Decision Support System for Risk Assessment and Management of Floods

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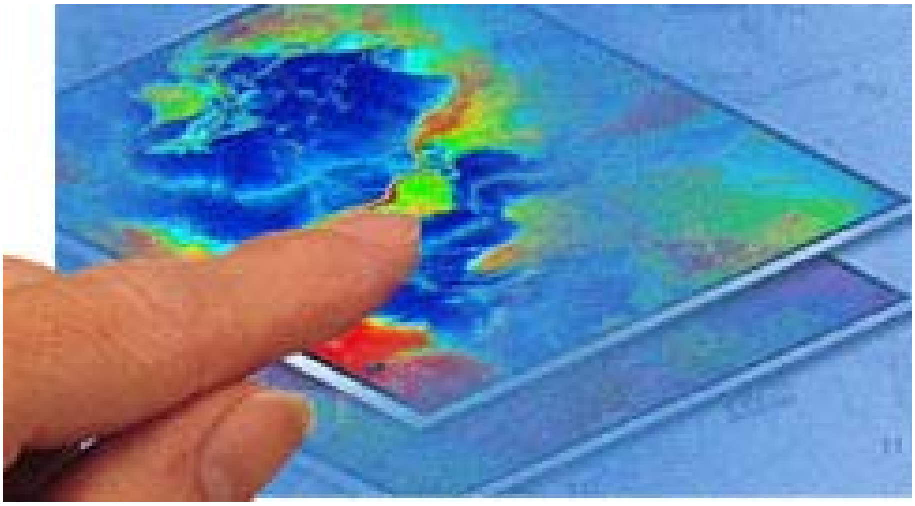

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SUMMARY

The objective of the RAMFLOOD project is to develop and validate a new decision support system (DSS) for the risk assessment and management of emergency scenarios due to severe floods. The DSS combines environmental and geo-physical data from earth observation, with advanced computer simulation and graphical visualisation methods and artificial intelligence techniques, for generating knowledge contributing to the risk prevention of floods and the design of effective response actions maximising the safety of infrastructures and human life.

The new RAMFLOOD DSS integrates advanced methods for collecting, processing and managing hydrogeological data, quantitative methods based on simplified 1D models and more complex finite volume based 2D computer simulation models, graphical visualization methods and artificial neural networks (ANN) for generating knowledge contributing to support decision makers by providing a quick response to specific “what if” scenarios during a flood emergency.

The project partners are:

- A research centre in Spain specialised in the development and integration of IT tools and expert systems and pre and postprocessing software for generating computer simulation data and graphical visualisation of numerical results (CIMNE). CIMNE was the coordinator of the project.
- A SME company in Germany specialised in capturing satellite based high resolution geophysical and environmental data transferring these in useful geographic information (EUROMAP).
- An Hydraulic Department within a prestigious Technical University in Spain specialised in the computer simulation and risk analysis of flood situations (UPC).
- An Agricultural University in Greece with long tradition in the prevention and analysis of floods using geophysical and environmental data (AUA).
- An end-user water management agency belonging to a regional Government in Spain responsible for the prevention and management of floods in specific delta regions (ACA).
- An end-user consortium grouping 15 municipalities in Greece responsible for management of large flood plain areas (SPAP).

The partnership was carefully sought in order to gather the maximum complementarity of skills for the successful development of the RAMFLOOD DSS requiring experts in geophysical and environmental data providers (EUROMAP), risk analysis and computer simulation of floods (UPC and AUA), integration of the DSS including ANN based models and advanced pre and post-processing tools (CIMNE) and two end user water management government organizations in Spain and Greece responsible for prevention of floods and the design and management of emergency situations (ACA and SPAP).

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EUROMAP
(http://www.euromap.de)

The Agriculture University of Athens (AUA)
(http://www.aua.gr/)

The Catalonian Water Management Agency (ACA)
(http://www.gencat.es/aca)

The Attica Municipality Association (SPAP)
(http://www.spap.gr/)

The project work was developed in the period January 2003 – March 2005.

