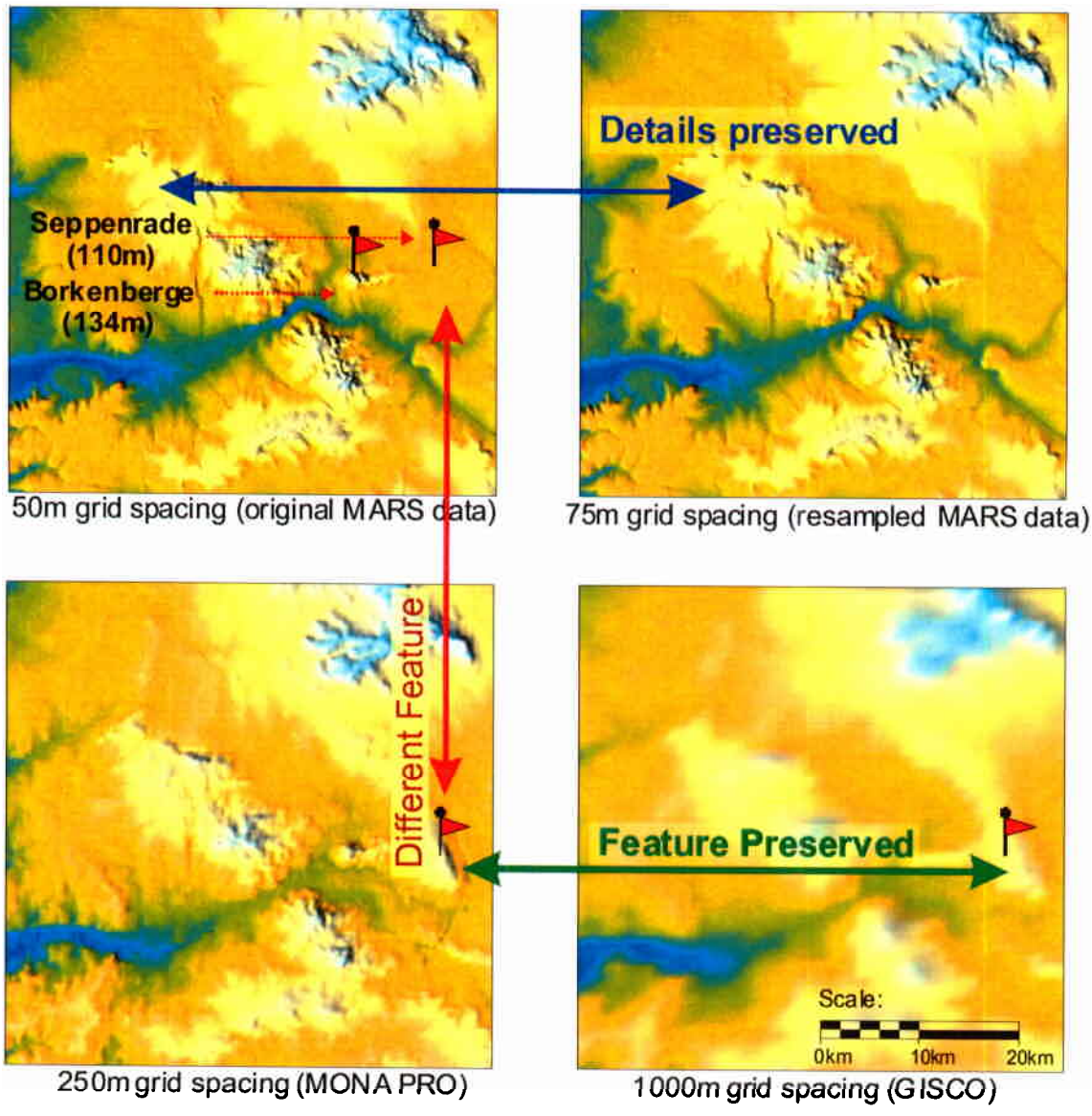


Figure 3: Preservation of detail in DEMs with different grid spacing

The sites pointed out in Figure 3 concerns the "Borkenberge" and the area around the village "Seppenrade". The graphs show that the loss of detail between the 50m and the 75m data is not dramatic. This is hardly surprising, considering that the source maps were at scale 1:200,000. When going to the 250m DEM the degradation in detail is quite obvious, while the 1km DEM looks blurred at the scale of the test site. This visual degradation is also present in the data. The elevation of the "Borkenberge" is given as 134m on the topographic map. The MARS DEM reports 127m, the MONA Pro DEM 130m and the GISCO DEM 83m.

However, features between the 250m and the 1km DEM are mainly preserved, which is not the case for the 50m MARS DEM. The elevation of "Seppenrade" is given as 110m. The MONA DEM gives an elevation of 108m and the GISCO DEM of 99m. In the MARS DEM the site is as flat as the surrounding area, namely 60m.

This comparison goes to show that precision is not necessarily accuracy is demonstrated by the lack of a feature in the 50m MARS DEM.

3.3 River Data

The river network is based on a commercially available river data set (Bartholomew, Euro 1mio.[9]). The data set was selected over similar products based on the density of the river data presented, when e.g. compared to the Digital Chart of the World (DCW) data (Defence Mapping Agency, 1992), but not least because the data has been included in the GISCO data set Version 7. Experience with the data is also documented in the report on the ERIKA project (Flavin *et al*, 1998).

However, the river data are not directly useable and have to be modified to assure connectivity of rivers to the sea, connectivity within a river system and separation of different systems in the raster representation of 1km grid spacing. All rivers were given different weights according to their importance in delineating catchments. In deltas the main arm is given the highest weight to ascertain that only one outlet exists.

3.4 Qualified Accuracy of River Data

The contents and geographic properties of the river database were generally compared to the 1:3mio. water pattern data set of GISCO, the 1:1mio. DCW river layer, the 1:250,000 ArcEurope Basemap, ESRI[10], the MapBSR project[11], Corine Land Cover data and the Times Atlas of the World (Times Books Ltd., 1988).

The geometry and contents of the European river database were assessed in more detail for Portugal, using the 1:1mio. river database the Atlas do Ambiente, of Direcção Geral do Ambiente (DGA), Portugal[12], the 1:3mio. Eurostat GISCO data and the ArcEurope base data.

A local investigation concentrated on the MARS site near Essen, Germany. The MARS site covers an area of 1600km^2 (40km x 40km), while the DEM for the area covers 2000km^2 (42.5km x 47.0km) and is digitised to 50m grid spacing. Data from the European river network were compared to the surface water layer of the 1:200,000 and 1:500,000 topographic maps TÜK200 of the Bundesamt für Kartographie und Geodäsie (Top200, Germany[13]).

---

[9] Bartholomew Mapping Solutions
Westerhill Road
Bishopbriggs
Glasgow G64 2QT, U.K.
http://www.bartholomewmaps.com/

[10] Environmental Systems Research Institute (ESRI) Inc., GIS Store
380 New York Street
Redlands, CA, 92373-8118 U.S.A.
http://gisstore.esri.com/acb/showdetl.cfm?Product_ID=1578&DID=6&ncp=yes

[11] Heli Ursin,
Coordinator of MapBSR Project
National Land Survey
P.O.Box 84
00521 Helsinki
FINLAND
http://www.mapbsr.nls.fi/

[12] Direcção Geral do Ambiente,
Rua da Murgueira - Zambujal Apartado 7585
Alfragide 2720 Amadora, Portugal
http://www.iambiente.pt/atlas/index.html

[13] Bundesamt für Kartographie und Geodäsie,
Richard-Strauss-Allee 11
D-60598 Frankfurt am Main
http://www.ifag.de/Kartographie/Produkte/top200/start.htm

A graphical representation of the river data at three different scales overlaid over Portugal and the MARS DEM is given in Figure 4.

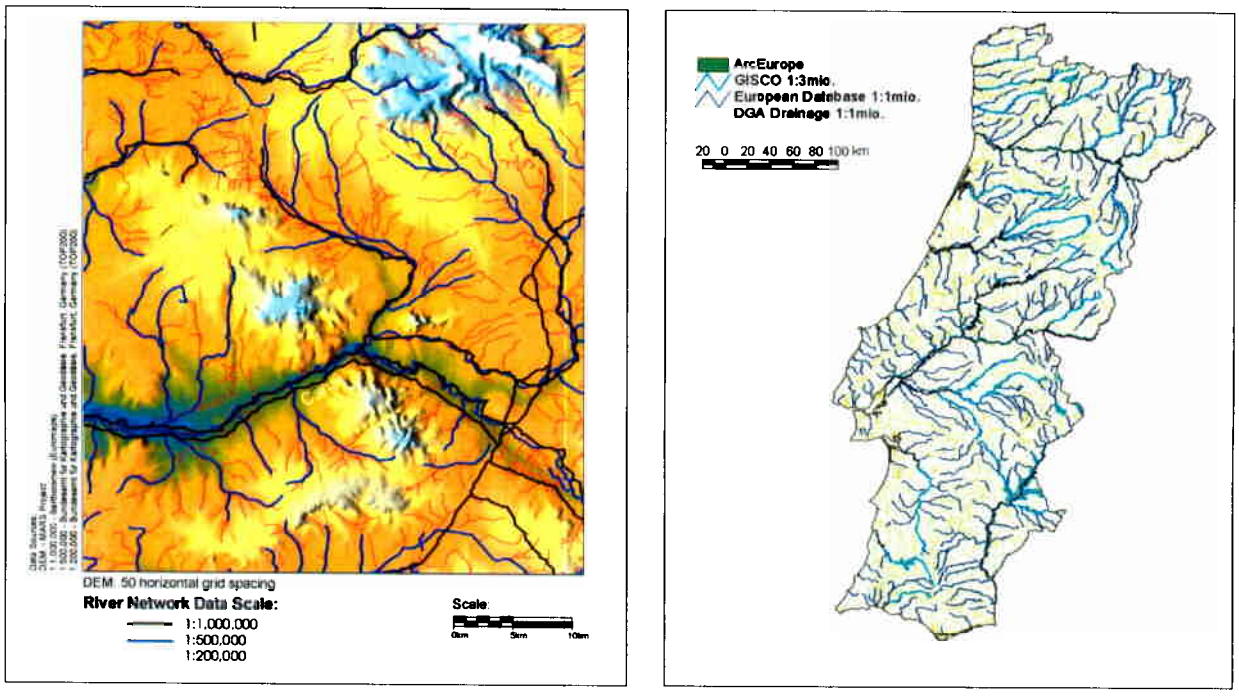


Figure 4: River Network Data at Scales 1:1,000,000, 1:500,000 and 1:200,000 (MARS Site "Essen" and Portugal)

There are numerous canals over the site, which are used for transport rather than drainage. Those canals were later removed from the data to assess only the drainage system. In cases where only raster data were available the density of the river network was approximated by converting the pixel counts of rivers into values of total length.

