Decision Support System for Risk Assessment and Management of Floods

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Abstract The paper describes the essential features of a new decision support system (DSS) for the risk assessment and management of emergency scenarios due to severe floods. The RAMFLOOD DSS combines environmental and geophysical data from earth observation, satellite positioning systems, in-situ sensors and geo-referenced information with advanced computer simulation and graphical visualisation methods for generating knowledge contributing to the risk and damage assessment prevention of floods and the design of effective response actions maximising the safety of infrastructures and human lifes. The new DSS is the result of the RTD work in the project RAMFLOOD carried out with support from the IST Programme of the EC.

1 Introduction

Floods can lead to important environmental emergency situations affecting the integrity of large infrastructures and the life of many human beings. There is a need for efficient systems to assist public administrators and emergency services in the risk assessment of floods and in the management of different emergency scenarios in the floodplain area.

Modern day satellite information about the land surface terrain properties and meteo processes, combined with on-site information from traditional surveys and sensors, is the basis for regional-scale hydrologic modelling. The devastating impacts of recent severe floods has sparked interest in the regional hydrologic modelling in different countries worldwide. As part of the current modelling effort, maps of the hydrologic properties of the soils of the region can be developed using databases populated with data from various remote and on-site sensors. Such maps can be used with process-based models of the land surface to provide information to decision makers regarding the likelihood of floods and the design of different emergency situations.

It is nowadays accepted that the main component of the conceptual framework for flood management is a decision support system (DSS). It is envisioned that the DSS should not only estimate flood management strategies based on today's situation but that also predict: (a) alternative levels of vulnerability based on future population in the basin and other factors; (b) losses in future floods based on alternative decisions made today, such as different land use and building planning decisions; and (c) impacts on and changes in other aspects of sustainability like environmental quality, economic vitality, and social equity [11, 13].

Consistently with above, the authors are taken in the development of new DSS with the following key requirements: (a) provision of support for planning different flood damage reduction alternatives; (b) evaluation of operational alternative choices and emergency scenarios during the flood fighting; and (c) support during the flood recovery period.

Consortiums

The new DSS has been developed within the framework of the RAMFLOOD project of the IST Programme of the EC. The partners in this project are CIMNE, Dept of Hydraulics Engineering of the Technical University of Catalunya (UPC), EUROMAP (DE), the Agriculture University of Athens, the Catalonian Water Management Agency and the Attica Municipality Association (SPAP) [16].

2 Specific Features of the Ramflood System

The following essential technologies are integrated in the new RAMFLOOD DSS:

- Advanced methods for capturing, correcting and merging updated geographical an environmental information with (at least) 5 meter resolution.
- A powerful and universal technology for multiscale analysis and transfer of high resolution data emanating from optical an radar measurements of the earth observations into classified and usable information to be ingested into the flood simulation system.
- Advanced computational methods for the fast and accurate simulation of different flooding situations for evaluating the effect of alternative response scenarios
- Innovative IT tools for generating the data necessary for the computer simulation of floods and the 3D visualization of the numerical results
- An artificial neural network (ANN) based decision model educated using innovative Monte Carlo simulation tools. The ANN model will be the kernel for assisting in real time public administrators and emergency services in the risk assessment of floods and in the design and management of specific emergency scenarios.

The intelligent decision support concept chosen links four basic elements of flood decision-making: (a) engineering expertise; (b) a systems approach; (c) GIS data; and (d) a decision module based on neural network tools. As such, this concept becomes very similar to the integrated model-base decision support approach.

RAMFLOOD DSS not only is a tool for flood analysis, but an instrument for communication, training, forecasting and management of emergency scenarios. The innovative aspect of this concept is that the DSS is application and problem-oriented rather than methodology oriented. Advanced AI technology through neural nets provide real time response necessary for taking decision in emergency situations. The neural net technology is combined with more classical techniques of engineering analysis, data processing and computer simulation.

Figure 1 shows the basic flow chart of activities to be carried out within the RAMFLOOD DSS.