1. PROJECT BACKGROUND AND OBJECTIVES

Floods can lead to important environmental emergency situations affecting the integrity of large infrastructures and the life of many human beings. The risk of severe floods in Europe in the next 50-100 years will increase an average of five times due to the Ozone layer and related effects as clearly indicated in study of the Reading Weather Prediction Center published by Nature [Milly et al., January 2002]. Indeed, a number of "floods of the century" in recent years in different European and non-european countries suggest that there is a need for a new paradigm of flood management that can be called "sustainable flood management" (Bumsted, 1997; Clark et al., 1997; Global Disaster Information Network, 1997; Myers, 1998; Smith and Ward, 2000). This concept calls for empowerment of stakeholders, adjustment to the environment and integrated consideration of economic, ecological and social consequences of disastrous floods. The new paradigm must go beyond simply reducing losses to building a sustainable flood management strategy on the local, national and international level.

The International Joint Commission (IJC, 1999) conducted a number of public hearings and supported a set of workshops concluding: (a) that water management agencies must exchange and share information in order to accomplish their own individual objectives; (b) that the stakeholders must be involved in all stages of flood management; and (c) that considerable improvement is required in integrating data and modelling tools in order to develop more efficient flood damage reduction strategies.

The aim of the RAMFLOOD project is to develop a new DSS 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.

The new DSS (hereafter also called the RAMFLOOD DSS) is the result of the developments integration and validation of the essential technologies provided the project partners:

- Advanced methods for capturing, correcting and merging updated geographical an environmental information with (at least) 5 meter resolution (EUROMAP)
- 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 (UPC and AUA)
- Advanced computational methods for the fast and accurate simulation of different flooding situations for evaluating the effect of alternative response scenarios (UPC)
- Innovative IT tools for generating the data necessary for the computer simulation of floods and the 3D visualisation of the numerical results (CIMNE)
- An artificial neural network (ANN) based decision model educated using innovative Monte Carlo simulation tools developed by CIMNE. The ANN model will be the kernel of the new integrated RAMFLOOD DSS 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 (CIMNE).

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 model. 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 the correct flow pattern in floodplains.

The risk criteria chosen in the project 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. The flooding time is an other significant parameter used to define a risk map, specially in rural areas.

The main innovative aspect of the project is the *integration* of state of the art geographical and environmental data with simulation and ANN decision tools in order to produce a new DSS for risk assessment and management of floods.
The *intelligent decision support* concept chosen in this project 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 artificial neural network tools. The concept envisions public, technical specialists and the decision- and policy-makers as the potential users of the DSS. In this environment, the DSS is seen as a link between the field expert and the decision-maker, between science and policy. Therefore, the RAMLODD DSS is not only 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. In this project, advanced AI technology through neural nets will provide *real time response* necessary for taking decision in emergency situations.

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2. OVERVIEW OF PROJECT TASKS

The project work was split in the following workpackages:

Workpackage 1 - Specification of the decision support system features and users requirement.

Workpackage 2 - Collection and management of geo-physical and environmental data.

Workpackage 3 - Multiscale, and multidata analysis of geo-physical and environmental parameters.

Workpckage 4 - Risk analysis and computer simulation of floods.

Workpackage 5 - Integration of the Ramflood DSS.

Workpackage 6 - Validation of the new Ramflood DSS for the risk assessment and management of floods.

Workpackage 7 - Definition of pre-standardisation guidelines for design and management of flood prevention and control scenarios.

Workpackage 8 - Dissemination and exploitation plans.

Workpackage 9 - Project management.

Workpackage 10 - Assessment and evaluation.

The following sections describe the work carried out in the project with emphasis in the main achievements toward the development and validations of the RAMFLOOD DSS. The descriptions of the project work following the activities planned in the different workpackges.