The results thus obtained are presented in Table 1.

Table 1: Density of 1,000,000, 1:500,000 and 1:200,000 River Network (MARS Site "Esse" and Portugal)

RIVER DATA	DENSITY		
	PORTUGAL	MARS SITE "ESSE"	
	m river / km² vector	*m river / km² 50m raster*	*m river / km² vector*
1:3mio. GISCO River Data	38[6]	17	16
1:1mio. European Database[1]	98[5] / 107[6]	82[5] / 140[6]	88[5] / 136[6]
1:1mio. DGA River Network[2]	285	N/A	N/A
1:500,000 BKG Topomap[3]	N/A	275[5]	N/A
1:200,000 BKG Topomap[3]	N/A	798[5]	N/A
1:250,000 ArcEurope[4]	36	9	8

1 Bartholomew, U.K.
2 Direcção Geral do Ambiente, Portugal
3 Bundesamt für Kartographie und Geodäsie, Germany
4 Environmental Systems Research Inc. (ESRI)
5 Excluding all canals and lakes
6 Including canals

For Portugal the river length for was derived directly from the vector data. The 1:3mio. GISCO data covers the country with 38m/km², which is roughly one third of the figure found for the 1:1mio. data set. By comparison, the 1:1mio. data from DGA is 2.7 times denser and more comparable to the 1:500,000 data from the BKG. The river density of the ArcEurope data layer is comparatively low. The information provided in the data is certainly much more detailed than the information from smaller scales, but there is little of it.

For the MARS sample site near Essen, Germany, the density figures from raster data with 50m spacing change in line with scale. For the site it was found that the 1:500,000 scale data set is about twice as dense as the 1:1mio. scale data, but the 1:200,000 is 5.7 times denser than the small scale data. It should be noted that the raster river data still contained canals. The figure for the river density derived from the European river network was found to be very close to the raster values (136m/km² vs. 140m/km²). Without canals a value of 88m/km² was found. The 1:3mio. GISCO data covered the site with only one river of 32km length, i.e. 16m/km² for the site.

When comparing the density figures for the various river data one should consider that some sets contain more additional data than others, such as shipping canals or drainage channels, which may be dry at times. Where possible, canals were identified by their attribute codes and removed from the data, but for Portugal some river-coded elements may have remained. Nevertheless, the findings illustrate that the use of scale as a measure of suitability of a data set to be used to generate river networks or delineate catchments can be misleading. As the data sets used demonstrate scale is not necessarily related to the amount of information, here the density of the river data. For the compilation of a European catchment dataset the differences in river information between data supplied by a variety of sources pose a serious obstacle.

Apart from the density of the data the geometric accuracy is of consequence to the generation of a river network. For this purpose the position of the rivers as compared to the GISCO elevation data was assessed. At 680 locations, distributed fairly evenly across the area covered, the co-ordinates of a point in the DEM and the corresponding point in the river data were identified. A graphical presentation of the results from the sample locations, which were interpolated across Europe, is given in Figure 5.

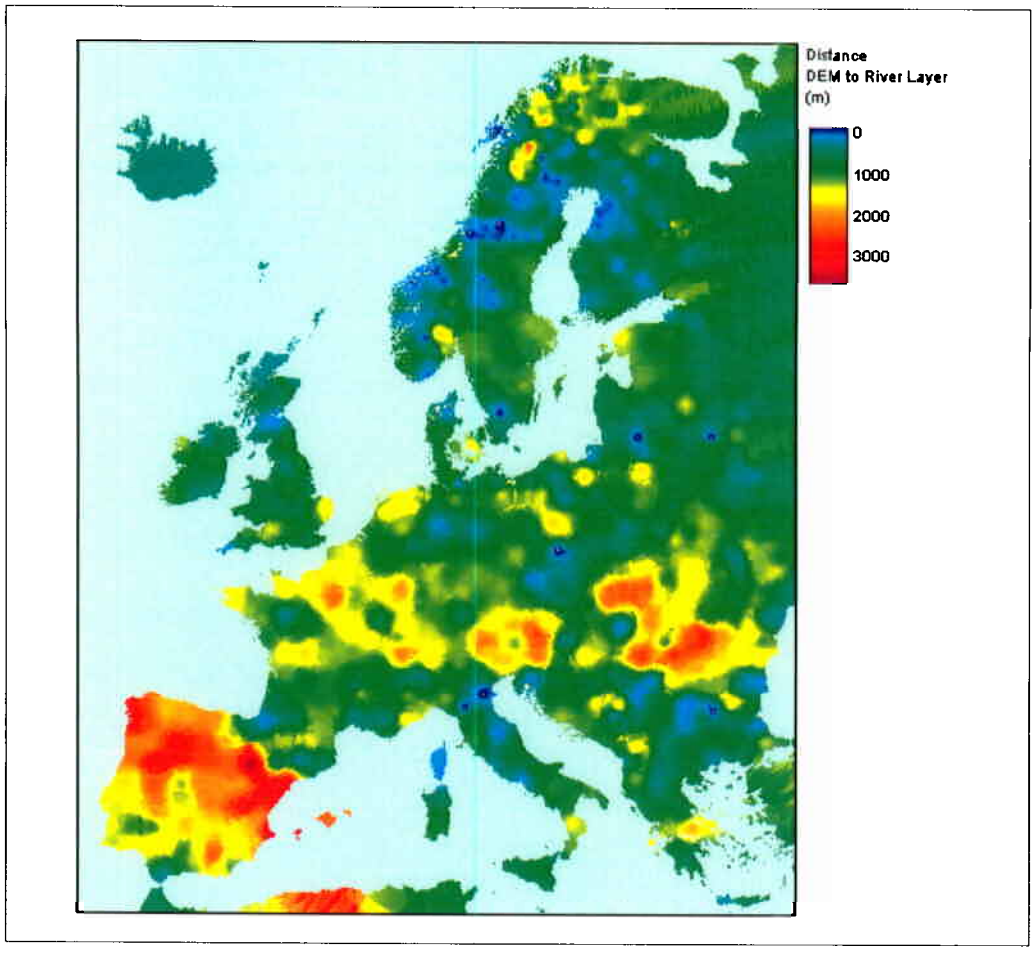


Figure 5: Difference between drainage lines in GISCO DEM and in River Data Layer (m)

The average distance between DEM and the river data found at the locations was 934m. Given the scale and resolution of the data layers compared the figure would not appear unreasonably high. However, the differences were not distributed uniformly. In general, the two datasets matched well in Northern Europe. Some problems were found in Austria, Slovak Republic and Romania. The largest differences of 3km and above were found in Spain and Portugal.

Since the differences could not be attributed to an error in any one of the data sets used, the same analysis was performed using the 50m MARS DEMs. For the 406 locations the average distance from DEM to river data was 746m. The lower average value for the DEM-river layer difference can be mainly accounted for by the absence of MARS sites in some of the problem areas (Slovak Republic and Romania) and areas with generally good matches in Sweden and Finland.

For additional verification of the co-location of river data with other data layers the unrelated Corine Land Cover data were used. A graphical illustration of the problem found is presented for an area near Zaragossa, Spain in Figure 6.

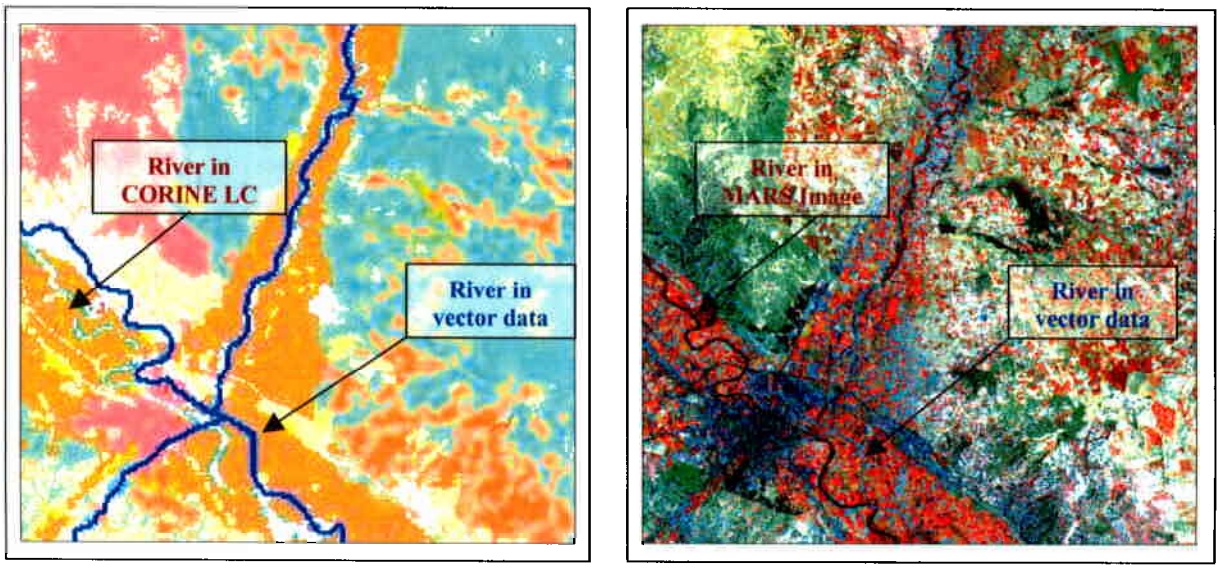


Figure 6: European River Network over MARS DEM and MARS Image (Zaragossa, Spain)

The left graph of the figure shows Corine Land Cover information around the town Zaragossa, Spain. The river Ebro runs diagonally in the lower half of the graph. Clearly visible is the difference in position of the river in the Corine data (light blue) and the river database (dark blue). In places the difference exceeds 3km, but is mainly approximately 1.5km. However, for the river Gallego, coming from the north to Zaragossa, the data sets correspond well. It is not clear, why there should be such a local difference in location of features.