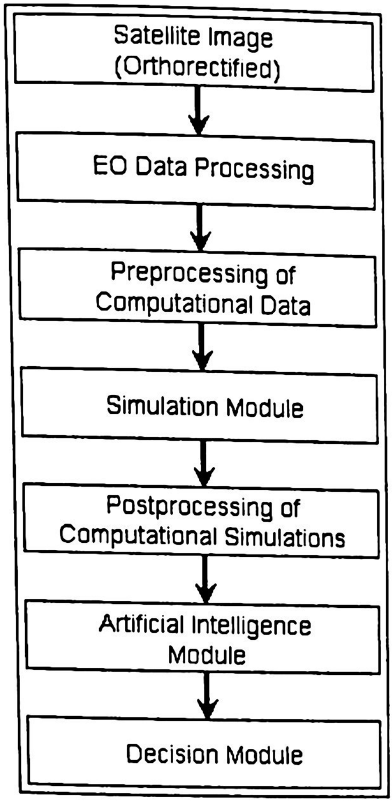

Fig. 1. Basic flow chart of the RAMFLOOD DSS

Three levels of functional support are provided within the new RAMFLOOD DSS to different users:

- Information support is the first level of support provided by the RAMFLOOD DSS. It includes maps, plots, animations, video, spatial data and reports to all potential users classified as information users.

- Technical support is the second level of support. It will include access to databases (archival, spatial, real-time, etc.) and modelling tools to all technical users responsible for flood management.
- Application support is the third level provided by the RAMFLOOD DSS mostly decision-makers and managers at different levels. Application users will be able with the assistance of the RAMFLOOD DSS to focus on a practical problem for initial implementation, test and fine tune various aspects of strategy and supporting infrastructure in flood emergency situation. Also the impacts of different measures, decisions and procedures can be tested and analyzed before moving on to full implementation.

Flood management is a decision-making process bordering between the art and science of making choices for desirable change, to solve problems and minimize negative impacts of floods.

The new RAMFLOOD DSS has the following key roles:

1. Guiding role through the decision-making process during planning, emergency management and flood recovery;
2. Assisting role in establishing the social, economic and environmental goals for managing floods:
3. Supporting role in describing the flood problem to be solved in terms predefined objectives, and constraints for generation of alternative actions;
4. Active role in collection and integration of information that will support flood problem description, evaluation of consequences of actions, and learning;
5. Aiding role in evaluation of alternatives using multiple and often conflicting objectives; and
6. Educational role in learning from the decision process itself and from outcomes of the implemented decisions.

The new RAMFLOOD DSS integrates advanced methods for collecting, processing and managing hydrogeological data, quantitative methods for simulation of flood scenarios, graphical visualization methods and artificial neural network (ANN) based techniques for generating knowledge contributing to support decision makers at the upper level by providing a quick response to specific "what scenarios during a flood emergency.

The main innovative aspect of the new DSS is the integration of state of the geographical and environmental data collection and data management tools with simulation and ANN decision tools for risk assessment and management of floods.

The calibration and validation of the performance, scalability and effectiveness the DSS will be assessed in its application to two high risk flash floodplain scenarios in the Llobregat river deltaic area in the Mediterranean region of Spain and in Attica region in Greece where the 2004 Olympic Games will be held.

3 Methodology for Collecting Data and Generating Hydrological Information

Basic hydrological data for the RAMFLOOD DSS is based on satellite data for geophysical and environmental observation. A posteriori management of collected geophysical and environmental data requires a radiometrical correction and processing and the merging the resulting panchromatic and multi-spectral data into a 5 x 5 m. natural colour product in TIFF format.

A "hydrologic" module provides basic data for subsequent computer simulations of floods. This means that object parameters are generated from the basic raster data input, which constitute meaningful values in order to monitor and manage flooding events. Special attention is paid in the fusion of information for soil and land coverage with those of the hydrological network (i.e. digital elevation model).

The hydrological model data is upgraded to derive basic terrain slope, aspect and hydro-network parameters directly from the supplied raster DEM and use this information directly in the object generation and image classification process. Whilst the generation of these parameters is a standard procedure, the automatic fusion of these parameters (and the subsequent knowledge based processing) with basic soil and land use information is an innovative approach.

4 Risk Analysis of Floods in Plain Areas

Flood problems are the consequence of one of the natural hazards that periodically affect urban and suburban areas. Public administrations are responsible for keeping living areas free of flood danger, as well as for providing the infrastructures that could be used by the emergency services during and after floods. State of the art risk criteria are based in the combination of hydraulic and territory factors.