3. SPECIFIC FEATURES AND REQUIREMENTS OF THE RAMFLOOD DSS

The partners decided in WP1 that the RAMFLOOD DSS should be web-based; i.e., it should be accessible to users via a web browser. The following key utilities were defined for the RAMFLOOD DSS:

- Flood hazard analysis on a study area in real time.
- Hydraulic analysis on a study area in real time.
- Access to flood related information.
- Users communication tools.
- New projects development tools.
- Users management.

The DSS provides tools for hazard assessment due to floods. The users of the Ramflood DSS can define hydraulic parameters as input and obtain the hazard assessment of a flood in real time. System operation takes place by means of a set of menus, forms and dialog boxes for selecting the desired operations, registering the necessary information and obtaining the graphical results.

The list of actors and relevant processes taking place in the Ramflood DSS include:

Actor	Use cases
User	Gets hazard assessment on the study area in real time. Designs management of a possible flood scenario.
Expert User	Develops, updates or deletes new or old projects (study areas).
System manager	Maintains the system. Adds new projects (study areas) to the system.

User: The user is the person for whom the Ramflood DSS is developed. In most cases he/she does not have a deep computing knowledge, but just hydrological knowledge. A user must be registered to enter in the Ramflood DSS. The user inputs the hydraulic parameters for a study area in order to evaluate the hazard assessment in that area for that hydraulic process. Also, the user will have useful documentation at his/her disposal. This documentation contains information about the study area which may help the user to take the decisions needed to successfully manage a flood scenario.

Expert User: The expert user is a person with a deep computing knowledge. He/she develops the whole task needed to create a new project (study area) for the Ramflood DSS. This includes defining the study area, creating a hydrological model and training a neural network for fast emulation of the model. The expert user also updates or deletes any existing project or documentation related to the study area. The Ramflood DSS provides with the expert user with the necessary tools and documentation.

System manager: The system manager maintains the Ramflood DSS. This includes maintaining the Web server or updating the Ramflood System environment. The system manager also adds, updates or removes to or from the system new or old projects that the developer requests. That is, the expert user creates a project, while the system manager includes it into the system.

Figure 3.1 shows a schematic view of the flow chart of the RAMFLOOD DSS. The main steps are the following:

1. Definition of the land uses map using satellite image data. This involves the reading and processing of the earth observation (EO) data.
2. Interfacing the satellite data with the input for flood flow simulations using a finite volume method. The interfacing work is performed with the help of the GiD pre/ post processing system developed by CIMNE.
3. Simulation of different flood flow situations using the finite volume code CARPA developed by UPC. The aim of the computer simulation is to provide the necessary information on specific flood risk situations for training the artificial intelligent module based on a neural network technology.
4. Training of the artificial neural network (ANN) developed by CIMNE. The ANN allows to predict in quasi-real time flood hazard situations for specific hydrological data.
5. Prediction of flood hazard situations in quasi-real time (20-30 seconds) for each hydrological situation defined by the user.

