ANFAS: a Decision Support System for Flood Risk Assessment

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Abstract. ANFAS is a decision support system developed as part of a joint IST project between the EU and the People's Republic of China. The system can be used by decision makers and stakeholders to simulate river floods and estimate the potential impacts. Some of the key characteristics of the integrated system are that it is web-based with a distributed architecture. In order to compare flood scenarios and assess the impacts, it integrates in a transparent way for the user different modules: GIS data bases, hydraulic models, and impact assessment procedures. Data of various nature (topographic, hydrologic and socio-economic) and different acquisition techniques (ground survey, airborne and satellite remote sensing) are fused and integrated in specific data bases to be used in the different modules: set up and calibration of the hydraulic models and evaluation of the elements at risk. Extensive visualization capabilities have been implemented and end users can visualize the results in terms of graphs or maps on the web or download them on their PC using specially designed software. The system was tested in three pilot sites: the Loire river in France, the Vah river in Slovakia and the Yangtze river in China.[1].

1 Introduction

Rivers floods have caused extensive damages in the world over the past years resulting in human losses and extensive economic damages. In 1997 extensive rainfall and flooding of the Oder and Danube river killed 100 people, while in the summer of 1998 floods in China affected almost a quarter of the population with economic damages estimated to be billions of USD. More recently, in the summer of 2002 central Europe was hit by flooding that has not been seen for centuries. In Asia floods

[1] Earlier versions of this paper can be found in [1] and [2].

are a common phenomenon not only in China but also in Bangladesh and India, whereas in the USA the Mississippi river floods every other year. In Latin America, torrential rains in the Parana and Paraguay rivers in 1993 caused extreme flooding in Argentina, Brazil and Paraguay.

Through the years, governments have established several measures for diminishing the impacts of river floods. Some of these include the construction of embankments on the side of the river, the adoption of land use policies or even as in the Yangtze River in China setting flood retention areas in order to mitigate damages downstream. Most flood prevention measures are capital intensive and/or may have political and economic consequences therefore there is a need for tools that would permit decision makers to test their policies before adopting them. Since floods generation, propagation and resulting damages are affected by several factors (rainfall, terrain configuration, established protection measures, economic activity etc.) these tools must consider all cause and effect relationships and evaluate in a systematic way the various alternatives.

Similarly to other environmental decision support problems the appropriate way for doing this is through the use of systems theory. This 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 [3, 4, 5, 6]. 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" [6].

Although several attempts have been made to develop mathematical models for flood simulation [7] there is 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. The numerical models used for flood simulation require excessive data processing for model setup (preparing input files) and model output visualization. Data quality, availability as well as computational power requirements are also important considerations to be taken into account. Moreover, extensive analysis of the simulation results involves additional data sets and dedicated tools.

2 ANFAS Framework, Objectives and Features

2.1 Project Framework

In order to address these problems the European Union and the People's Republic of China undertook a large research project involving a multidisciplinary consortium (Table 1). The Information Society Technologies program (IST-1999-11676) financed the work of European partners, while Chinese researchers were funded from the Ministry of Science and Technology (MOST) of China. The overall objective of the ANFAS project (datA fusioN for Flood Analysis and decision Support, 2000-2003, http://www.ercim.org/anfas/) was the development of a prototype of Decision Support System (DSS) for flood prevention and protection, integrating the most advanced techniques in data processing and management.

Table 1. ANFAS consortium

Europe	
ERCIM, FR	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
Slovak Academy of Sciences, SK	Numerical models, HPCN
CCLRC, 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.

As part of the project a prototype DSS was developed which was then implemented in three pilot sites with very different scales, contexts and stakes: (1) the Middle Loire river in France, (2) the Vah river in Slovakia, and (3) a portion of the Yangtze river in China. Two different versions of the DSS were developed, one by the European partners and another by the Chinese team. The structure of the two systems is conceptually similar, nonetheless different informatics tools and numerical models were used by the two groups. In this paper we provide a discussion of the DSS developed in Europe and its application in the two European pilot sites.

2.2 Overall Objectives and Features

The vision that guided the development of ANFAS was to provide decision makers with a tool that can be used to assess the potential impact of river floods. A tool which they could use easily in order to estimate the flood extent and the associated socio-economic impacts for different scenarios. The intended users of the system were defined to be not the highly skilled hydraulic experts or modelers, but rather the technical staff, managers, stakeholders and decision-makers, who have enough background in floodplain management and could interactively use the system and interpret its outputs.

In fact, the ANFAS system is dedicated to the technical services of the decision makers for the preventive planning of floods. It places at their disposal, through an Internet interface, a tool for building, simulating, and comparing flood scenarios. This tool is supported on the one hand by hydraulic modeling and on the other hand by their knowledge of the elements at risk.