The correspondence between the river data and an ortho-rectified satellite image for the MARS site Zaragossa (May 1998) is presented on the right graph in Figure 6. The situation when using an entirely different data set is very much comparable with what was observed when using Corine Land Cover or elevation data. A visual examination of the position of the river data on Corine Land Cover in other areas also indicates the larger difference in Portugal and Spain than in other parts of Europe. To exclude an imprecision introduced by projecting the data the original data in geographic coordinates were compared to those of the ArcEurope Basemap. Here the same discrepancies were found.

Obtaining the same results from various, uncorrelated data sets it would appear that the positional error occurs in the river data rather than in the elevation data. Shifting the river data to the elevation data using a polynomial transfer function can only be seen as a partial solution due to the strong regional variation observed within the data set. In the end a better match between the river network and other data could only be achieved by manually modifying the river dataset.

3.5 Land/Sea Mask

The land/sea definition was based on the Seamless Administrative Boundaries for Europe (SABE)[14], as stored in the Eurostat GISCO database. This approach was given preference to one

[14] EuroGeographics
6-8, Avenue Blaise Pascal
Cité Descartes
Champs-sur-Marne
F - 77455 Marne-la-Vallée Cedex 2
France
http://www.eurogeographics.org/Projects/SABE/index.htm

derived from the DEM to better represent areas of land below sea level. As is the case for the river network the original vector data was rasterized to the same geometric properties of the other data layers (1km grid spacing). For data coherency the mask was then overlaid over the DEM. Any areas of sea in the mask were coded as such, while areas of land in the mask, but sea in the DEM were given an elevation of -10m.

3.6 "Stream Burning" Process

In the preparation of the data layers for stream burning all rivers were given graded lower elevations than the surrounding area. The lowest values were attributed to the sea. Rivers were lowered into the elevation data depending on their class value. The lowest values were attributed to the main rivers, while rivers of higher classes, i.e. defining smaller catchments, were lowered into the DEM to a lesser degree. A separate lake layer was not included in the procedure. Instead, all rivers were digitised through lakes with tributaries connected to the main river. The local drain direction thus calculated was then used to define the elements of the CIS hierarchical catchment structure. The procedure itself is applied in form of a PCRaster[15] batch file.

[15] PCRaster can be obtained from:
PCRaster Environmental Software, Po Box 427, 3500 AK Utrecht, The Netherlands
http://pcraster.geog.uu.nl/pcrwin32

4 RESULTS

4.1 Catchment Boundary Dataset

The highest level in the catchment hierarchy consists of primary catchments, i.e. those with an outlet into the sea. The procedure applied allows for one and only one outlet of a primary catchment. This outlet comprises of the culminating point of all upstream surface flow. Regions of river deltas are dealt with by linking adjacent primary catchments to the main catchment unit.

The level of detail in the base data sets limits to the minimum size of catchments, which can be delineated in the final set. In the CIS the lower limit was set to 250km^2. The value was found to be an acceptable compromise between the details of representing catchment boundaries and the relative uncertainty in delineating the area. Also, a 500km^2 threshold connects in some catchments in Denmark the Baltic Sea to the North Sea in Denmark, which was not deemed acceptable.

To achieve complete coverage areas below the limit and those, which could not be positively identified by the algorithm, were aggregated into coastal catchment areas. Those areas differ from primary catchments in that they do not have an identifiable single outlet. A graphical representation of the principle applied is given in Figure 7.

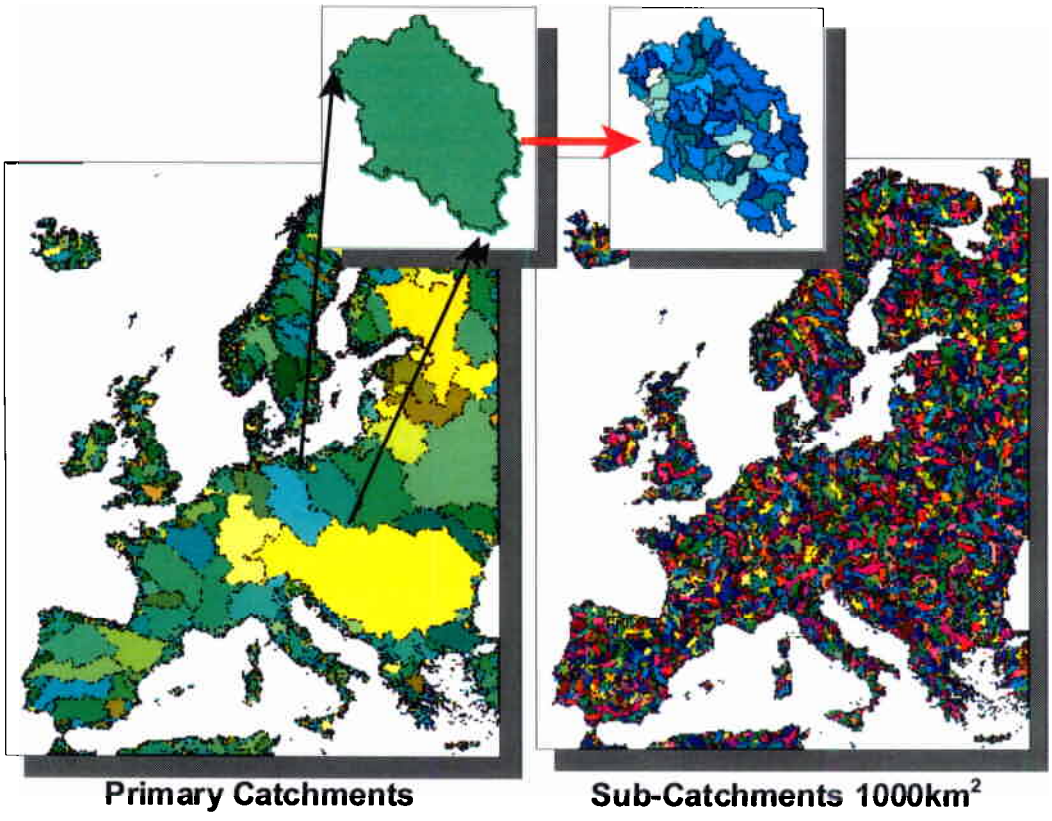


Figure 7: Sub-division of Primary Catchments

Layers of the hierarchical system are generated by sub-dividing primary catchments. The algorithm warrants that

1. sub-catchments cannot cross primary catchment boundaries and
2. boundaries common between the different layers are identical.

Hence, larger units can be completely reconstructed from the elements of the lower layers. This circumstance is of particular importance for aggregating data available at a more detailed level to those of a more general level (see below).

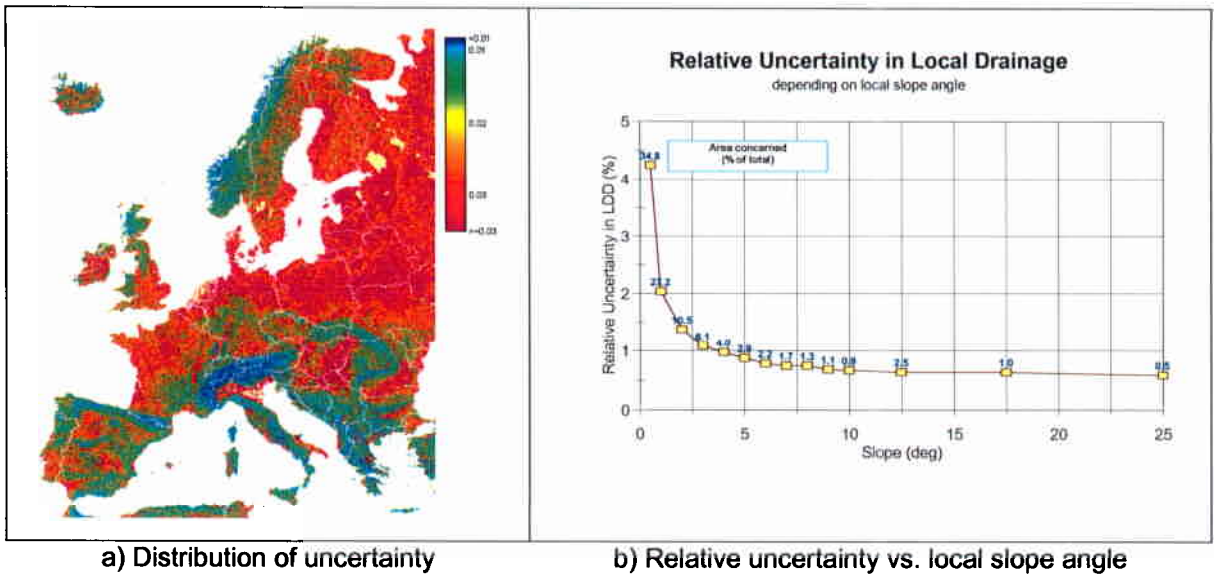
Sub-catchments are delineated following a binary system of area limits. This procedure ensures that all larger sub-catchments within a primary catchment are identified and no nested sub-catchments exist within a layer. The first layer is defined by sub-divided primary catchments larger than 256km^2. Further dividing the sub-catchments of the higher level generates subsequent layers. The lowest level of sub-catchments uses a threshold of 1000km^2.

The output of the procedure consists of 10 layers of the primary catchments and sub-catchments. Each layer covers completely the area of interest, i.e. units already delineated during a preceding processing step and new sub-divisions.

4.2 Uncertainty in Defining Catchment Boundaries

The method used in delineating catchments ensures the stable position of the outlet of a primary and sub-catchments through the river network. In contrast, the boundaries separating catchments depend to a large degree on the elevation data. In areas of little variation in slope it may not be possible to determine a definite local drainage direction. In those cases the algorithm uses a procedure based on a random value to set the local drainage direction.