RAMFLOOD DSS

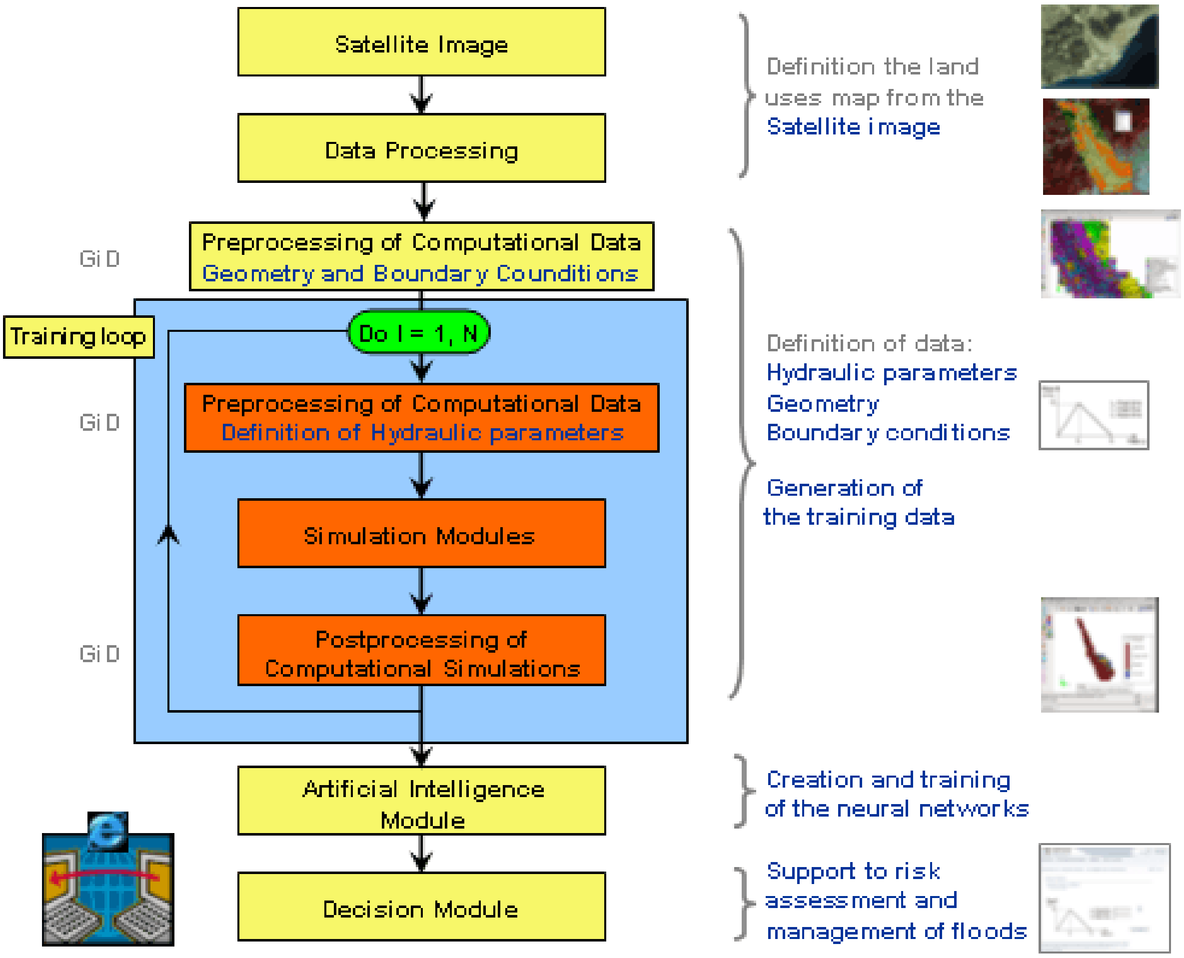


Figure 3.1 – Flowchart of the Ramflood DSS

4. COLLECTION AND MANAGEMENT OF GEO-PHYSICAL AND ENVIRONMENTAL DATA.

Work in WP2 focussed in the following activities: (i) The retrieval of remote sensing and other data types used in the validation study, (ii) the documentation of spaceborne and other data sets, (iii) the pre-processing and standardization of remote sensing data sets (radiometric calibration, georeferencing/geocoding, (iv) the quality control and assurance of the processed data and (v) the improvement of processing chains.