The analysis must be made for different scenarios associated to various rainfalls using simple or more sophisticated qualitative models. The risk analysis provides data for the DSS in order to define risk zones and emergency scenarios.

Water management agencies usually establish their risk maps on the basis of simple 1D flood models. These models are clearly appropriated for river studies but they are not applicable to floodplains, specially when water flows out of the river. A two-dimensional behaviour is however the correct flow pattern in floodplains.

Flow risk associated to floodplains can be divided in the following categorities:

- Risk associated to water depths: Water can reach to certain levels, producing flooding damages. This is the usual approach and sometimes the only one considered by water management agencies.
- Risk associated to water velocity: erosion and dragging capacity of high speed waters can be a serious danger to pedestrians or traffic vehicles.
- Risk associated to a combination of water depth and velocity. This combination can still be dangerous, producing that a adult human could not stand or manoeuvre through the flow.
- Risk associated to the capacity of the flood to produce erosion and carry debris.

Besides these risk factors, the time associated to the flood is an other significant parameter. The risk criteria traditionally used have been selected as a limiting value of water depth, water velocity or a combination of both parameters. This approach was proposed in last decade using a reduced experimental data set.

The human instability condition is a basic approach parameter to define risk zones over the floodplain. In the RAMFLOOD DSS, the combination of velocity and water depth is taken into account.

New experimental tests on the hydraulics laboratory of the Technical University of Catalonia (UPC) have been carried out with human subjects in a recirculating flume, in order to determine the velocity and depth of flow that cause human instability.

Prior to apply the defined risk parameters on the floodplain area, a thorough hydraulic analysis is performed considering the most severe historical rainfalls as well as the discharges produced by design rainfalls associated with selected return periods in specific flood plain regions.

Simple 1D analyses and more sophisticated 2D hydraulic analysis provide water depth and velocities over the floodplain discretized with a cell resolution of 15 to 20 meters.

Data for the flood simulation analyses and the visualization of numerical results are handled by the 2002 IST Award Winner pre/post-processing system GiD developed by CIMNE [9]. The linking of existing hydraulic simulation codes with the new pre/post processing system GiD is another innovative aspect of the new RAMFLOOD DSS.

New risk maps considering these criteria have been obtained for two specific territories in Spain (Llobregat river delta area including the Barcelona airport) (Figure 2) and Greece (Pendelikos mountain in the Attica region) (Figure 3). Limit values of water depth, velocity and their combination as well as the flood time are visualized in a global map, providing a useful tool for emergency management as well as for determining protective measures against floods.

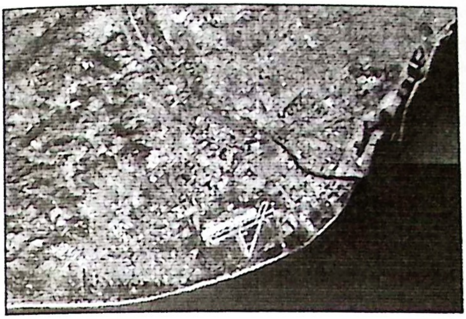

Fig. 2. Llobregat river delta region. Barcelona airport can be seen in the lower central image

Fig. 3. Pendelikos mountain in the Attica region in Greece

5 Design Architecture of the Ramflood DSS

DSS literature offers two main development architectures: functional and tool-based [15, 19]. However, the development of the RAMFLOOD DSS is based on an original approach identified earlier as the intelligent decision support architecture [18]. The main power of this architecture is in its ability to integrate efficiently technical knowledge of flood management, systems approach to problem formulation and solution, with the personal experience and set of visualization tools for data presentation and flood simulation analysis.

Schematic presentation of the RAMFLOOD DSS architecture is shown in Figure 4. It is comprised of a web-based user interface that provides easy access to distributed databases (through a shared internet-based data catalogue), and modeling tools.