In order to identify the uncertainty in the catchment boundaries the procedure was applied several times. Areas, in which the LDD differed between runs were mapped and related to local slope angle. The spatial distribution of the uncertainty in LDD and its relation to local slope angle are given in Figure 8.



a) Distribution of uncertainty b) Relative uncertainty vs. local slope angle

Figure 8: Relation between Uncertainty in LDD and Local Slope Angle

Uncertainty is expressed as the ratio of the area with random LDD to the total area. The ratio was established for areas with 14 different slope classes:

1:	0.0-0.5	2:	0.5-1.0	3:	1.0-2.0	4:	2.0-3.0	5:	3.0-4.0
6:	4.0-5.0	7:	5.0-6.0	8:	6.0-7.0	9:	7.0-8.0	10:	8.0-9.0
11:	9.0-10.0	12:	10.0-15.0	13:	15.0-20.0	14:	>20.0.		

The distribution of the slope classes and the corresponding values of uncertainty are depicted in Figure 8a. The relation between the two factors is graphically presented in Figure 8b. For the class with the lowest slope angle (0-0.5%) the average area of uncertainty is 4.25%, while it is 2.0% for areas with 0.5-1.0% local slope angle. An average value below 1% is attained in areas with a local slope angle of 3-4%. However, the area of less than 4% slope accumulates to 79% of the total area. This indicates the importance of including the river network in determining catchments boundaries.

The distribution of uncertainty in the delineation of primary catchments is given in Figure 9. Of the 1273 primary catchments 4 exceeded 5% for the coefficient of variation, 13 exceeded 2.5% and 38 1.0%.

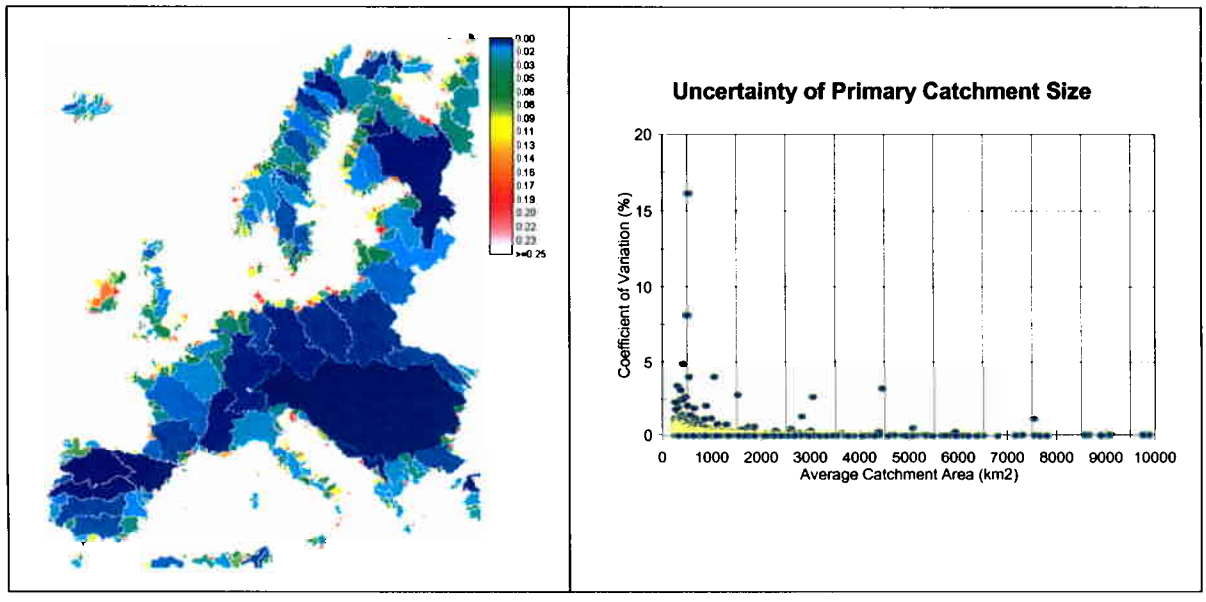


Figure 9: Distribution of Uncertainty in Primary Catchments by Size

A comparison of the figures given by different sources for the area of a selected number of major European catchments is given in Table 2.

Table 2: Comparison of River Basin Areas

Basin Name	CIS*	HYDRO 1K**	GISCO 1:3mio.***	DGA****	UNH / GRDC***** STN	Register of Intl. Rivers******
	km²	km²	km²	km²	km²	km²
Danube	799169	779537 *97.3%*	810131 *97.8*		807000 788002	790100
Duro	97473	96217 *98.5%*	93675 *93.0%*		91491 90154	96200
only Portugal	18649			18620		18200
Ebro	85424	85081 *98.6%*	91065 *96.3%*		84230 82841	85800
Elbe	140308	139450 *97.6%*	148119 *98.1%*		131950 148530	139500
Garonne + Dordogne	56116 80528	79750 *98.4%*	96777 *96.8%*		52000 53590	55800
Guadiana	66880	65697 *97.2%*	66370 *91.5%*	11563	NA 65021	67900
only Portugal	11488					13000
Kemi	51047	42762 *76.4%*	48801 *91.4%*		NA 50179	55700
Loire	116724	115990 *98.3%*	113815 *91.0%*		110000 118282	
Oder	117843	116492 *94.9%*	117364 *97.7%*		109729 119846	122400
Po	72158	87132 *97.9%*	75070 *98.4%*		70091 102183	87100
Rhine	163896	193716 *95.0%*	170946 *98.2%*		159680 165059	172900
Rhone	97310	84737 *86.4%*	101060 *96.0%*		95590 99298	100200
Seine	74268	86068 *98.8%*	80344 *97.0%*		44320 73472	85700
Tejo	70926	69945 *97.7%*	81146 *95.4%*	24478	51958 73363	77900
only Portugal	15347					26100
Wisla	193346	193879 *95.1%*	197634 *98.4%*		194376 180583	194000

* Catchment-based Information System of JRC, Ispra, calculated in Lambert Azimuth Equal Area projection
** US Geological Survey HYDRO1k, calculated in Lambert Azimuth Equal Area projection
*** Eurostat GISCO layer WSEU3M, calculated in Lambert Azimuth Equal Area projection
**** Direcção Geral do Ambiente, Portugal, calculated in Lambert Azimuth Equal Area projection
***** University of New Hampshire / Global Runoff Data Centre, Available at http://www.grdc.sr.unh.edu/html/Stn.html
****** Transboundary Freshwater Dispute Database, Register of International Rivers, http://www.transboundarywaters.orst.edu/
STN: Potential Simulated Topological Network, STN-30p, http://www.watsys.unh.edu/Stn-30/stn-30.html

The figures stated in Table 2 for catchment can only provide an indication of how well catchment boundaries were delineated. For once, the figures for the CIS catchment areas are calculated from a single outlet without integrating neighbouring coastal zones. Figures related to river basins may include those coastal zones in the area. Secondly, the catchment areas from the GRDC are calculated as the upstream area of a measurement station. The most downstream measurement

station may still be some way off the outlet. The area for the Po is given at station Pontelagoscuro, 118km from the outlet and for the Seine the Paris station was used, still 225km from the outlet. Consequently, the STN-30p area should be larger than the GRDC station area. This is generally, but not always, the case. The largest discrepancy was found for the Wisla river, though the cause of the difference could not be established.

For the catchments areas found in the HYDRO1k and the GISCO 1:3mio. Data set the relative area as compared to the CIS figures are included in the table. The CIS areas agree to over 90% with the GISCOdata for all catchments. High agreement was also found with the HYDRO1k catchments, except for the Kemi and the Rhône. The various catchment boundaries where therefore superimposed to identify, where the boundaries differ.

The resulting images are displayed in Figure 10.

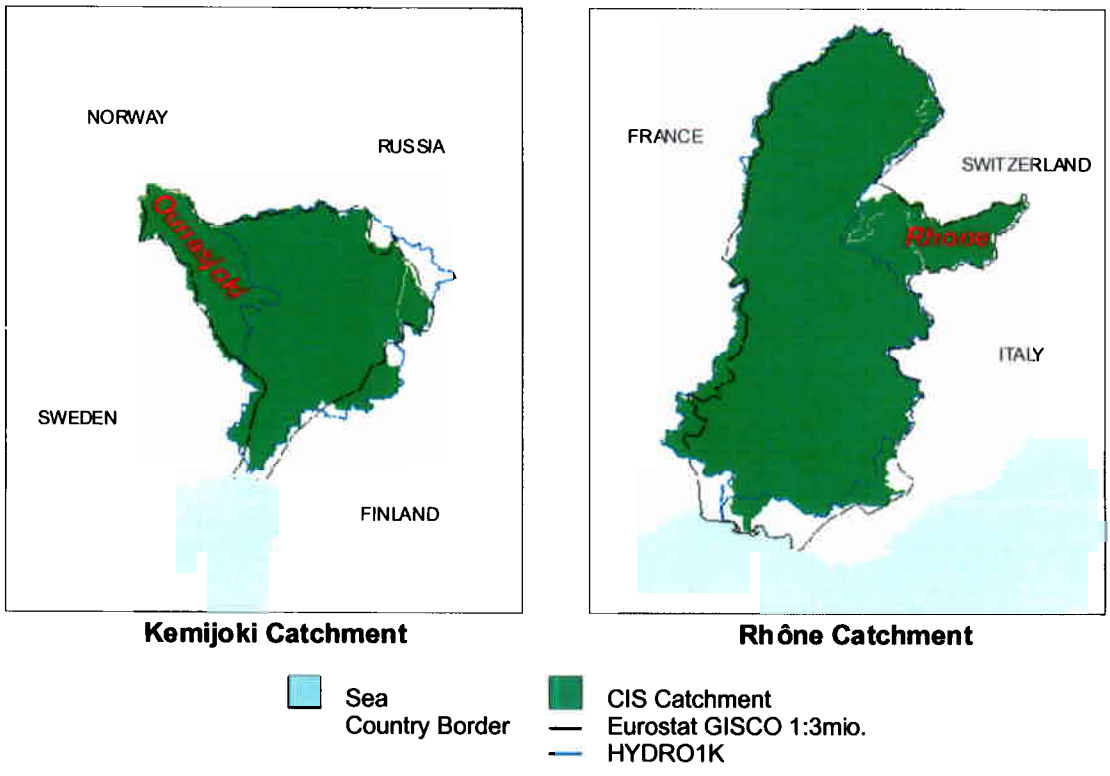


Figure 10: Superimposition of CIS, Eurostat GISCO and HYDRO1k catchment boundaries for rivers Kemi and Rhône

The Kemi catchment in the HYDRO1k data excludes from its contributing area the Ounasjoki river. For the Rhône Lac Léman is not included in the catchment. The latter omission is peculiar, because the lace level has been increased in the HYDRO1k DEM data.