4.1 Selection and acquisition of satellite data

The first step was to define the area of interest to be studied in each region.
ACA and UPC defined the Llobregat deltaic region in Spain, and SPAP and AUA defined the Attica region in Greece. The following figures show each of the areas defined:

Figure 4.1 - Area of study in the Llobregat region, Spain

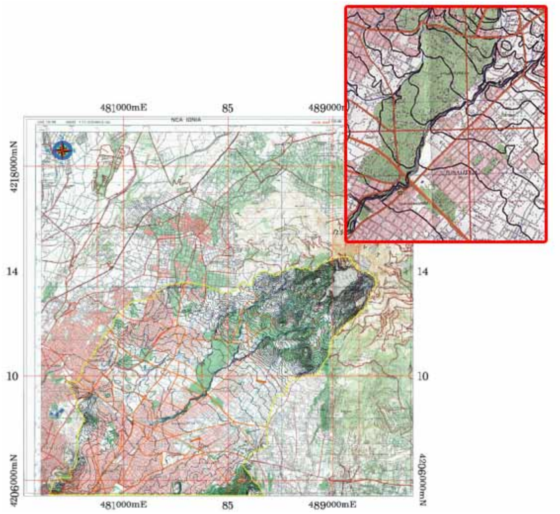


Figure 4.2 - Area of study in the Attica region, Greece

For each region the satellite sensors to acquire the satellite images were specified, as well as the pixel resolution and the type of satellite images to be classified in order to develop the land uses map.

EO satellite data from the Indian Remote Sensing Satellites IRS-1C and IRS-1D was used in the Llobregat region. In the Attica region EO satellite data from the Ikonos Satellite was used.

For the Llobregat region, EUROMAP made available 4 satellite scenarios with different acquisition data. UPC specified the scenarios to be analyzed on 13/05/2002. In the Attica region the satellite images selected were acquired on 21/09/2002.

Figure 4.3 – Satellite image of the Llobregat region, Spain

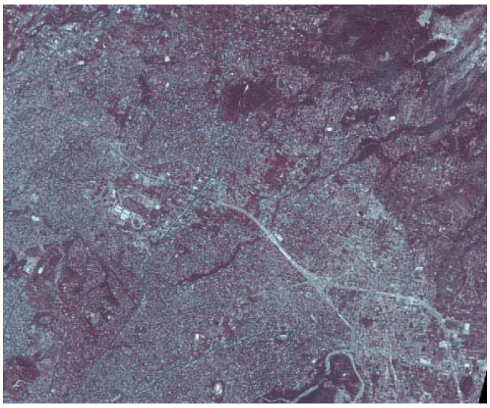


Figure 4.4 – Satellite image of the Attica region, Greece

4.2 Initial correction of data.

For the area of interest in the Llobregat river region (Spain), the necessary Digital Elevation Model and the ground control points were provided by ACA and EUROMAP. These inputs were checked by UPC, ACA and Euromap.
The selected 5m panchromatic and 25 m multispectral IRS data were radiometrically corrected and processed into computer readable products in Super Structure format. Radiometrically corrected data in Super Structure format were merged to produce 5m natural colour products in TIFF format.
A parametric ortho correction with bundle adjustment was applied to the data. An accuracy of 10 to 15 m relative to the Ground Control was achieved.

4.3 Merging of data.

The radiometrically corrected data in Super Structure format were merged in order to produce 5m natural colour products in TIFF format. The final mosaicing of the data included a colour balancing and a visual enhancement of the products.

4.4 Final correction of merged data.

In order to mosaic the radiometrically balanced ortho products, it was necessary to manually define cut lines in the overlap area of neighbouring data products. These cut lines were placed at edges of natural features like woods or fields, so that the remaining radiometric differences do not lead to disturbing visual impressions. The resulting mosaic was calculated using the radiometrically balanced ortho products, the defined cut lines and a fading algorithm. During a final visual check of the mosaics, the quality of the colours and the result of the fading along the cut lines was checked. The mosaics were written in GeoTIFF format. The processing chains were studied to allow faster, more reliable and automated production with an assured level of quality.

