ANFAS: A Decision Support System for Simulating River Floods

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SUMMARY

This paper discusses the ANFAS system, developed under a joint research effort between the EU and the PR of China. ANFAS is a decision support system that can be used by decision makers and stakeholders to simulate river floods and perform "what-if" scenarios. It is a web based distributed system that integrates the GIS databases, the mathematical models and the impact assessment methodologies. Both 1-D and 2-D models are included in the system and the interface between models and databases is done in a transparent way. The system includes extensive facilities that permit users to visualize the results on the web and/on their own personal computers. The system is presently applied in three pilot sites; the Vah River in Slovakia, the Loire River in France and the Yangtze River in China.

KEYWORDS: *decision support systems, river flood modelling, integrated system*

INTRODUCTION

Rivers floods have caused extensive damages in the world over the past years resulting in human losses and extensive economic damages. Governments have established several measures for diminishing the impacts of river floods such as construction of embankments on the side of the river, adoption of land use policies to diminish the severity of the impacts. Most of these flood prevention measures are capital intensive, hence careful planning is needed before implementing them. In order to be able to assess the impacts of the various alternatives tools are needed that would permit permit decision makers to test policies before adopting them.

Similarly to other decision support problems that deal with the environment the appropriate way for doing this is through the use of systems theory. That is an approach that accounts for the feedback among the various components of the ecosystem studied and which attempts to express mathematically the interrelationships that exist. In the literature of spatial analysis the concept of spatial decision support systems (SDSS) has emerged as the leading paradigm for addressing complex decision problems, whether these have to do with business decisions (location allocation problems) or complex environmental problems (Densham and Goodchild, 1989; Crossland et. al.. 1995; Malczewski, 1998). SDSS are defined "as computer based systems designed to support a user or group of users in achieving higher effectiveness of decision making with solving spatial decision problems" (Malczewski, 1998).

Several attempts have been made to develop mathematical models for flood simulation (Samuels, 1999); however, there is still a need for an integrated approach that brings together models, data and methodologies in a way that permits decision makers to use the available tools. Flood simulation models are numerical models often developed years ago that require excessive data manipulation to prepare inputs and visualize outputs. Data quality and availability and computational requirements are also important considerations when running such models.

To address these problems the European Union and the People's Republic of China undertakook the ANFAS (datA fusioN for Flood Analysis and decision Support) project in order to develop a Decision Support System for flood prevention and protection, integrating the most advanced techniques in data processing and management. The project started in 2000 and was completed in 2003. The research team included eight European and five Chinese teams (Table 1). The Information Society Technologies (IST) programme financed the work of European partners, while Chinese researchers were funded from the Ministry of Science and Technology (MOST) of China. Due to the importance of flood disasters it was felt that there is a need for a multidisciplinary approach that could be of benefit to both areas Europe and China.

In this paper we provide a brief overview of the ANFAS system its underlying assumptions, architecture and components. A complete presentation of the system and the project can be found in Prastacos et. al. (2003).

Europe	
ERCIM, F	Administrative management
FORTH, GR	Scientific coordination, GIS
U. Reading, UK	Computer vision/Remote Sensing
INRIA, FR	Numerical models
BRGM, FR	End user's requirements, Impact ass.
EADS, FR	System integration
Inst. of Informatics, Slovak Academy of Sciences, SK	Numerical models, HPCN
CLRC, UK	Impact assessment
China	
Inst. of Automation (IOA), Chinese Academy of Sciences (CAC)	Scientific coordination, Computer vision/Remote Sensing
Inst. of Remote Sensing Applications (IRSA), CAC	GIS, System Integration
Inst. of Atmospheric Physics (IAP), CAC	Numerical models
Wuhan University	Numerical models
Yangtze Water Research Institute	End user's requirements, Impact ass.

Table 1: The ANFAS Research team

ANFAS FRAMEWORK

The overall objective of ANFAS was to provide decision makers with a tool for assessing the potential impact of river floods. A tool that would permit them to easily estimate flood extents for various scenarios and estimate socio-economic impacts in the surrounding area. The intended users of the system were defined to be the technical staff, managers, stakeholders and decision-makers, who have enough background in floodplain management and could interactively use the system and interpret its output.