On the whole it could be concluded that the CIS catchment boundaries coincide well with boundaries from identified by other activities. The specific care taken in building the flow network had a decisive impact on the delineation of catchments and sub-catchments. The results confirm the validity of the method used and represent an improvement over other spatial data sets of pan-European catchments.

4.3 Hierarchical Catchment Structure

The hierarchical catchment structure is translated into a reference coding system, which retains the spatial relation of sub-catchments at the various levels. The relationship between a sub-catchment and the larger unit, to which it belongs, is determined by analysing the spatial domain of the layers. By comparing the location of each catchment within the catchment boundaries of the neighbouring level a table describing the links between the layer elements can be established. This table is then used to generate the hierarchical structure of the catchment database.

In principle, the hierarchy could be established from either of two approaches:

- **Sub-setting of larger catchment units**
  The catchments units are arrangement as the elements derived from sub-dividing larger units. The elements of each layer follow the order of the processing algorithm. Complete coverage of the area of interest is maintained for primary catchments.
- **Aggregation of smaller catchment units**
  The approach regards the elements of the smallest sub-catchment layer as building block for larger units.

The CIS uses the sub-setting approach to define a reference structure. The reference structure is used for linking attribute information to catchment units, but also for coding catchments. The advantage of the system is that it directly follows the procedure used to delineate sub-catchment layers. However, this organization runs against the concept building larger units through the combination of smaller elements. A schematic view of the CIS Reference Structure is given in Figure 11.

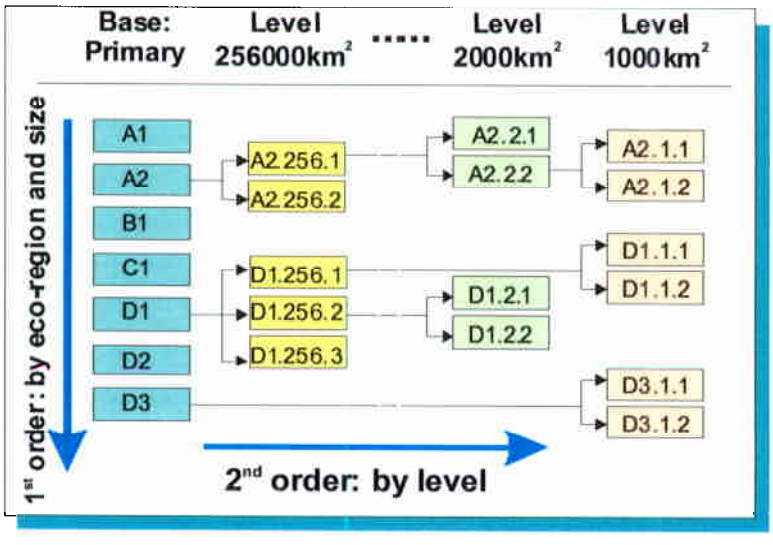


Figure 11: Schematic view of CIS Reference Structure

Based on the table containing the CIS Reference Structure the corresponding spatial reference layers are created. Thus, each unique catchment unit is represented only once in the spatial data. Examples of the coverage offered by the reference layers of primary catchments, sub-catchments identified at the 16000km^2 threshold and 1000km^2 threshold are given in Figure 12.

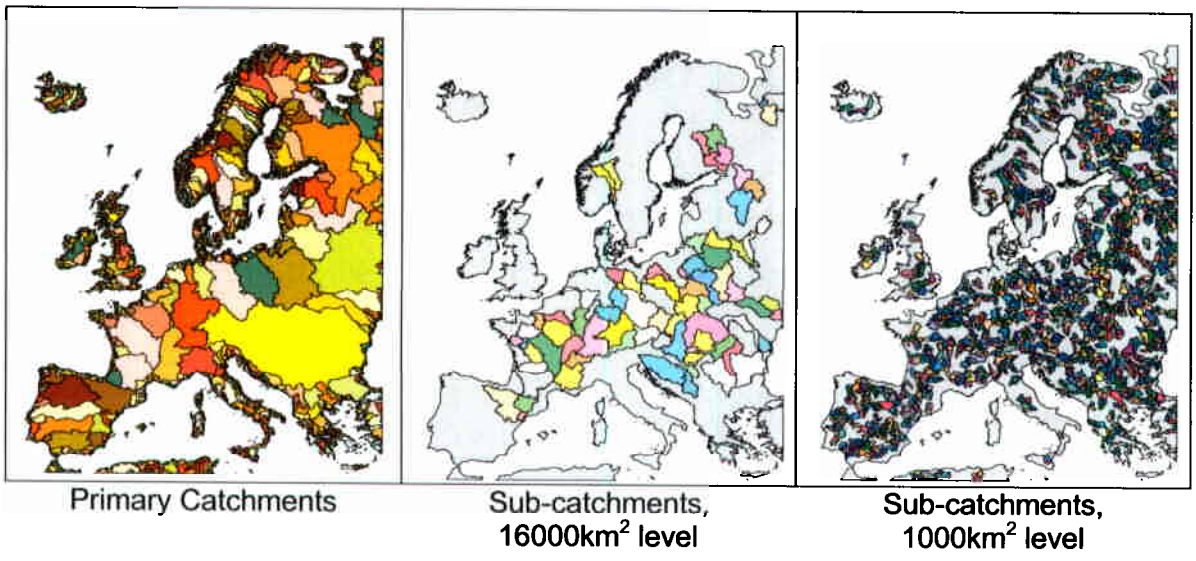


Figure 12: Coverage of CIS Reference Catchment Layers (primary, 16000km² and 1000km² threshold)

For reasons of simplified processing and presentation of results the system also stores for each hierarchical level a spatial layer with complete cover.

4.4 Reference Coding

For an unambiguous identification of a catchment regardless of the level at which it was identified each unit has to have one unique code. The first *CIS Reference Codes* consisted of an alphanumeric value containing 12 elements and looked like "0003.1.01.01.02.01.04.01.01.01.04". The code allowed the complete reconstruction of the catchment hierarchy, but was found cumbersome in use as a common reference.

A simplified coding was developed, which uses only 4 elements to describe a catchment. An example of the code would be " D1.2.2". The fist part of the code signifies the position of the catchment outlet with respect to the eco-regions for transitional and coastal waters[16]. The first digit identifies the primary catchment within the eco-region, sorted by size. Hence, primary catchments are referenced by just two alphanumeric values. The following CIS coding applies: A: Atlantic Ocean, B: Norwegian Sea, C: Barents Sea, D: North Sea, E: Baltic Sea, F: Mediterranean Sea. Not specified, but used by the CIS are: G: Black Sea, X: aggregated coastal catchments, Z: undefined outlet on land.

Sub-catchments have as the third element an identifier for the level, at which they were delineated. The last digit relates to the size of the sub-catchment within the primary catchment at the given level, sorted in descending order.

A graphical presentation of the association of catchments to eco-regions is given in Figure 13.

[16] The "Eco-regions for transitional and coastal waters" are given in "Map B", L327/72 of the "Directive 2000/60/EC of the European Parliament and of the Council of 23. October 2000 establishing a framework for Community action in the field of water policy".

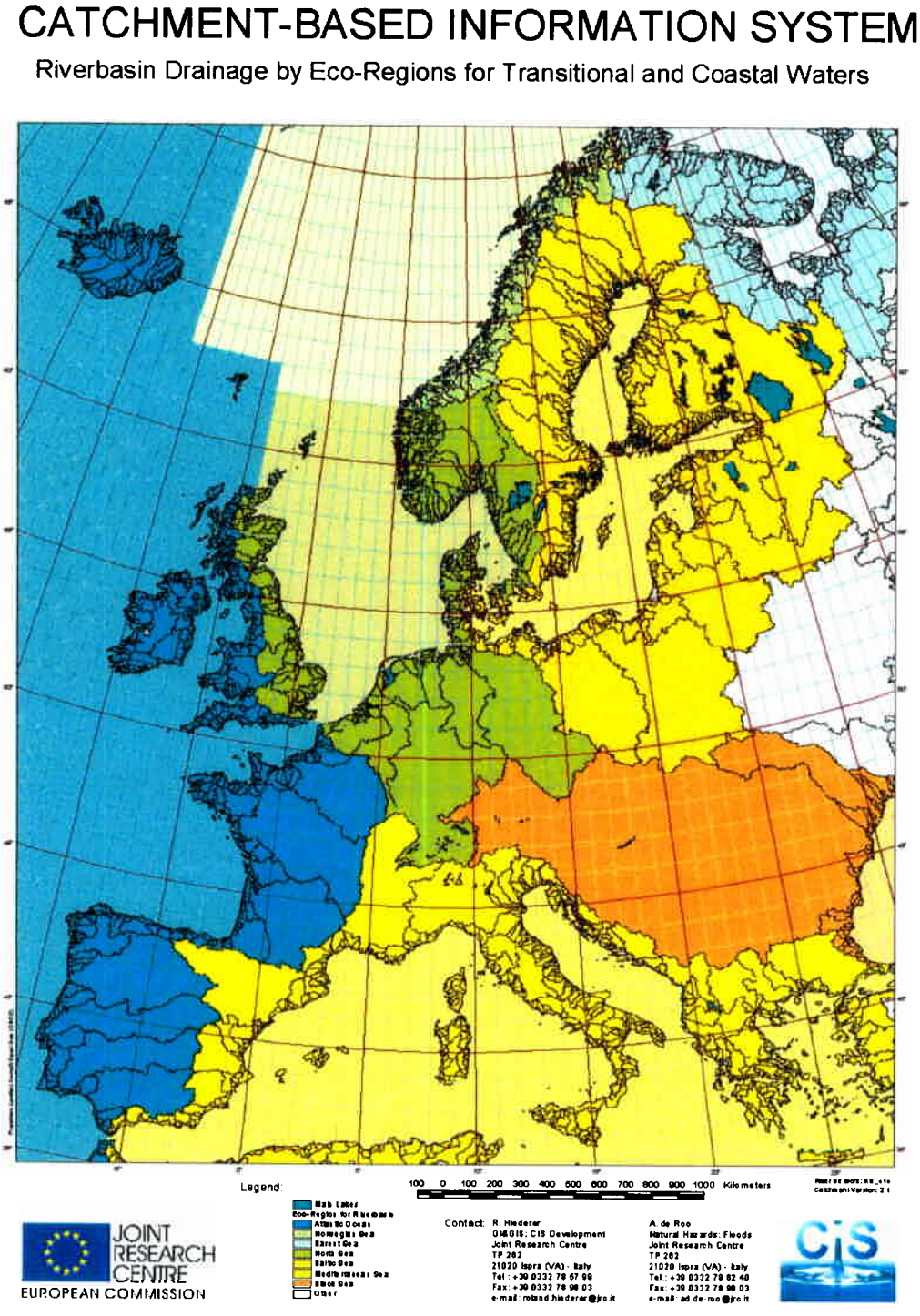


Figure 13: CIS Primary Catchments and Eco-Regions for CIS Reference Coding

An advantage of the coding system used is the relative robustness of the codes for major river basins. The main elements of the coding, drainage towards an eco-region and the size of the catchments, are stable or vary very little. Furthermore, changes within a catchment only concern the coding of the area thus affected.