Comparison of scenarios is one of the major tools that can help the decision of stakeholders. As shown in Figure 1 decision makers are concerned with identifying the "hazard" events, determine their impact on the "elements at risk" and then adopt mitigation measures. Hazard events arise either because of natural events such as increased rainfall (hydrologic conditions) and/or by hydraulic and terrain configurations which are taken into account in hydraulic modeling. Associated with the elements at risk are vulnerability estimates and monetary (or nonmonetary) damage curves that will permit the estimation of total damage cost.

End users can use a tool that brings together these two components for medium term simulations and "what-if" scenarios of river flood analysis. Simulating the effects of structural or non-structural measures (increasing the height of a dyke, provoke a voluntary flood in a given valley by opening a gate to safe a downstream strategic area,...) should assist decision makers to determine which ones are the most appropriate to implement 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/terrain structures and perform "what-if" simulations.

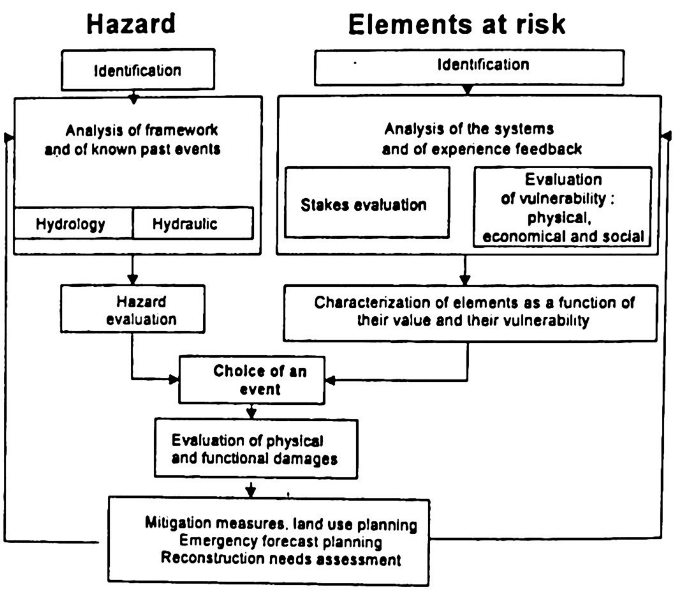

Fig. 1. Scenario definition

To reach this objective, the ANFAS system was structured and developed with the following features:

- Integrated system; the complete system consists of different modules that are transparently integrated. The flood models, the databases and the post processing tools are separate modules, but are integrated so that data flow is transparent to end users. Users have the capability to replace some components (flood models, impact assessment methodologies) with their own as long as the input and output formats are respected.
- Web based interface; The complete system has been developed following a distributed architecture and end-users can access the system through their web-browser. The models, which often require excessive computation time can reside on a distant server and can be also submitted for solution to a remote cluster.
- Extensive visualization capabilities; All flood model results are translated to maps, diagrams and tables and extensive post processing tools are provided in a GIS environment for further analysis.
- Generic; The system has been designed in a generic way and can be used for flood simulation in a variety of rivers and situations. It integrates both 1-D and 2-D flood models, it can be implemented in data rich and data poor environments and impact estimation methodologies can be adapted to the particular characteristics of the application area.

3 Components of the ANFAS System

The tool developed in the ANFAS project consists of an information system and several methodologies that were tested during the course of the project. The different components were integrated in the information system as separate modules. The key components are identified below.

3.1 Data Fusion and Preparation

A key issue identified by flood risk managers was the capability to develop easily the various datasets needed for implementing flood models and performing impact assessment. Implementing a flood model requires an extensive and expensive data collection effort. However, the most recent sensors provide more and more image datasets (satellite images, aerial images...) relevant for environmental issues. The processing of this huge amount of data requires image-processing methods to save time for human operator and also to provide precise accurate quantitative measurements. In the context of floods most of the very recent image processing techniques are not used in operational context.

Hence, one of the objectives was to explore different techniques for deriving from sensors various information and parameters needed for hydraulic modeling and impact assessment. Then, this information was integrated inside the GIS system as separate layers and used in the integrated system.

The type of datasets needed for hydraulic modeling and impact assessment include mainly the topography of the area and land use. Given the diversity of pilot sites features and data environments, data was processed from various airborne or satellite sensors. In fact, ground based survey, LIDAR (Light Detection And Ranging), stereo-optical images and interferometry processing were used to assign the required ground elevation data and terrain features (semi-automatic detection) for hydraulic modeling. Concerning the land use and land cover mapping necessary for roughness estimation and set up or updating of the elements at risk databases, radar (RADARSAT and ERS) and optical (SPOT) images were used singly or in combination.