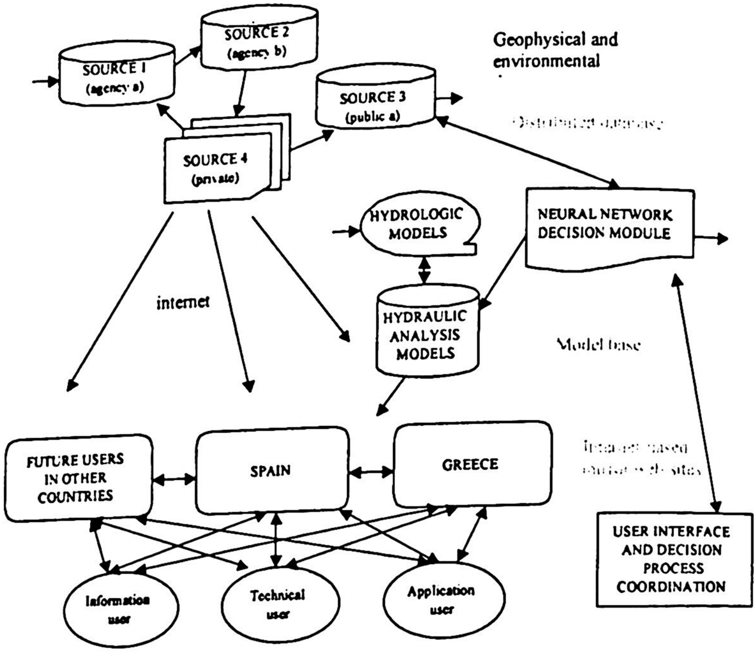

Fig. 4. RAMFLOOD DSS structure

Distributed database. The main intent of the RAMFLOOD DSS is to ensure that all data (topographic, land use, hydrologic, hydraulic, environmental and economic) are accessible to all users in order to provide support for flood management activities. The RAMFLOOD DSS includes a distributed database allowing data acquisition from various agencies assuming responsibility for continuing, maintaining and updating database components.

The distributed database provides the following internet-based services: (a) quickly locate data required for flood reporting and flood fighting; (b) describe in detail the contents and limitations of the data; and (c) present the data in different formats (maps, graphs, pictures, videos, etc.). The database is searchable by data type, data holder/owner, location, etc.

The distributed database has no single data repository thus eliminating the requirement to provide regular updates of data to a data clearinghouse. Some data sets, however, may need to be centralized depending on the preferences of the data set providers. Data attributes (a text file describing various characteristics of each data set, such as accuracy, format, etc) is critical for users of distributed databases to accurately evaluate data sets in terms of usefulness for various types of analyses.

Development of the distributed database has taken into consideration the needs and capabilities of data providers, and data users, as well as seamless integration of database with other components of the RAMFLOOD DSS. The distributed database is used in three modes: (a) planning and design for flood protection; (b) real time flood emergency; and (c) flood recovery. Table 1 below lists some initial data components.

Modelbase. Improved flood management calls for a coordinated and integrated use of descriptive and predictive modelling tools. Hydrologic, hydraulic, economic, and environmental models are required to support decision-making in a basin.

Hydrologic models combine precipitation and other inputs to forecast runoff in a river system. The RAMFLOOD model base includes some simple hydrologic forecasting tools and allows for the integration of alternative existing tools and others which are in the process of development.

Table 1. Initial RAMFLOOD database components

INFRASTRUCTURE Roads - elevation and alignment Railroads - elevation and alignment Levees - elevation and alignment Wells - Active and abandoned Bridge and Culvert openings (>5ft) Utilities – Hydro, gas, water, sewage, etc. Drains - dimensions and alignment Raised Pads - locations and elevations Impoundments: size, sill elev., construction date Critical Facilities Potential Spill Sources (Hazardous Material) Historic Sites **TERRAIN/ENVIRONMENTAL** Digital Elevation Data Land Use - current and historic National Wetlands Database Soils Water Quality Threatened and Endangered Species (T&E) Digital Elevation Data (detailed) Drained Basins Agricultural and other Chemical Use Critical Aquatic & Wildlife Habitat Archeological Sites **MISCELLANEOUS** Census Data Emergency plans and Organizational charts	**HYDRO-METEOROLOGICAL DATA** High-water Marks – Flood Extent X-sections (bathymetry) Hydrometric and meteorologic sites/network Gauge locations Precipitation, snow, temperature, dew point, wind, solar radiation, etc. Stage and discharge data Elevation-Discharge Curves Discharge-Frequency curves Stage- Damage Curves Head loss – Structures/roads/levee breaches Head loss – Changes since flood Ice data **GEOGRAPHIC DATA** Political Boundaries (State, County, Province) Hydrologic Units River reach Lakes Transportation Network (roads and railway) Geodetic Control Floodway/Floodplain Alignment **IMAGERY DATA** Satellite imagery Aerial Photographs