5 DATA SET APPLICATIONS

The applications of the data set produced should be seen in the context of supporting sustainable development and assisting environmental protection measures. During the feasibility study for the CIS (Hiederer, 1998) a list of potential applications was produced, for which the CIS should be used. Other demands for the CIS are being added to the list as they become apparent.

5.1 N-Balance for the Agricultural Sector

One application developed using the CIS is calculating the nitrogen balance for catchments to support the implementation of *Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources* (European Communities, 1991) by identifying potential areas of problems of nitrogen from agricultural areas.

Basic data on N-balance for the agricultural sector were available at NUTS 2 level in the Eurostat GISCO database, with a published report providing further information (Hansen, 2000). Some of the source data had to be re-assessed and more detail added. In particular, figures on animal numbers were newly compiled from other Eurostat databases and manure coefficients were based on information provided directly by the Member States of the European Union under the reporting obligations of the Nitrates Directive (DG ENV, 2002).

The data on animal statistics are based on information stored in the "NewCronos" database of Eurostat. They can be found under "Theme5" (agriculture) and the domain "Eurofarm". Most detailed information on the distribution of livestock originates from the Farm Census of 1989/90 (table G1R14). However, the Farm Census is performed only every 10 years and data are therefore somewhat outdated. Furthermore, the table contains no information on livestock on countries, which joined the EU in 1995 (Austria, Finland and Sweden).

More recent information is available through regional statistics of the domain "Regio" (table A2ANIMAL). The table contains data since 1977 and is updated when new data become available. The advantage of having recent data presented is offset by the larger spatial reporting units and less detailed livestock types when compared to the Farm Census table. Another useful source of data is the domain "Eurofarm" (table ER14). The table contains information starting in 1990 in intervals of 2 to 3 years.

For the compilation of information from the various tables into one common structure three main problems had to be solved:

1. **Data refers to diverse livestock types**
   The disparity in livestock types was approached by arranging very detailed livestock types into more general groups (e.g. "bulls 1 to 2 years" and "heifers 1 to 2 years" into "growing cattle"). A total of 18 livestock types were thus reduced to 14 livestock categories, for which coefficients for the amount of N in manure were defined.

2. **Missing data for a given year**
   In case of a complete absence of data for one year the missing data were estimated by interpolating between years. In cases where only data at a more general reporting unit are available the temporal changes were transferred to the detailed reporting units.

3. **Altered spatial definition of reporting units**
   Over the years the spatial cover of the reporting units has changed. In particular areas in the UK changed coding and spatial cover after 1990. The Farm Census and Eurofarm use the older spatial definition of NUTS reporting units, while the Regio table corresponds to a more recent definition. All data were transferred to units of NUTS V7, as defined in the Eurostat GISCO database. This required to re-map data from the older definition and extract the information for the standard units. The task was performed using a simple transfer function and a GIS.

In total the numbers for 26 categories of animals were compiled for the years from 1990 to 1997. The categories were combined into 16 groups of animals, for which manure coefficients were defined. A summary of figures for EU15 is given in Table 3.

Table 3: Livestock Number, Manure Coefficients and Manure from Livestock (1994-97)

LIVESTOCK GROUP	LIVESTOCK NUMBER				MANURE COEFFICIENTS		LIVESTOCK MANURE			
	mio. animals				kg/ha/year		1000t/year			
	1997	1996	1995	1994*	MIN	MAX	1997	1996	1995	1994*
Equidae[1]	2.6	2.5	2.5	2.3	60.0	60.0	154.4	150.8	149.4	138.7
Calf[2]	24.6	25.0	25.0	23.1	25.7	25.7	632.1	638.7	643.0	594.8
Cattle, growing[3]	17.6	18.2	18.2	16.8	41.3	41.3	729.8	746.5	751.7	692.3
Dairy[4]	21.7	22.5	22.5	21.3	70.0	125.0	2268.5	2307.9	2352.8	2243.6
Cows, other[5]	11.7	11.3	11.3	10.7	49.2	101.2	860.0	859.8	838.2	791.1
Cattle, other[6]	8.0	8.2	8.2	7.7	40.0	80.5	453.0	450.8	462.6	435.9
Piglet <20kg[7]	34.0	31.6	31.6	30.0	0.2	0.2	8.2	7.8	7.6	7.2
Breeding Sows[8]	13.1	12.4	12.4	11.7	21.5	21.5	281.7	272.6	267.2	251.4
Pig, other[9]	75.5	72.8	72.8	69.3	10.1	10.1	762.8	743.3	737.1	700.4
Goat, breeding[10]	9.0	9.1	9.1	8.8	10.2	13.0	99.1	98.3	100.3	97.8
Goat, other[11]	3.6	3.0	3.0	3.5	4.4	5.6	16.8	15.9	14.3	16.5
Ewes[12]	69.8	68.5	68.5	69.4	11.3	15.9	847.6	851.4	835.2	848.2
Sheep, other[13]	29.3	26.2	26.2	26.6	4.9	6.8	152.5	134.6	136.8	139.8
Broiler[14]	501.0	494.4	494.4	482.6	0.4	0.4	181.8	180.0	178.8	174.7
Laying Hen[15]	390.0	378.2	378.2	361.8	0.6	0.6	220.3	216.3	213.1	204.1
Poultry, other[16]	134.6	136.9	136.9	135.1	1.0	1.0	135.0	136.0	137.2	135.4
Total Livestock	**1346.1**	**1320.7**	**1320.7**	**1280.6**			**7803.7**	**7810.7**	**7825.3**	**7471.8**

1 average for 2.5% N in diet and 600kg/animal/year excretion
2 bovine <1 year, average m/f large breed DK (25.7 kg/year)
3 bovine 1-2 years, average m/f large breed DK (41.3 kg/year)
4 regional N-coefficients
5 mainly suckler cows, = dairy*0.9444-16.88
6 bovine > 2 years and buffalo
7 assuming 20 live pigs per sow per year
8 sows with piglets till weaning (7.5 kg)
* Value for EU12
Source Eurostat New Cronos Database (missing values estimated by interpolation)
9 average value for slaughter pigs from 25-105 kg
10 goat with kids (1.8 /goat/year, 7kg slaugther weight), varied by country
11 other goats, 30% of goats with kids
12 ewes with lambs (1.6 /ewe/year, 40 kg slaughter weight), varied by country
13 other sheep, 30% of ewes with lambs
14 medium feed conversion (1.8), medium N loss (30%)
15 medium feed conversion (2.5), medium N loss (30%)
16 principally duck and turkey
Date 22.08.2001

Coefficients of the amount of N in animal manure were based on the study performed by ERM and AB-DLO (Environmental Resources Management, 1999).

The values were modified to

a) correspond to the various groups of livestock types used and

b) take into account introduce regional variations.

To allow for the regional variations in coefficients of N in animal manure EU15 was divided into 178 regions. For each animal type and spatial unit a specific coefficient could be set. This regional variation was used for the livestock types "dairy cows", "other cows", "other bovine", "breeding goat", "other goat", "ewes" and "other sheep". The minimum and maximum values used for each of the livestock groups are given in Table 3. The figures from the statistical database are linked to administrative units and were subsequently re-mapped to CIS catchments using a method of modified spatial weighting (Hiederer, 2000b). Weights are given on the basis of the distribution of land cover, which was defined by the Corine Land Cover layer in the CIS.

The spatial representation by sub-catchment derived from the processing for the amount of N in animal manure is given in Figure 14.