The main features of ANFAS are as follows:

- ***Generic in terms of flood models and data resolution;*** ANFAS was designed as a generic system that is a system that can be used for flood simulation in a variety of rivers and situations. Hence:
    - It integrates both 1-D and 2-D numerical models for flood simulation,
    - Is not constrained by data availability and resolution, and can be therefore implemented in data poor or data rich environments,
    - Its functionality was defined in close cooperation with end users,
    - Was tested in three pilot areas to assess overall functionality

- ***Tool for simulating river floods under various hydrological conditions;*** ANFAS can be used for medium term simulations and "what-if" scenarios. It is not an early warning system with real time predictions.
- ***Facilities for defining scenarios;*** In addition to flood simulations under different hydrological conditions decision makers must determine what are the most appropriate structural or non-structural measures to take in order to prevent floods and mitigate their impact. ANFAS includes facilities that permit users to define scenarios that consist of modifications in the hydraulic structures and perform "what-if" simulations.
- ***Integrated but modular structure;*** The complete system consists of different modules that are transparently integrated. Users have the capability to replace some modules (numerical models, impact methodologies, GIS system used in their PC) with their own and/or use other datasets. A key issue is the integration of the models and the databases that is performed without user intervention through appropriate software components.
- ***Web based distributed architecture;*** The system is completely web based**.** There are two main reasons that necessitated the adoption of a distributed architecture. First with the storage of all datasets on a server data updates are immediately available to all end-users. Second, since the numerical models often require excessive computational time the models can run on a separate fast computer dedicated to this task.
- ***Extensive visualization capabilities;*** To facilitate the use of the model results by non experts, all results are translated into maps and diagrams. Additionally, users have the capability to easily identify issues that are of particular concern to them such as how long an area will be flooded, how long it will take for the flood to reach a particular area etc.

The ANFAS system consists of four different modules. These include:

- Remote sensing/Computer vision; ***This is the component that prepares from a variety of sensors the topographic databases needed (Digital Terrain Model –DTM--, river morphology, land uses etc.). In the implementation of this component in the three pilot sites LIDAR, SPOT, SAR, sensors were used resulting in data that are of different resolution.***
- Geographic Information System**;** ***The GIS is a key component of the whole system since it stores all datasets (both alphanumeric and spatial) and also through various scripts prepares in a transparent way the input files for the models, stores the results of the models in the various databases and is also used for visualization. Visualization is carried out either on the server or on the user's PC.***
- Numerical models; ***This is the component that includes the numerical models for flood simulation. Two existing commercial models CARIMA (1/1.5-D) and FESWMS (2-D) are integrated in the system. Integration with the databases and visualization is done in a transparent way.***
- Impact methodologies; ***In this module the results of the models are used to evaluate the impact of the flood on the surrounding area. The results are presented in terms of maps and tables.***

The ANFAS integrated system with which users interact includes the GIS databases, the models and the impact methodologies coupled with the appropriate user interfaces (figure 1). Preparation of the various GIS layers is performed outside of the integrated system through remote sensing analysis, digitisation or data base manipulations. Once the various datasets have been prepared they are stored as standard shapefiles in the system data repository and from then on are used as the need arises.

Key components of the integration are the "Model encoding" and "Model decoding" components. The former prepares the necessary model input files when users perform a simulation, while the latter translates model results into GIS coverages and stores them in the databases for further processing and visualization. The use of these two components is necessary to accomplish transparent use of the models.

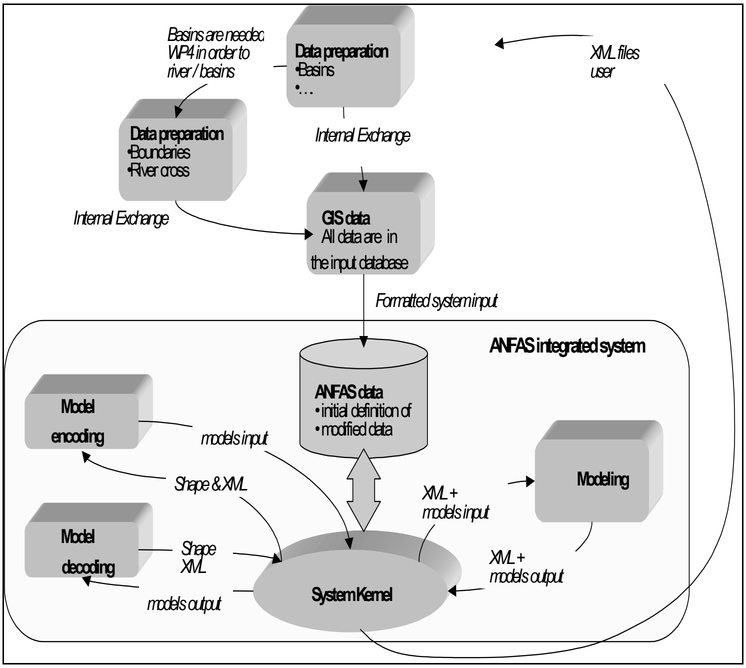

Figure 1: ANFAS data flow overview.