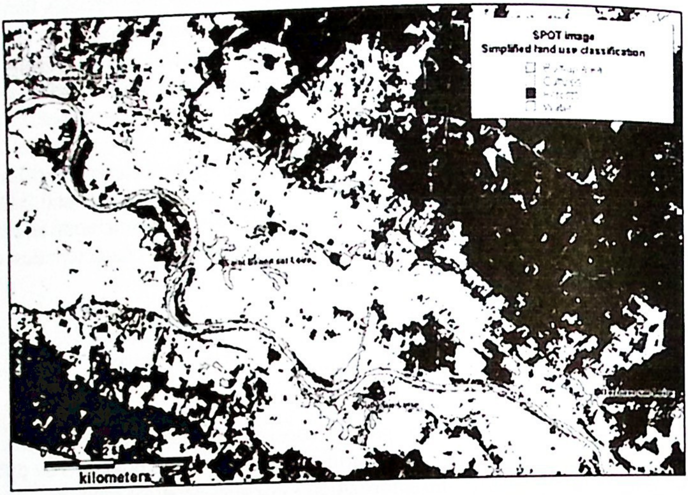

Fig. 2. Land use classification from SPOT image on the Loire pilot site

3.2 Hydraulic Modeling, HPCN and Data Assimilation

The centerpiece of any decision support system is the mathematical model used for flood simulation. A flood model is necessary to estimate the height and eventually the velocity of the water in the river channel and the floodplain as a function of time. Then, the results obtained can be used to assess the impacts for the simulated scenario.

However, there is no optimal model for all potential applications. Model choice is affected by the purpose of the study, the valley configuration, the range of simulated flows, the available data and the computational power accessible. In ANFAS, since the objective was to develop a generic system, both 1-D and 2-D models were adapted and integrated. Integration in the ANFAS system of different modeling approaches should contribute to the extension of its range of applications. In fact, 1D (or quasi-2D) models like CARIMA [8] require less set up data, have relatively low computational cost and therefore can be used on very long river reaches (hundreds of kilometers). On the contrary, 2D models like FESWMS [9] or DaveF [10] require a detailed representation of the area and excessive computer power. However, the key components of the flow field will be naturally reproduced by the two-dimensional model providing a much more detailed description of the flood.

To address the computational cost issue underlying the use of 2D models, High Performance Computing Network (HPCN) algorithms were implemented and fully integrated in the ANFAS system [11, 12, 13]. Therefore, users can submit simulation from inside the system to remote computational platforms. During the project, HPCN version of FESWMS and DaveF were used on PC clusters from II-SAS and INRIA for model calibration and system demonstration.

In addition, flood models represent only the mathematical information for the study of floods. They are necessary, but not sufficient for predicting the evolution of a flood. In fact, they only provide a conceptualization of reality and require extensive calibration to fit the available observation data. Hence, the issue of data assimilation was investigated in a prospective study [13, 14] using optimal control techniques operational in Meteorology. Although, this particular component was not fully integrated in the system the work performed opens new trends for the future use of variational data assimilation and adjoint sensitivity analysis in hydrology and river hydraulics.

3.3 Geographic Information System (GIS)

The GIS plays a very significant role in the system since it manages the databases, handles the two-way data flow between databases and models and provides the needed visualization once a model run has been completed. All geographic files in the system are of shapefile format. This is a well-known format originally defined by ESRI, Inc. that all commercial GIS packages can read. Internally the map server that displays the results on the web is using its own optimized format.

All data in ANFAS are stored in GIS databases/coverages. There are two sets of databases: the first includes the topography of the area and the land use characteristics (location of population, elements at risk etc.), whereas, the second includes the results of the model runs (water depth, velocity). All model results are converted into GIS databases so that users can easily visualize them. As discussed in the next section, keeping all datasets in a GIS format permits a smooth data flow between the mathematical model and visualization components of the system and also permits the immediate estimation of the impacts once a model run has been completed.

Since a key concern of the end users was to be able to easily visualize model outputs and most importantly visualize the results in terms that could be of use to them a significant amount of effort was dedicated to develop such facilities. Two types of visualization capabilities are provided in ANFAS. The first one is embedded in the web system and permits end users to display maps on the web that show the flood extent and the "alert time", that is the time it will take for the flood wave to reach any particular area. The second type is handled outside of the system using a software that was developed for that purpose using the ArcView software. The latter provides users with a variety of visualization options (Figure 3) 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.