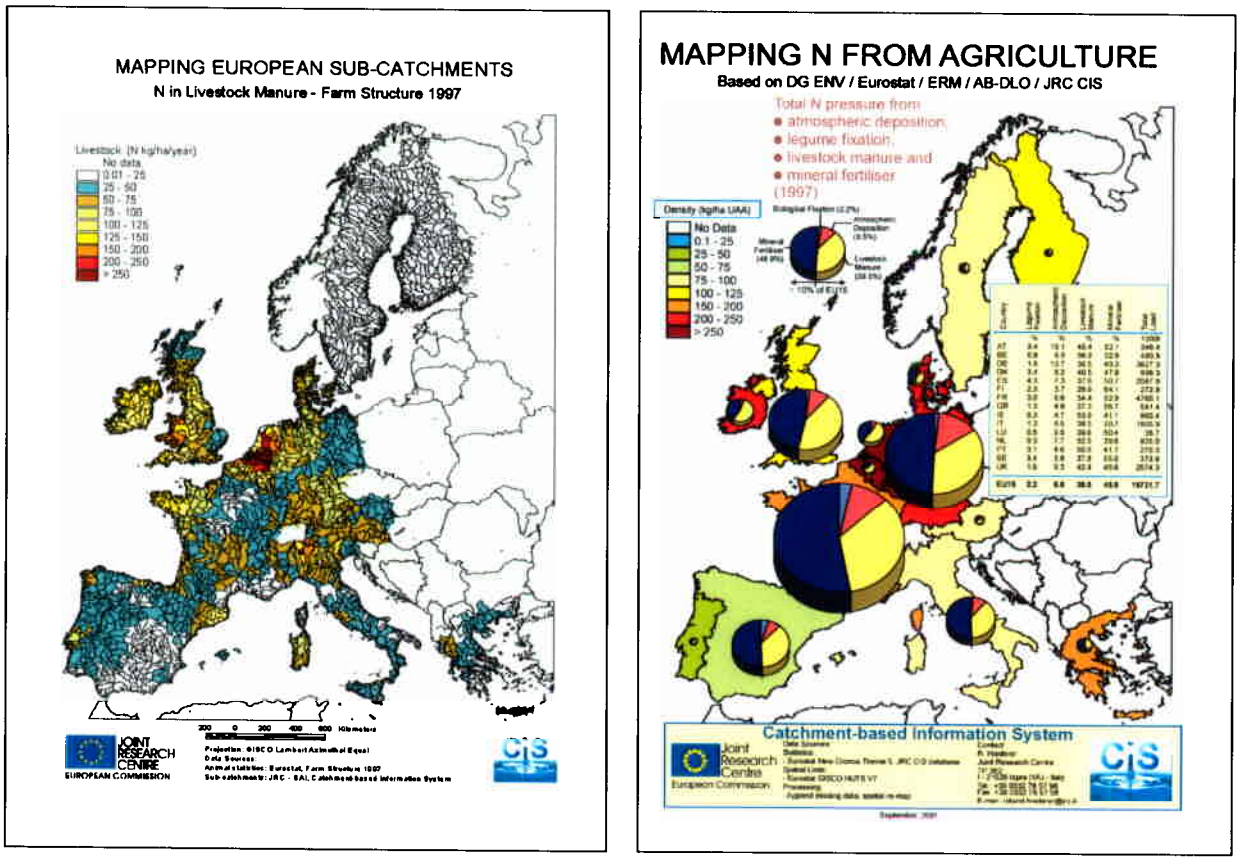


Figure 14: Distribution of Livestock by CIS sub-catchment (a) and N-balance for agriculture by EU Member State (b)

Other values used to estimate the nitrogen balance were mineral N from fertilizer, biological fixation, atmospheric deposition and removal through harvest. Figures for those sources and sinks of nitrogen are available in the Eurostat Regio database. The final N-balance figures were aggregated at EU Member State level, and are graphically presented in Figure 14 (DG ENV, 2002).

5.2 Hydrological Modelling of Large River Basins

Another application of the CIS dataset is for the hydrological modelling in large trans-national catchments. For all hydrological modelling, a high quality flow network such as the one developed in the CIS is essential to obtain realistic results.

Within the 'Natural Hazards Project' of the JRC, the flood simulation modelling system LISFLOOD has been developed. The physically-based LISFLOOD model (De Roo, 1999; De Roo *et al.*, 1999; De Roo *et al.* 2000) simulates the hydrology and river discharge in catchments. The model has been used to evaluate flood mitigation scenarios and is used for flood early warning at a European scale. LISFLOOD has been developed explicitly for the simulation of floods in large European drainage basins. Unlike most other hydrological models, it is capable of simulating large areas, while still maintaining a high resolution, proper flood routing methods and physical process descriptions. Since the physical process descriptions are universal, no or little additional calibration is needed if applied in a new catchment. LISFLOOD is also especially designed to simulate the effects of change in an easy and realistic way: land-use changes, modifications of the river geometry, water reservoirs, retention areas and effects of climate change. LISFLOOD is embedded in a GIS and is using readily available European datasets, such as Corine Land Cover, the CIS, and the European Soils Database.

Full basin-scale simulations can be carried out, such that influences of land use, spatial variations of soil properties and spatial precipitation differences are taken into account. LISFLOOD consists of a catchment-scale water balance model (LISFLOOD-WB), run with a daily time step, a catchment-scale flood simulation model (LISFLOOD-FS), run with an hourly time step, and a floodplain simulation model (LISFLOOD-FP) (Bates and De Roo, 2000), run with a time step of several seconds (Figure 15). The water-balance model is started approximately one year or more before a flood, to simulate the initial conditions (discharge, soil moisture, snow cover, groundwater) before the flood event. The catchment flood simulation model starts just a few days before a flood. The main difference with the water-balance model is the time step, which is smaller to improve the river routing. Typical model grid-sizes for the Meuse and Oder catchment are 1 km. Sub-basins of the Meuse and Oder are simulated using 100-300 m grids. The LISFLOOD floodplain model simulates with high spatial and temporal resolution a part of the floodplain of a river, using either observed discharges as boundary condition, or simulated discharge from the catchment LISFLOOD model.

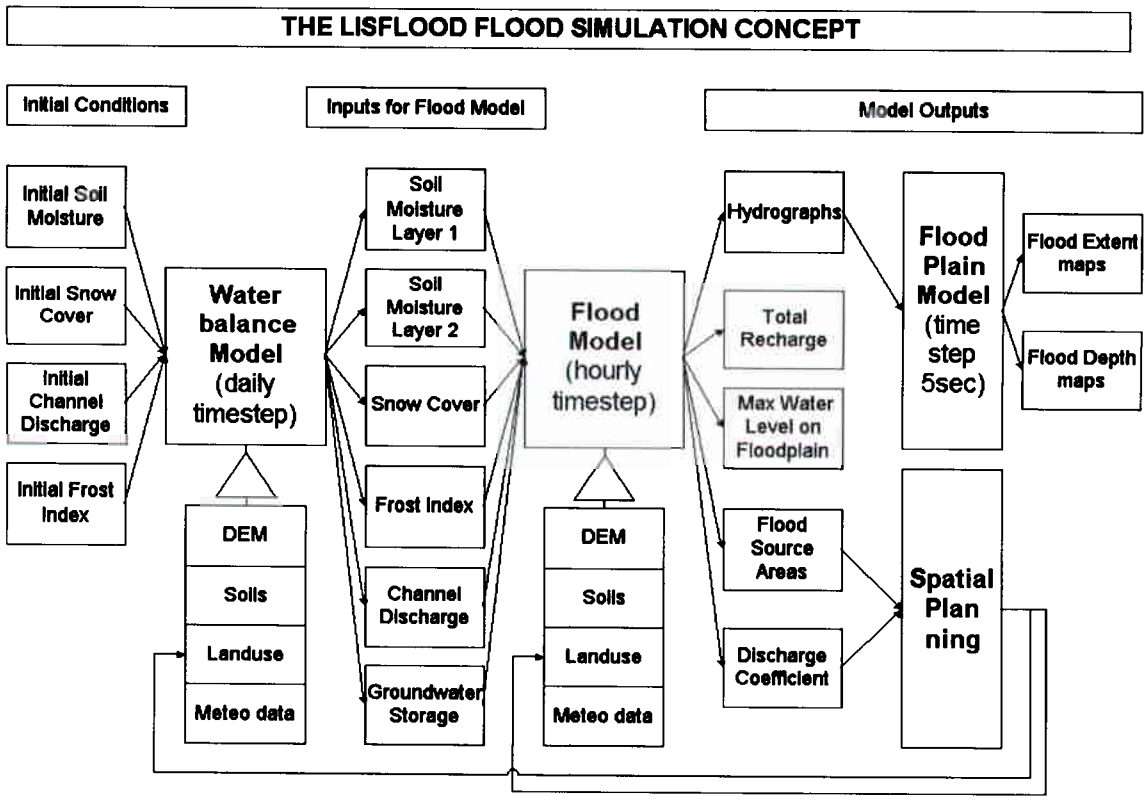


Figure 15: Flowchart of the LISFLOOD model

LISFLOOD simulates the hydrological processes at the surface, in the soil, and in the river channel network on a regular horizontal grid (Figure 16), usually using a high resolution compared to the catchment size: LISFLOOD can easily handle 100,000 grids or more. In the vertical a total of 4 different layers are considered. For each grid point a value is calculated at every time step.

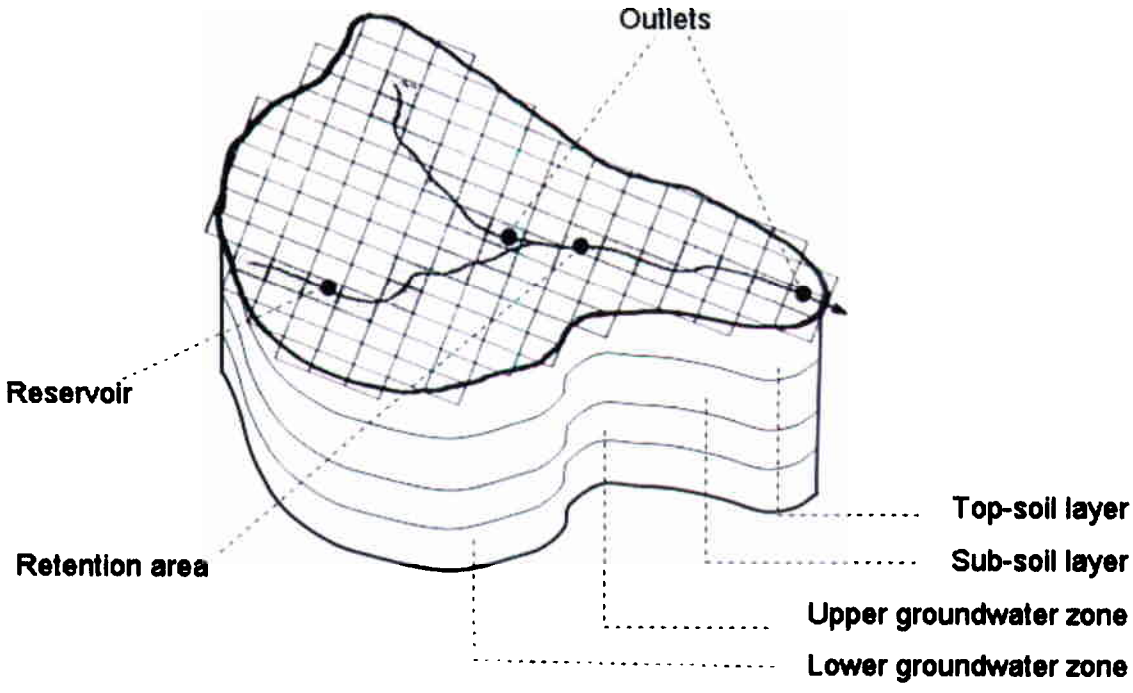


Figure 16: Schematic view of a catchment in LISFLOOD including soil and groundwater layers

Processes simulated are precipitation, interception, soil freezing, snowmelt, evapo-transpiration, infiltration, percolation and capillary rise, groundwater flow and surface runoff. Overland flow is simulated using a kinematic wave approximation. Channel flow is simulated using either a kinematic wave or dynamic wave approximation, depending on river channel bed gradient and the occurrence of back-water effects. The user can define which sections of the river to simulate with a kinematic wave, and which sections with a dynamic wave. The user can choose both the spatial and temporal resolution of the model. The channel routing part contains a simple solution to account for floodplain storage and flow.