ANFAS ARCHITECTURE

ANFAS is a web based distributed system. Users with appropriate privileges can access the system through the web browser and perform simulations. Results are displayed in terms of maps and tables. The various components can be implemented on different computers or even different locations. Java technology is used throughout the system to ensure platform independence. Figure 2 provides a schematic description of the architecture, while a complete description of the architecture is provided in Houdry et. al. (2001)

Although the web-based interface to ANFAS offers several advantages, it can limit users that are interested in analysing model results on their own. Users might be interested to view the results with their favourite GIS desktop software, perform a statistical analysis, compare the results of various scenarios, tabulate them in a different way or even include them in reports. It would be impractical to develop appropriate interfaces on the system that will permit ANFAS to handle all potential data uses.

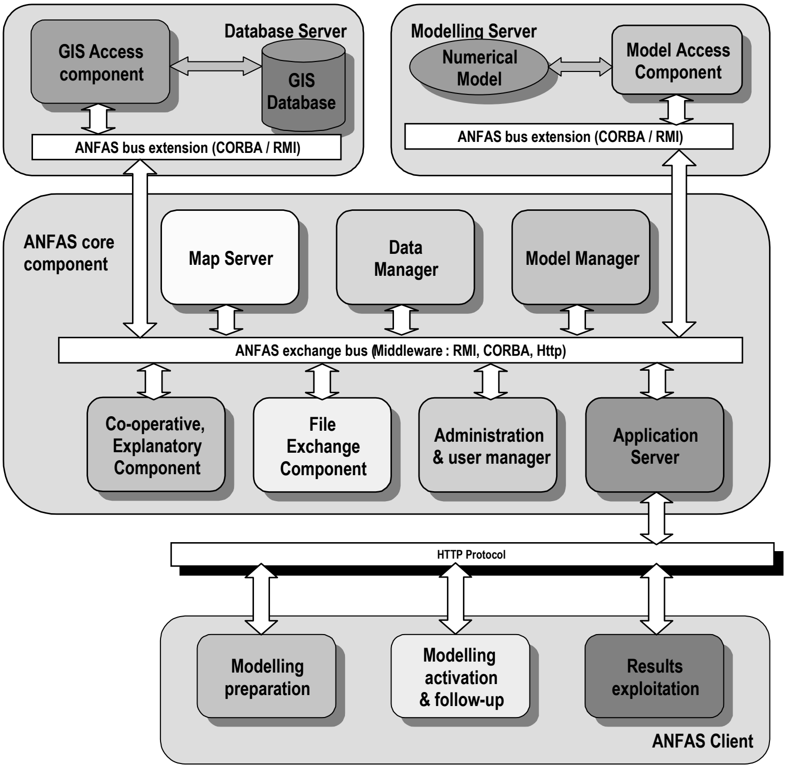

Figure 2: Architecture of the ANFAS System.

Another limitation of the web system is related to the available bandwidth, which is a crucial problem when performing 3-D visualization. 3-D visualization permits users to see the flood evolution in a realistic way but requires specialized software that cannot be easily integrated in a transparent way and also generates files of large size that can strain Internet connections.

To provide freedom of choice the following procedure was adopted. Users can select to download the results in the standard shapefile format. A metadata file describing the data can be downloaded as well. The downloadable file can be viewed without any further processing by all commercial GIS packages. To further facilitate the user in analysing the results outside the ANFAS system a library of software components was developed. These are not generic and must be used with the desktop software for which they were developed. End users can download these components and import them in the software they are using. Presently such components have been developed for ESRI's ArcView v. 3.2™ using the Avenue script language. They permit users to perform thematic mapping, produce graphs displaying water depth at any point in the floodplain, display flood propagation in 3-D visualization etc.