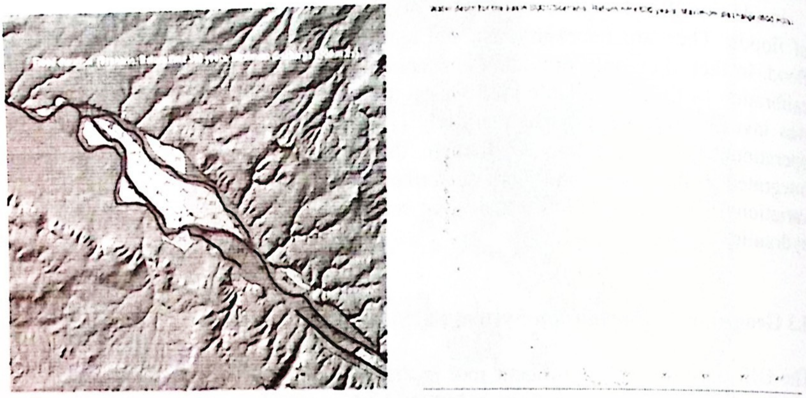

Fig. 3. Visualization of model results

3.4 Impact Assessment

A key problem in flood-risk management is the methodology to assess the damages resulting from different decisions. Decisions are taken on the basis of the impacts, monetary or non-monetary, which must be estimated with an accepted methodology. The topic of impacts assessment is often neglected in flood modeling and the emphasis is placed on the actual modeling. Although models can estimate the height of the water in the floodplain and the extent of the flood these are not the figures on which stakeholders will base their decisions. The decisions are based on the valuation of the modeling results in terms of their impacts on human life, buildings, industry, roads etc.

In ANFAS significant amount of effort was dedicated in establishing a methodology that will permit the estimation of the damages from floods. A generic methodology was established and adapted to the particular contexts related to the pilot sites. The proposed methodology was based on:

- Identification of the elements at risk (houses, roads, agricultural production etc.) and assessment of their value,
- Determination of the vulnerability of the elements at risk, i.e. the degree of loss (0% to 100%) resulting from a potentially damaging event and

- Estimation of financial, economic and social damages using defined estimation procedures.

The adopted procedure is of course affected by data availability. It requires an extensive amount of data which often are not available in data poor environments. Also it focuses in the direct impacts and does not consider indirect or induced effects arising from a catastrophic event. For example, the flooding of a major roadway may affect the transportation of goods and the supply and distribution chain of several manufacturing companies. However, to include these it would require an extensive economic analysis and this was deemed to be outside of the scope of the project.

4. System Architecture

4.1 Distributed Architecture

ANFAS is a web-based distributed system. Users with appropriate privileges can access the system through the web browser and perform simulations. A screen capture of the web interface is shown in Figure 4.

The integrated system available for user interaction includes the GIS databases, the models and the impact methodologies coupled with the appropriate user interfaces. Preparation of the various GIS coverages is performed outside of the integrated system through either remote sensing analysis, digitisation or data base manipulations. Once the various datasets have been prepared, they are stored as standard shape files in the system data repository and from then on are used as the need arises.

The key components of the system are as follows:

- *ANFAS Core Server:* this is the core component of the complete system since it handles the interactions between the various servers, the user management, the display and manipulation of data, etc.,
- *GIS, Database Server:* This is the component that handles all databases of the system; it stores the data and extracts data as needed.
- *Modeling server:* This server integrates the various models into the ANFAS system; it applies the model on a defined data set, monitors the progress and the status of the processes (needed since flood models can sometimes run for several hours) and sends the results to the rest of the system.