Hydraulic models used to route forecasted flood volumes fall into two categories: real-time flood forecasting, and planning and design. Identified needs are: (a) real-time flood forecasting (determine flood levels and timing of peaks; determine hydrograph shape and inundation; account for overland flows; conduct backwater calculations at critical locations; incorporate infrastructure changes such as breaches and blow outs; carry out what if analyses); and (b) planning and design (post flood analyses for infrastructure evaluation and design; determine effects of flood operations; analyze structural and non-structural peak reduction proposals; conduct what-if and sensitivity analyses; define data and monitoring requirements; evaluate the aerial extent and volume of the flood).

Simple one-dimensional unsteady flow models mainly for predicting the river flow pattern have been implemented in the RAMFLOOD DSS together with more a sophisticated 2D finite element model developed by UPC to simulate the flow in the floodplain area.

Environmental models such as spill response models and habitat evaluation models will assist in evaluating the environmental consequences of flooding.

The RAMFLOOD DSS also includes the facilities to incorporate base economic models that will help decision-makers to compare the flood-related economic factors of alternative means for flood damage reduction. Their role will be in economic assessment of structural and non-structural flood damage reduction measures and investigation of potential incentives/disincentives facing individual activity in the floodplain.

An ***Artificial Neural Network*** (ANN) based decision model has been incorporated in the modelbase to assist the decision-makers in real time. Sustainable flood management is built on the assumption that an acceptable compromise must be achieved between the three main sets of objectives: ecological, economic and social. Each of these three sets constitutes a larger subset of specific objectives. The quantification and evaluation of the objectives and their associated trade-offs are the main tasks of multi-objective ANN tools [10]. One of the possible ways for dealing with the complexity of sustainable flood management is a modified multi-objective ANN framework. It requires definition of objectives for all stakeholders. Application of this formulation produces a set of nondominated solutions, as opposed to a single optimum followed by a subjective process to select one of the nondominated solutions, as a most robust solution.

The "most robust" solution is defined as "an alternative least sensitive to changes in the objectives and preference structure". It has been demonstrated that the idea of combining the sensitivity analysis of the multi-objective solution to objective values and preference (weight) structures results in the replacement of a 'best compromise' solution with the 'most robust' solution [4, 18].

Two types of ANNs based systems are considered here:

- First, ANN as a functional predictor, which is able to capture the main information regarding the numerical simulation of floods but requiring a lower computational effort and
- Second, ANN as a classifier of risky situations. Note that ANNs are recognised to be robust classifiers, with the ability to generalise in making decisions about imprecise input data.

The ANN will be educated for each specific application on the basis of the results form a number of flood simulation analysis using Montecarlo method. The education process is obviously problem dependent. Two alternative education processes will be carried out for the two validation test sites chosen in Spain and Greece.

Once the education process is completed the ANN will provide a real time decision support tool for management of flood emergency situations in the chosen locations.

Applications of the RAMFLOOD DSS to other flood scenarios will obviously require repeating the education process for the ANN. Guidelines to carry out this education are available.

User interface. The RAMFLOOD DSS architecture is based on a single link user interface. A multiple-level web-based interface has been developed to be the door through which the distributed database, the modelbase and the information sources will be accessed.

Different users will be granted appropriate access through simple user identification. In this way the RAMFLOOD DSS will provide for security of data sources and against inappropriate use of modelling tools. The user interface will guide users of the RAMFLOOD DSS in a language that is sensitive to a user's level of technical and social understanding.

As a background of the user interface an additional RAMFLOOD module will be introduced in order to control the decision processes and the user interaction with the DSS. This component of the system allows different decision options to be considered and assists the collaborative flood management decision-making process.

6 Example

Figures 5-9 show some examples of some of the features of the RAMFLOOD DSS for risk assessment and managing of emergency scenarios in floods. The user interface includes a module for computer simulation of different flood scenarios, a tool for managing simulation results, communication tools, a complete database with available information of the study area, administration tools of the Ramflood system, etc.