MATHEMATICAL MODELS

Simulation of flood propagation is carried out through numerical models. The models consist of a set of non-linear partial differential equations which to be solved numerically are discretized in space and time. Development of a flood model is an expensive task and presently there are few efforts to develop new models and the focus of the research community is to improve existing ones.

The most significant difference among the various models is on how they treat the dimension of the river and the floodplain. The approximation of the area can be in one dimension (1-D/1.5-D models), or in two or three dimension (2-D and 3-D models). Although the latter result in more accurate description of the flow they have excessive data requirements and heavy computational loads. In the 1-D models water flow in the river is assumed to be unidimensional and is represented by Saint Venant Equations. The floodplain is represented by a set of interconnected basins (cells-polygons) and water flow is governed by simple flow equations.

In 2-D models, a finite element mesh is used to represent the river and the floodplain. Through the use of hydrodynamic equations water surface elevation and flow velocities are computed at each of the nodes of the mesh. 2-D models require detailed representation of the area topography and require excessive computer power even for modelling floods in relatively small areas.

In ANFAS since the objective was to develop a generic system both 1-D and 2-D models have been integrated. These include for 1-D the **CARIMA** model commercially available from SOGREAH, Grenoble, France, and for 2-D the **FESWMS** (Finite Element Surface Water Modeling System: 2-Dimensional Flow in a Horizontal Plane) available from FHWA (U.S. Federal Highway Administration) and the **DaveF** model.

On the Loire pilot site both models have been implemented, while for the Vah pilot site only the 2-D models were applied since the end user felt that accurate results could not be obtained from a 1-D model. In the Chinese pilot site because of the large size of the area the 1-D model was used to model the flow in most of the area, whereas for a small portion of the area the 2-D model was applied. It must be pointed that the models used in China (1D model Susbed-NEW and 2-D model CSMS) are variants of the models used in the European pilot sites and also account for sedimentation an important issue for a large river such as the Yangtze.

THE GEOGRAPHIC INFORMATION SYSTEM – RESULTS VISUALIZATION

The GIS plays a very significant role in the overall system since it manages the databases, handles the two-way data flow between databases and models and provides the needed visualization once a run has been completed. On the European version of the system a Map Server was developed to handle web visualization of the geographic data, whereas the Chinese version is based on the Geobeans web-GIS software developed at IRSA.

All geographic files in the system are stored as shapefiles. Internally the map server that displays the results on the web is using its own optimised format. The data flow between models and databases is handled through the "model encoding" and "model decoding" components. The "model encoding" reads the geographic and attribute databases and prepares the file needed for running the numerical model. The format of that file is relatively rigid, defined by the model developer and its creation requires extensive data manipulation of the various layers. All of the input data files, with the exception of the mesh, are prepared automatically without any interference from the end user. The mesh, needed to run the 2-D model, is prepared outside of the system through specialized software, the mesher.

The results of the models, water depth, time and velocity (for the 2-D model only) are stored in large ASCII files that cannot be easily used by database or GIS software. The "model decoding" component translates these files into a standard structure (dbf format) that can be handled by any GIS software. For the 1-D model the structure is straightforward since each record of the database corresponds to a polygon that represents the basin. For the 2-D model the results are provided for each node of the mesh. To display these on the web average water depth is estimated for each element of the mesh.

One of the most important requirements that end users specified was to be able to easily visualize model outputs and most importantly visualize the results in terms that could be of use to them. Hence visualization of model results was a key concern in the system development. Two types of visualization capabilities are provided in ANFAS. The first one is embedded in the system and permits end users to display maps on the web that show the flood extent and the “alert time”, that the time it will take for the flood wave to reach any particular area. The second type is handled outside of the system using the downloadable components discussed earlier in this paper.

The downloadable component (*FloodView*) presently developed works with the ArcView GIS software. It provides users with a variety of visualization options including:

- Point and click on any water link, basin, cross section or hydraulic structure to see its characteristics,
- Display the duration of the flood for any area in the floodplain,
- Produce a variety of thematic maps for the water depth as a function of time,
- Display animations that show how the flood wave propagates,
- Display flood hydrographs (water depth as a function of time) for each cross section and area in the flood plain,
- Display a graph with the evolution of the longitudinal water line in the river as a function of time and others.