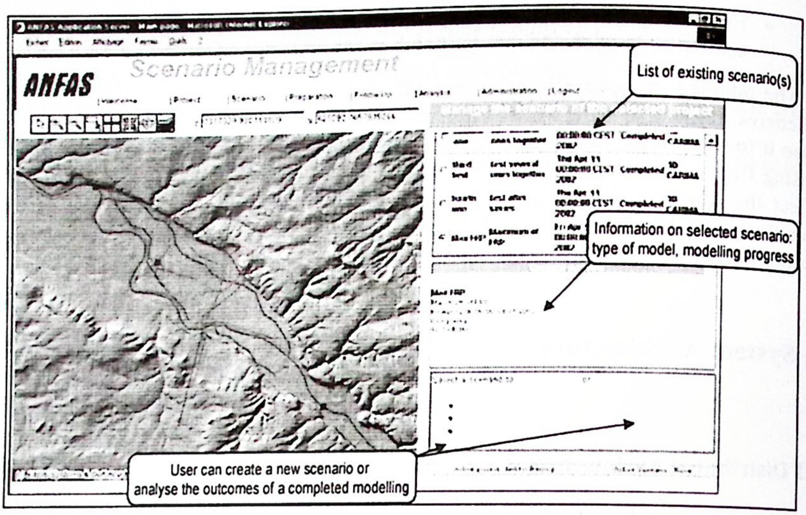

Fig. 4. Web-interface of ANFAS integrated system

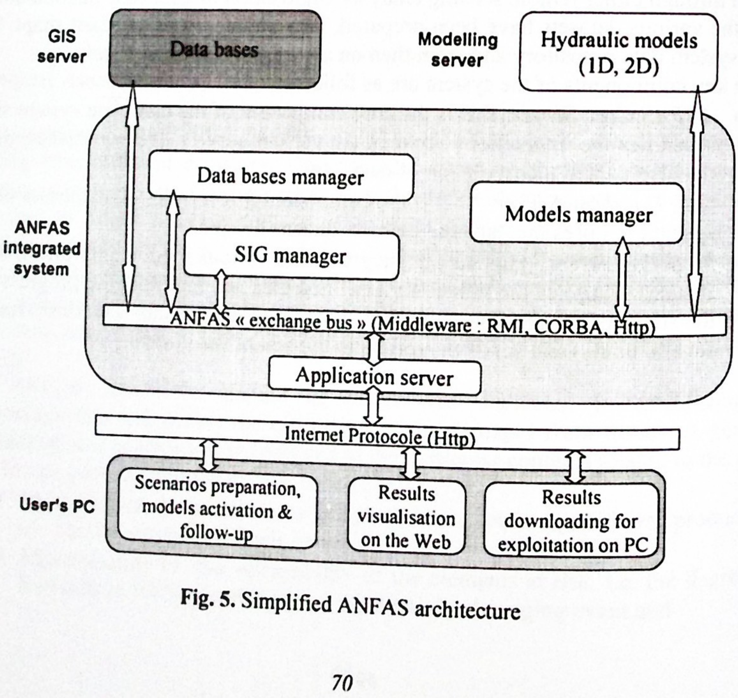

Fig. 5. Simplified ANFAS architecture

4.2 Data Flow

The data flow between models and databases (Figure 6))is handled through the "model encoding" and "model decoding" components. The "model encoding" reads the geographic and attribute databases and prepares the input file needed for running the numerical model. The format of these file is relatively rigid, defined by the model developer and its creation requires extensive data manipulation of the various coverages. 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 2-D model, is prepared outside of the system through a dedicated software, the mesher.

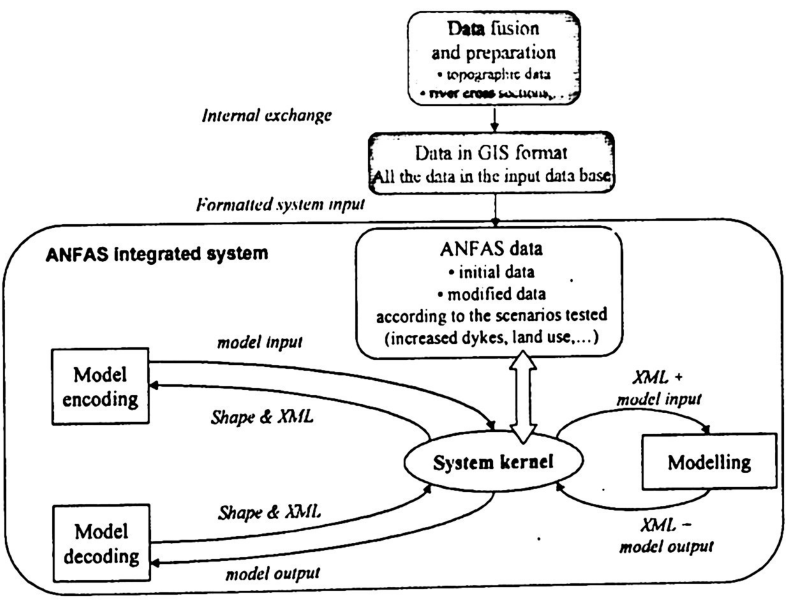

Fig. 6. Data flow overview

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 a 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 flood basin. For the 2-D models, the results are provided for each node of the mesh for the FESWMS model, whereas for the DaveF model they are provided for each mesh element.

4.3 Desktop Facilities

Although, as outlined above, the web-based interface to ANFAS offers several advantages, it can limit users that are interested in analyzing model results on their own. Users might be interested to view the results with their favorite 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.

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 can't 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 analyzing the results outside the ANFAS system a library of software components was developed. These of course 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. 3.3 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. The routines developed are named FloodView [15] and can be used also independently of the rest of the ANFAS system.

4.4 Hydraulic Expertise

One of the objectives of ANFAS was to develop an architecture that provides users with capabilities that permit them to simulate the effects of some preventive measures, such as increasing the height of the dykes, or performing flood simulations for different hydrological conditions. This was the reason that the encoder component was introduced to handle the interaction between the model and the datasets. The original scope was to provide end users with tools with which they could specify for example a new height for the dykes and then simulate the impact of that. The new height of the dykes would result in modifications in the GIS layers, and then the encoder would prepare automatically the input file for the hydraulic model.