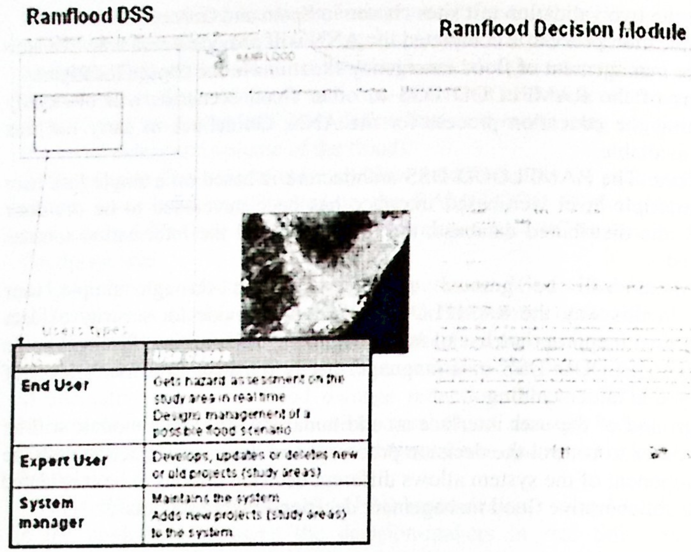

Fig. 5. Main screen of the RAMFLOOD system. Definition of users and the use cases of the Ramflood DSS. Access brief information about the area of study, Ramflood DSS, database, communication tools, etc.

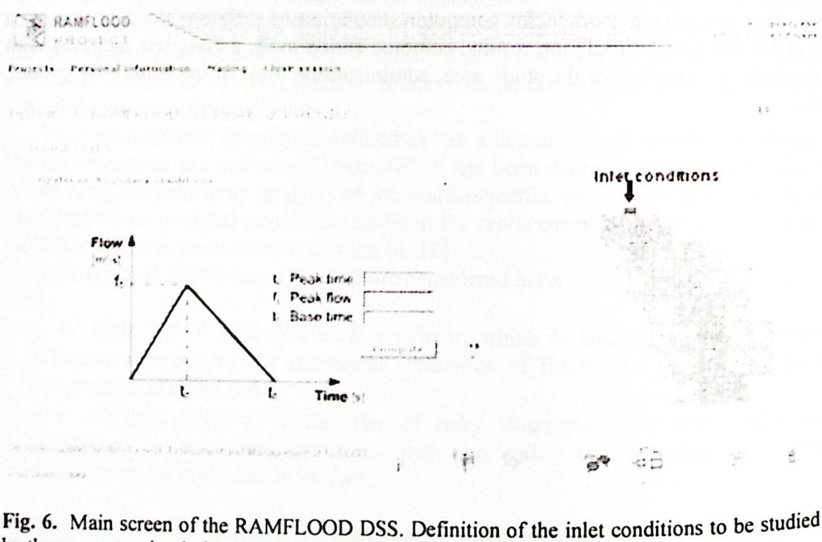

Fig. 6. Main screen of the RAMFLOOD DSS. Definition of the inlet conditions to be studied by the computer simulation module using artificial neural networks.