The input parameters for the LISFLOOD-WB and -FS model are maps of topography, land use type (Corine landcover database), soil depth and soil texture (European Soils Database) (Figure 17).

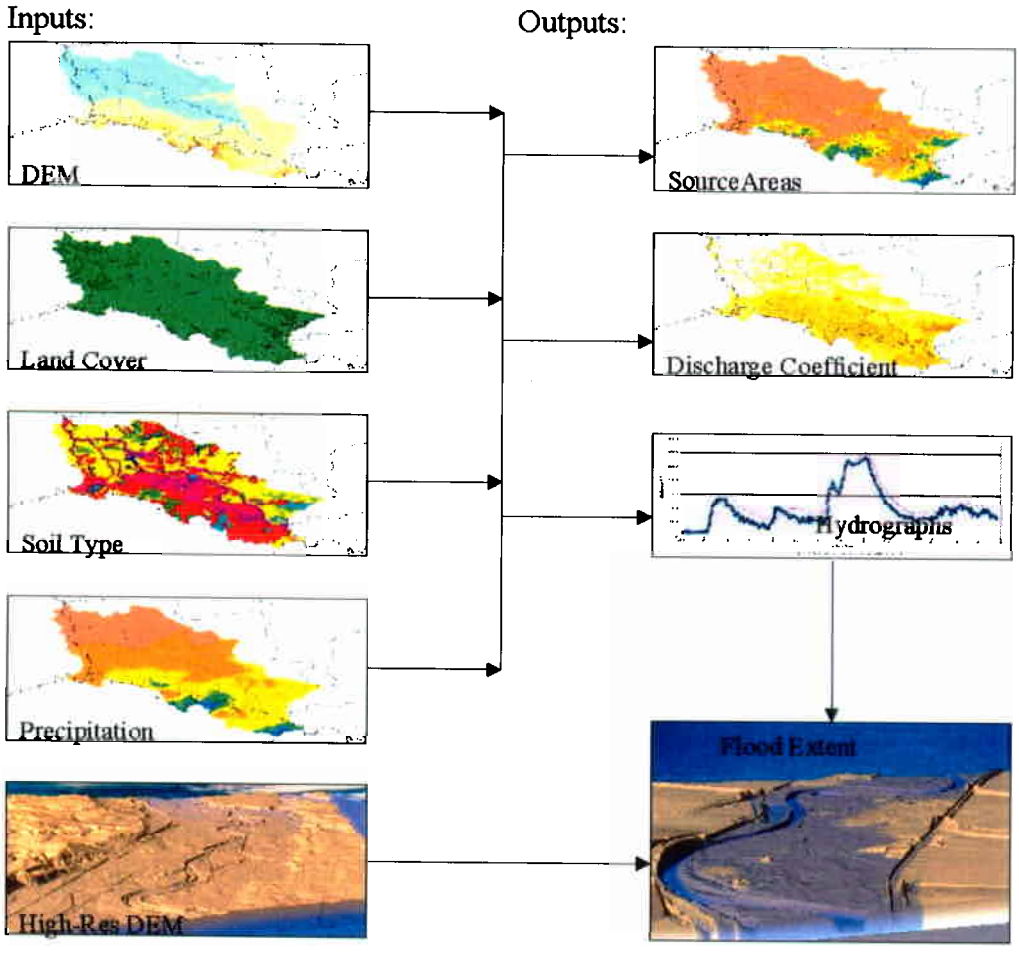


Figure 17: Inputs and outputs of LISFLOOD

Time series of precipitation amounts and other meteorological parameters (minimum and maximum daily temperature, actual vapour pressure, sunshine duration, cloud cover, wind speed at 2 m) are needed for as many meteorological stations within the catchment as possible. Precipitation and temperature are corrected for altitude. All meteorological parameters are spatially interpolated using an inverse distance method using the 5 closest stations. Seasonal NDVI profiles were derived from IRS-WIFS satellite images, showing the changes in vegetation cover during the year for each land use type. From the NDVI profiles Leaf Area Index values are derived for model parameterisation. Antecedent soil moisture conditions are taken from the LISFLOOD water balance model, which is used as pre-processing for the flood simulation model.

The outputs of LISFLOOD consist of hydrographs at user-defined locations in the catchment, usually the locations where also measured discharge is known. An example of the output of the flood model is given in Figure 18.

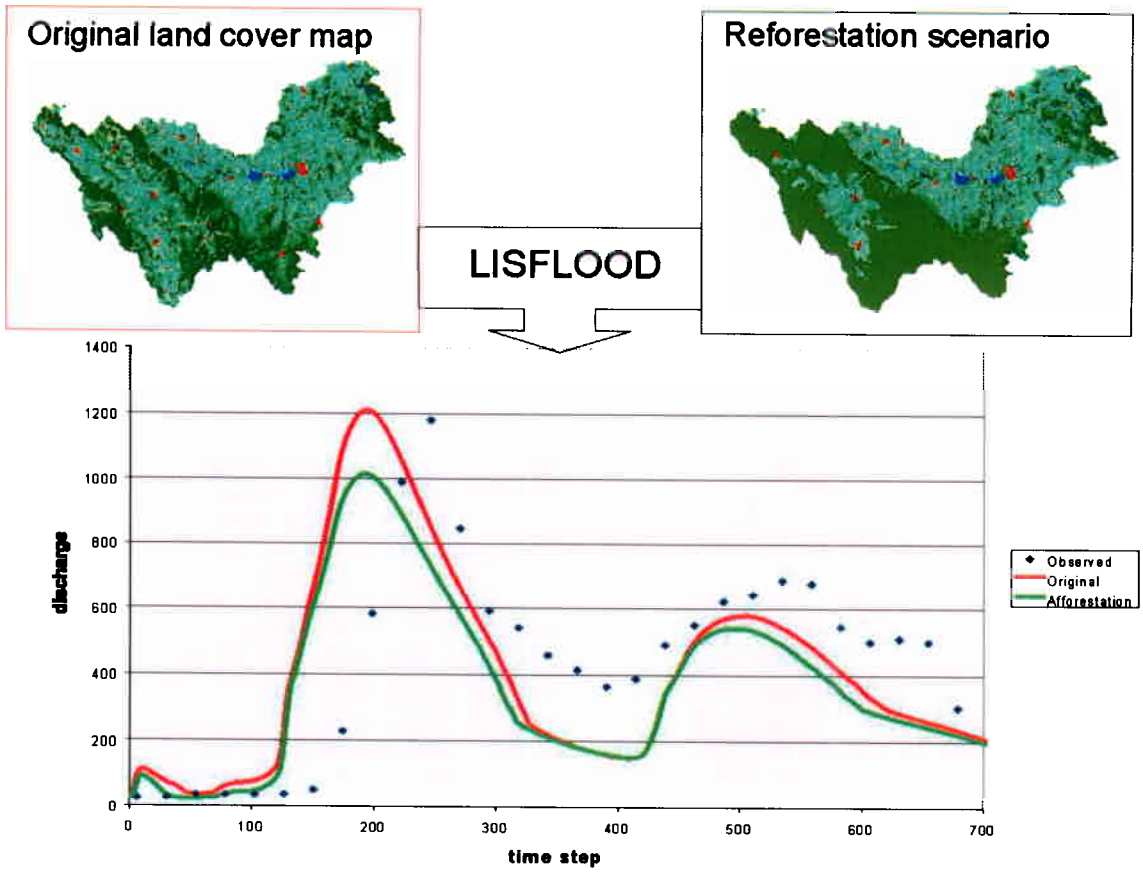


Figure 18: Example of an output of the flood model: effects of a land use change in a catchment on the discharge as compared to the present situation and the observed flood discharge

Furthermore, timeseries of for example evapo-transpiration, soil moisture content or snow depth can be created at selected locations, if validation data are available. The model produces a number of GIS maps, such as water source areas, discharge coefficient, total precipitation, total evapo-transpiration, total groundwater recharge and soil moisture maps.

Applications of the LISFLOOD modelling system:

The LISFLOOD modelling system described above, with the CIS flow network as a basis, is used for several studies on floods:

- Scenario studies for flood prevention in the Oder, Meuse and Elbe basin. Effects of land use changes and engineering measures on floods are evaluated;
- Flood forecasting in the Raba sub-catchment of the Danube;
- A pre-operational European Flood Early Warning system for which we simulate entire Europe using weather forecast data, to provide early flood warnings to national authorities.

6 SUMMARY

For applications related to measuring, modelling or monitoring water quantity and quality consistent European flow network and a catchment data sets are of primary importance. The lack of such data sets until the late 1990s indicates that producing a functional flow network is a non-trivial task. It requires significant amounts of effort, a sound methodological approach to the task involved and a clear understanding for the evaluation of the results obtained.

One of the main conclusions drawn from the work performed is to give thorough attention to the preparation of the base data layers. The layers have to be internally coherent, which applies in particular to the river network. Lines representing rivers should be internally joined, connected through lakes and separable in the raster data. Furthermore, overlaying spatial layers requires geographic agreement of features, like the position of riverbeds in the river network and the DEM or a common land/sea mask. The time spent on preparing the base layers reduces the amount of effort required in identifying irregularities in the flow network and catchment outlines.

When comparing the data sets with those from other sources some of the differences, but also limits, become noticeable. Since catchments were defined by a single outlet in areas of river deltas a main arm was defined in deltas. The delta is thus split into several individual catchment units. In the definition of river basins those units are frequently assigned to the main catchment. There is also some divergence between data sets with respect to the definition of the land/sea boundary. In cases, where the boundary moves inland areas generally assigned to a larger river become distinct catchments. This is most evident in case of the Elbe.

The data sets were developed in response to the demands from different applications. One was the need to assess the effect of agri-environmental measures on water quality, the other to model floods for forecasting extreme events. In both cases the data sets support scenario management for the evaluation of the effectiveness of measures considered to reduce the impact on the environment and damage to person and property.

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Catchment-based Information System

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