Although the architecture implemented permits that, it must be stressed that the preparation of the input files cannot be a completely automatic process since numerical problems might arise during model execution. In fact, for a given river plain, the generation of an optimized network which satisfies topological, hydraulic and numerical constraints cannot be done in a press button mode. Convergence might not be achieved, or the results obtained might be totally wrong. It must be therefore stressed that although the input files can be generated automatically by the ANFAS system, "manual" intervention by experts in hydraulic modeling, the technical support team of the ANFAS system, is advisable if not necessary. (Figure 8). This

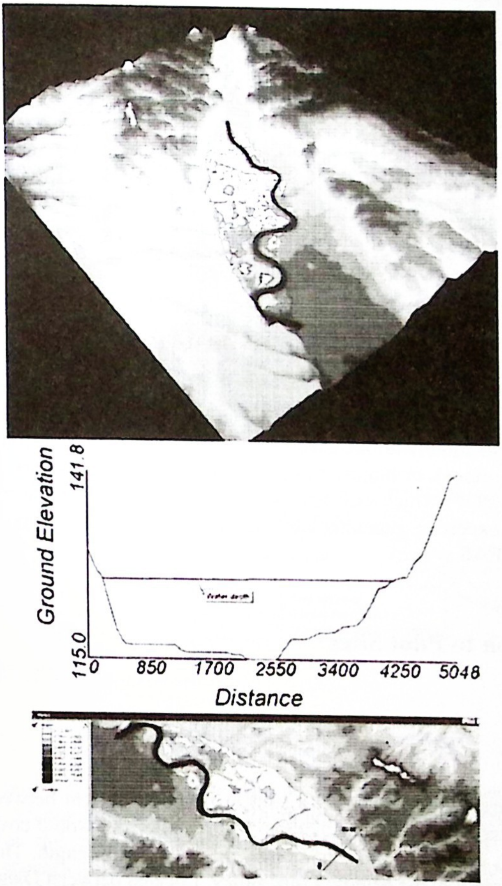

Fig. 7. Examples of FloodView visualizations for 2D models

intervention might be needed for either checking the input files of the model (for example a new mesh might be needed if the scenario includes changes in the topography or alters the flow of the river) and/or adjusting the hydraulic parameters to obtain model convergence.

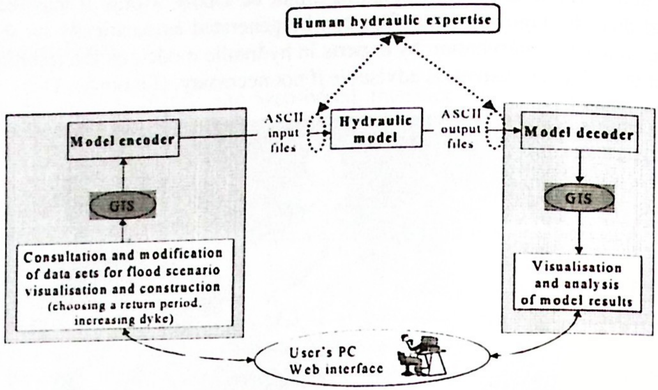

Fig. 8. Experts intervention

The need of few/great adjustment of the model parameters depends especially on the importance of modifications asked by the user: they can be minor ones (e.g. few dyke height increases). or major ones (e.g. opening of a water-work for intentionally flooding of a valley) which will involve a new calibration of the hydraulic model. This hydraulic expertise guarantees the quality of the results proposed to the users through the ANFAS system.

5 Application to Pilot Sites

5.1 Loire River

The Middle Loire valley represents a stretch of about 400 km between the cities of Nevers and Angers. It was agreed that the ANFAS pilot site would cover the Ouzouer and Sully valley, an area of 132 km² along a reach of 35 km length. This site is one of the widest floodplain in the Middle Loire valley. Located between Dampière-en-Burly and Châteauneuf-sur-Loire, it is a flat floodplain with very complex hydraulic features. The Ouzouer's valley is an important potential retention area on the right river bank: the entry of water in the valley is controlled by a hard core spillway whose height is raised by about 1.20m by a fuse dyke made of compacted earth. An overview of the area with the corresponding hydrological scenarios is given in Figure 9 [2].

Before this project, a quasi-2D model (HYDRA from Hydratec) was set up for the entire Middle Loire valley and hydrologic scenarios ranging from 50 to 500 years flood were investigated. Using the previously collected data another quasi-2D model, CARIMA, was adapted to the pilot site and used to simulate all previously mentioned hydrologic scenarios. Since the discretization was quite rough and the flow patterns very complicated, an accurate aerial photogrammetric DTM was prepared and ground surveyed cross sections were acquired and it was decided to apply also a 2D model.