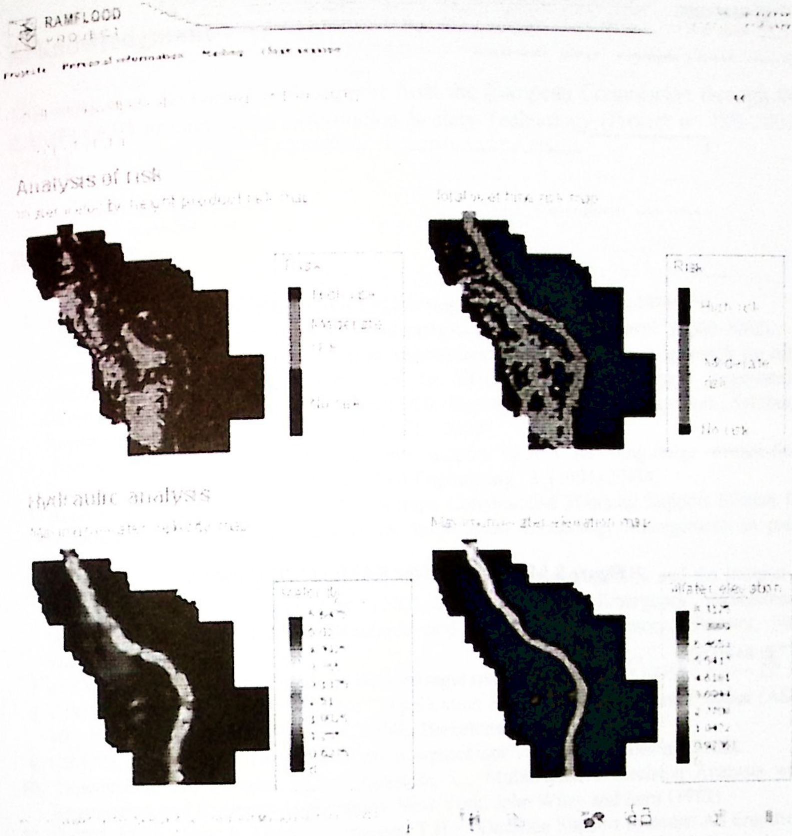

Fig. 7. Output data of the Ramflood DSS from the computer simulation module: Analysis of risk and Hydraulic analysis

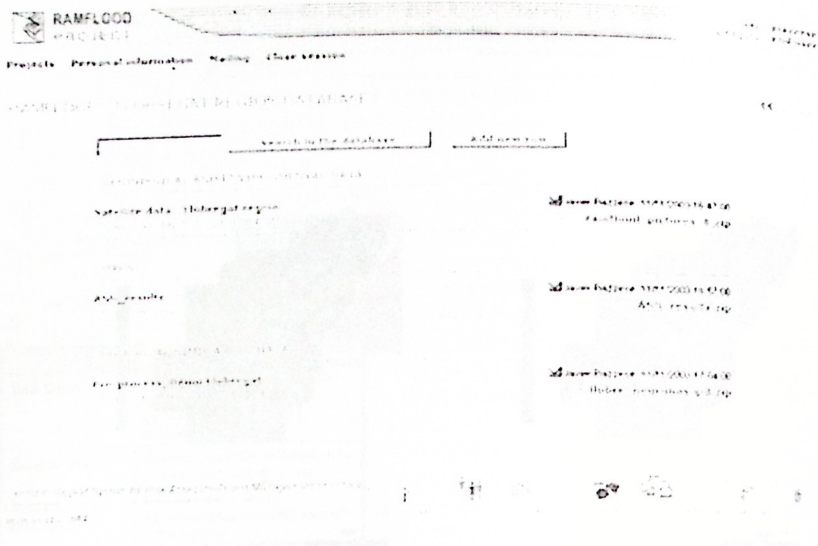

Figure 8. Main screen of the RAMFLOOD Database

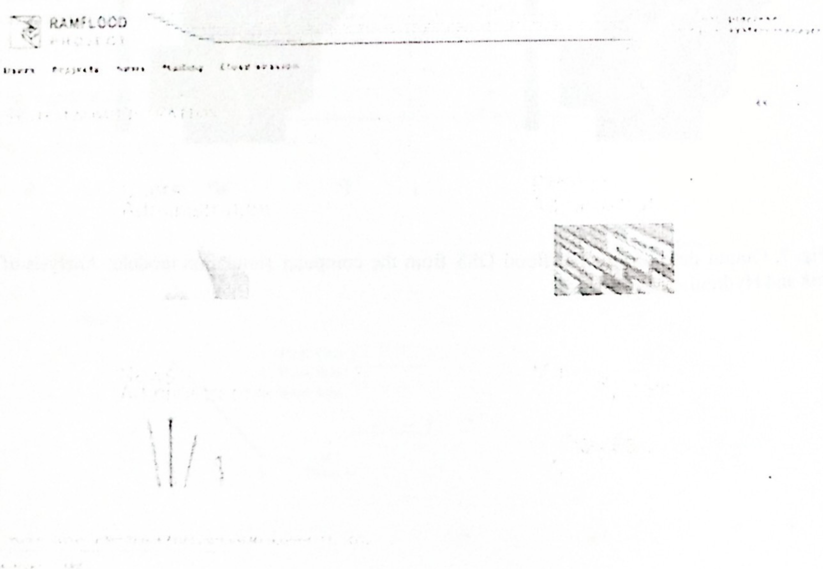

Fig. 9. Main screen of the RAMFLOOD System Administration

Acknowledgment

This work was developed with support from the European Commission through the RAMFLOOD project of the Information Society Technology (Project n° IST-2001-37581).

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