With the results of the 2-D models users can perform 3-D visualizations. The 3-D visualization (figure 3) is carried out using the 3-D Analyst extension of ArcView. Appropriate scripts have been developed that permit users to display the flood wave propagation in 3-D and also to produce fly-through. On the Chinese version of the system a Geobeans component is used to handle the 3-D visualization.

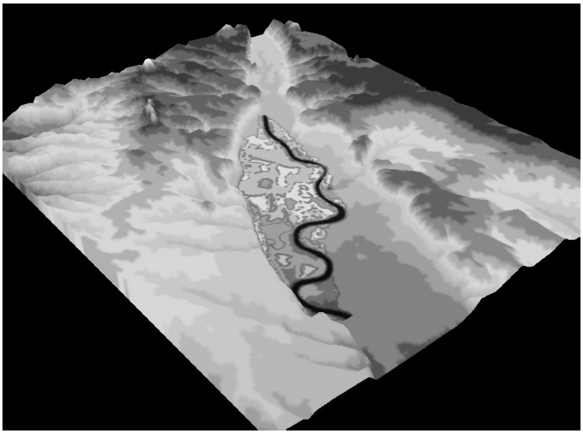

Figure 3: Examples of 3-D visualization.

PILOT SITES, DATA PREPARATION AND SCENARIOS SPECIFICATION

To test the generic aspect and the functionality of the complete system ANFAS was implemented in three pilot sites. An extensive effort was undertaken to assemble datasets for each of the pilot sites through satellite interpretation and aerophotography and organize them under ArcView (Prastacos et. al, 2001). For the European sites Digital Terrain Models with vertical resolution of about 20 cm were developed and used for the 2-D numerical model calibration. The set of datasets to implement a system such as ANFAS include:

- Terrain topography (DTM, soils, roughness, etc.)
- Hydraulic information on the river (cross sections, basins, dykes etc.)
- Infrastructure (roads, railways, bridges)

- Socio-economic information (needed for impact assessment)

On each pilot site a scenario to be tested was specified. A scenario can include assumptions about the hydrologic conditions (maximum discharge), and/or assumptions about changes in the hydraulic structures (dykes, spillways etc.) or the terrain (new road, bridge etc.). The hydrologic conditions represent "natural" events and are translated into boundary conditions for the hydraulic model; an imposed water discharge at the upstream point of the model and an imposed water level at the downstream point. A complete discussion on the various scenarios that were implemented can be found in Courtois et. al. (2002)

Loire pilot site, France

In Loire the ANFAS system was tested and validated in the "Val d'Ouzouer" area located in the Middle Loire valley. Length of the river is about 30 km and total area is 132 km². Since floods have been an ongoing concern several flood protection measures have been adopted in the past. A 1-D model (HYDRA) was developed in 1998 at a cost of 0.8 Million Euros and as a result of this modeling effort an extensive set of data was available to the ANFAS project.

These data were used for implementing the CARIMA model, but could not be of use for implementing the 2-D model. The DTM was very coarse and therefore a precise DTM, with vertical resolution of 20 cm, was obtained through aerophotography carried out in July/August 2001. Land uses, soil classification (used to estimate roughness), and location of several hydraulic structures were obtained from the interpretation of optical (SPOT) and radar (Radarsat and ERS) satellite images.

Vah pilot site, Slovakia

The part of the Vah river between the Hricov and Nosice dams is the pilot site in Slovakia. This represents a stretch of 37 km of river with a floodplain of 0.5 to 1 km width. Total area is 75 km2. No efforts have been made in the past for developing a flood model for the area.

Water Research Institute and Vah River Authority carried out an extensive data compilation to assemble the needed datasets for implementing the FESWMS and DaveF models. A very accurate DTM was prepared through a LIDAR (Light Detection And Ranging) survey. The grid size used was 1 x 1 m with an average vertical error of less than 15 cm.

Jing Jiang pilot site, China

The pilot site in China was the Jing Jiang Reach in the Yangtze River (figure 4). This is an area threatened by frequent huge floods. In the past 150 years, all of the huge floods in the Yangtze River affected the Jing Jiang reach, which is 340 km long. The Jing Jiang Reach and Dongting Lake in the south constitute a giant net river system with very complex hydraulic properties. The floodplain in the north is one of the most significant industrial and agricultural centers in China with a population of more than 10 million people. Extensive dykes have been constructed in the area and are the most important along the whole Yangtze River.