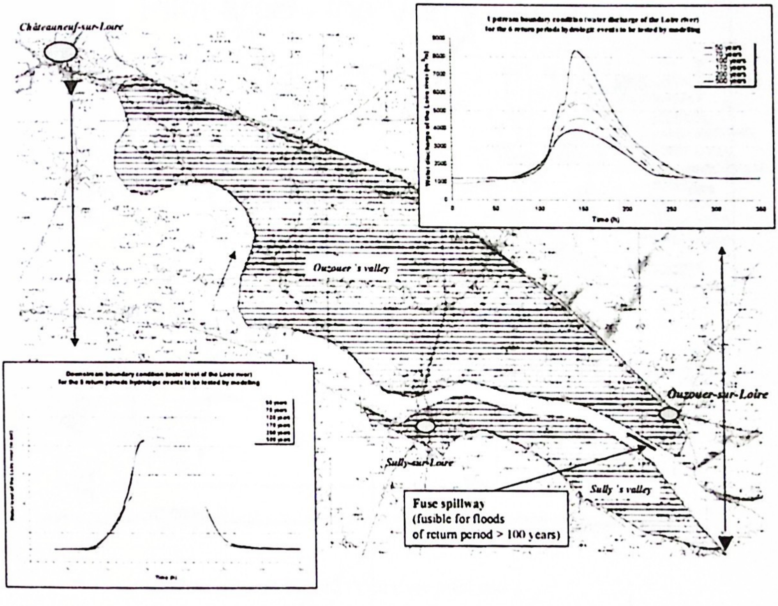

Fig. 9. Loire pilot site and hydrologic scenarios

FESWMS and DaveF models were also adapted to the Ouzouer and Sully valley. This analysis accounted from previous hydraulic analysis (HYDRA & CARIMA) carried out for this area and used the same 50, 100 and 200 years floods for hydrological scenarios. Moreover, different hypothesis on the lowering of the Loire riverbed and the fuse plug spillway operation led to additional hydraulic scenarios.

The results from runs carried out on the middle Loire valley were used to set boundary conditions, land use classification obtained from SPOT image for floodplain roughness estimation. Recorded data form the 5 to 10 years flood of May 2001 were used for channel roughness calibration and sensitivity analysis was carried out for floodplain roughness. As a result, 2D analysis provided spatially distributed results over the whole floodplain.

The Ouzouer's valley is mainly rural and therefore mapping of the elements at risk (Figure 10) shows very sparse behavior. Figure 11 show the calculated damages using the developed impact assessment methodology using results from CARIMA for the 200 years flood.

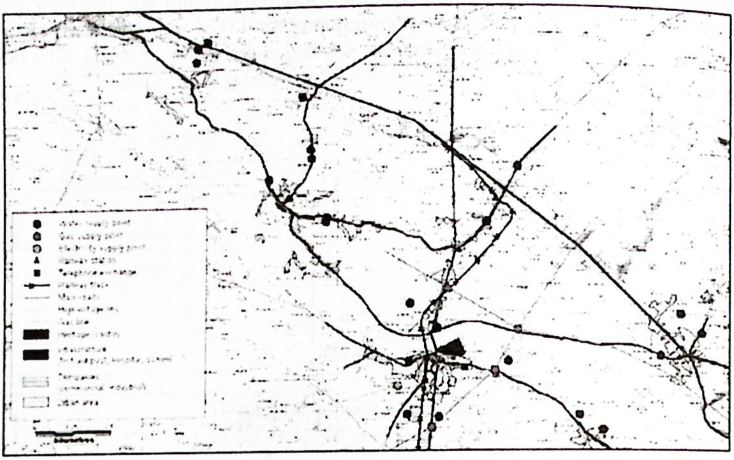

Fig. 10. Loire pilot site and elements at risk

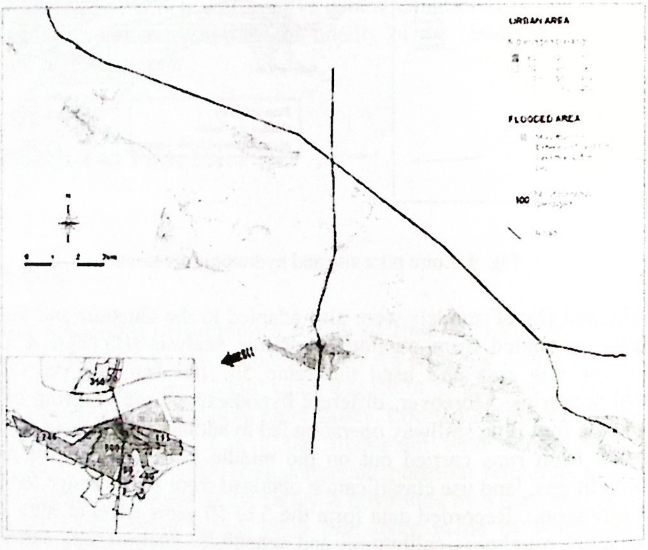

Fig. 11. Impact assessment map using CARIMA results

5.2 Vah River

The part of the Vah river between the Hricov and Nosice dams is the pilot site in Slovakia (Figure 12). This represents a stretch of 37 km of river with a floodplain of 0.5 to 1 km width. Total area is 75 km². Just after the Hricov dam, the flow is divided into the natural channel of the river, and an artificial power canal. Both join upstream before the Nosice dam. The simulated area is mainly bounded on the left side by railway and on the right side by the power canal and local roads.

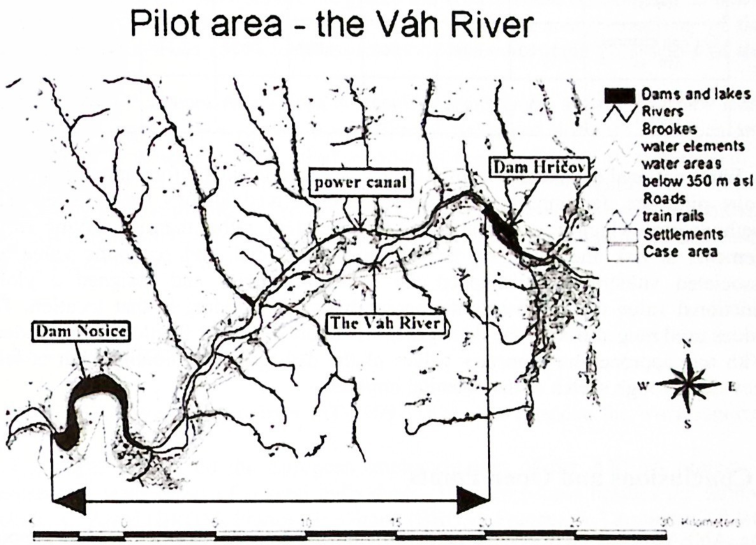

Fig. 12. Vah river pilot site

Given the small size of the area and the very complicated flow patterns involved during flood, it was decided to use a 2D model. A very accurate digital elevation model (1m resolution and 15 cm accuracy) was prepared through a LIDAR (Light Detection And Ranging) survey. Then, the land cover was evaluated using aerial photographs and scanned paper maps of the area in order to estimate the roughness.

Both FESWMS and DaveF models were adapted to the pilot site. Channel roughness was calibrated using recorded data from the July 2001 flood (5 years return period) and sensitivity analysis was carried out in the floodplain. Moreover, maximum discharges and flood marks were available for major flood events of 1813, 1903, 1925, 1958 and 1960.

The hydrologic scenarios investigated correspond to floods ranging from 5 to 1000 years return periods (see Table 2). Moreover, they were combined with hydraulic scenarios and terrain configurations involving non-overtopping of the embankments, different operations of the power canal and accounting for a future highway crossing the area. Flood extents were mapped for all scenarios and used for impact assessment analysis.

Table 2. Maximum discharges for the Hricov weir (without tributaries)

Return period T (years)	5	10	20	50	100	200	500	1,000
Q_T – inflow to Hricov reservoir (m^3/s)	1,500	1,740	1,960	2,280	2,450	2,510	3,074	3,500
Q (Vah channel) (m^3/s)	1,100	1,340	1,560	1,880	2,050	2,110	2,674	3,100
Q (power canal) (m^3/s)	400	400	400	400	400	400	400	400

Since national databases in Slovakia included less detailed information than for the Loire pilot site, for impact assessment a different methodology was adopted. This methodology, which was not integrated in the system, rather than identifying all the elements at risk and assigning them a financial, social, and economic value and associated vulnerabilities, mapped the elements at risk and assigned a global functional value that represents the acceptability of flooding in that location. The values used ranged from 1 (no damages if it is flooded) to 6 (it should not be flooded). With this approach no monetary values of the damages were obtained but at least provided a rough sketch of the potential impacts.

6 Conclusions and Open Points

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 conformed 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 three well-known models and develop the necessary infrastructure around these. 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.

There is no doubt that several extensions could be implemented in the system. The architecture could be altered so that scenario specification is carried on the user's PC and the web site is used for model execution and a first visualization. Several hydrologic scenarios could be estimated beforehand for a river and stored in databases and then retrieved at a time of a crisis thus transforming the system to a tool for early warning. Since HPCN facilities are integrated the system could be modified so that a set of results is provided for each scenario thus obtaining some sensitivity of the results to the roughness coefficients assumed and the other input parameters of 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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