The Jing Jiang retention area is a particular feature for flood management. In 1952, an area of about 930 km^2 was completely enclosed by dykes in order to be used as potential water retention area (total volume is estimated to be 5.4 billions m^3) in case of huge flood events to cut off part of the flow discharge.

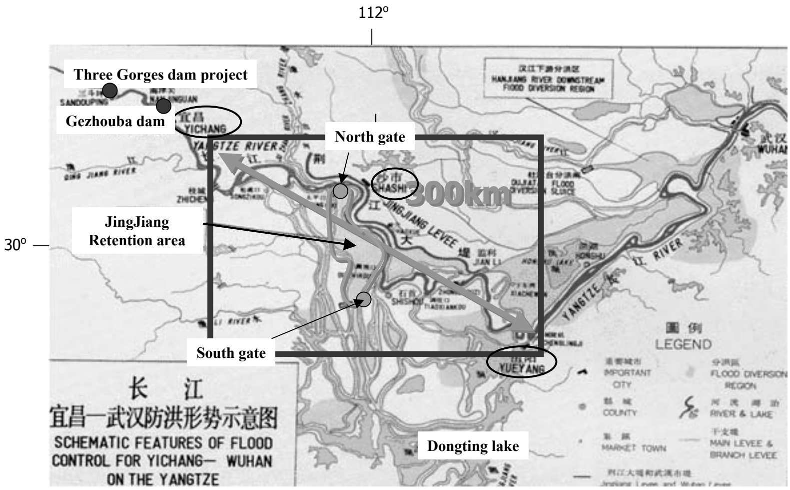

Figure 4: The Yangtze River pilot site.

The entry of water in the retention area is controlled by the 1.1 km long North gate (maximum discharge of 7,700 m^3/s), as the outflow to the Dongting lake network is controlled by the South gate (maximum discharge 3,600 m^3/s). The decision to open or not the North gate relies on various factors, based on the water level recorded at strategic points on Jing Jiang reach. When the decision of flooding the Jing Jiang retention area is taken, the population is evacuated, and a breach is made in the Yangtze dyke with dynamite, to permit the water to reach the North gate. The North gate has functioned three times during the 1954 flood event, and the 40,000 persons living at this time inside the retention area had to be evacuated.

The application of ANFAS in the area concentrated in the Jing Jiang retention area. Because of the complex relationships between the Yangtze, its tributaries and the Dongting lake using flood return periods from upstream is not possible. Since in China past floods are considered critical hydrological events the system simulated the big floods that occurred in 1954, 1981, 1996 and 1998. To demonstrate the effects after opening of the flood retention area to the water level in the main channel of the Yangtze River, different opening (inflow discharge to the retention area from 2,000 m^3/s to full open) were assumed. Since after completion of the Three Gorges dam, it will play the most important role in cutting flood peak from the upstream of the Jingjiang reach, in the scenario of 1998, simulation was also made to compare the difference with and without the Three Gorges dam in place.

CONCLUSIONS

The ANFAS integrated system represents an effort to develop a decision support system for river flood simulations. Of course, flood simulation is not a new subject; the major innovation that the system brings forward is that it permits end users to perform flood simulations and test "what-if" scenarios without being mathematics or informatics experts. The intricacies of the mathematical models and the necessary data processing are hidden from the users and extensive visualization facilities are provided so that end users can immediately see the results in maps and 3-D animations.

The methodologies used to develop the system conform to the latest techniques of data processing and informatics. It has been designed so that it can be used in a web environment (internet or intranet), the distributed architecture adopted permits to separate the models from the databases, the connection between models, databases, impact methodologies is done in a transparent way and the modular architecture permits users to replace some components (models for example) or extend it with new functionalities (more visualization capabilities, connect it to an early warning system etc.). It must be stressed that the forecasting capabilities of ANFAS are as good as that of the mathematical models included. The effort in ANFAS was to adopt two well-known models and develop the necessary infrastructure around these two. Flood simulation is a complex phenomenon and it is expected that with the availability of more data improved models will be developed in the future. These could replace the models already included in the system.

Finally, ANFAS represents a system developed jointly by a large research team that included a group of scientists from different fields and different countries and continents. It represents a large effort to address the problem of river floods in a multidisciplinary way using experiences from both the European countries and China, the nation where the problem of river floods is the most intense. The results achieved from this collaborative effort prove that environmental problems should be addressed in a multidisciplinary way.

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