4.5 Environmental data.

The Llobregat region data was obtained in order to establish the digital terrain model. This information was provided by the Cartographic Institute of Catalonia. Source data was available at 25, 5 and 1 meter resolution. These standards ensure a good quality of the DTM to be used in the hydraulic model. The cooperation of ACA, was very important to get this information.
Details of the infrastructures located in the area of interest were collected. Some of them are boundary limits to the flood area so its local definition will produce a much more detailed and reliable digital terrain modelling.
Landscape uses maps in a digital format were released by CREAF (Centre de Recerca ecológica i Aplicacions Forestals in Barcelona). This information was used as a reference for the satellite identification process carried out by other partners. The following figure shows the DTM available for the Llobregat region already integrated within the GiD pre/post-processing system.

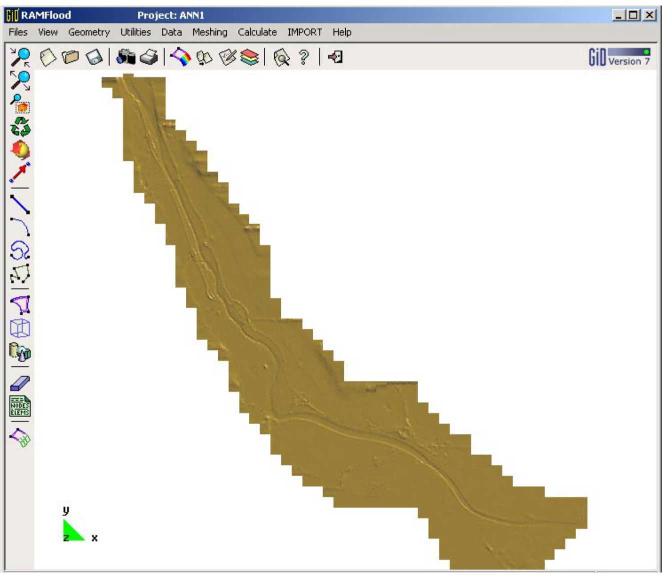


Figure 4.5 – DTM of the Llobregat region, Spain

For the Attica region the digital terrain model was already available and landscape uses were obtained through ortophoto images Data heal with enough detail to provide inputs to the hydraulic simulation model. All the data needed to run the test case was obtained.
The following figure shows the GiD output of the DTM available for the Attica region.

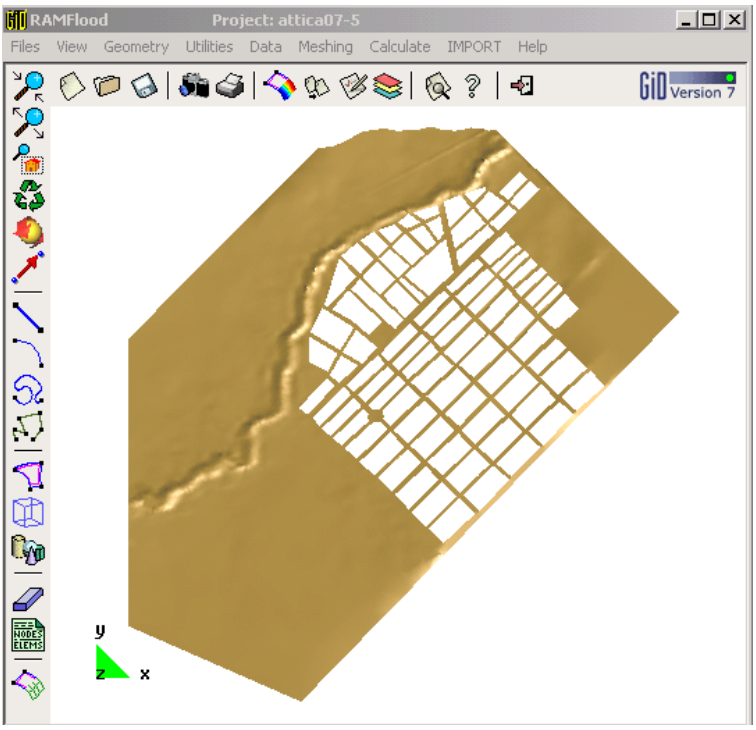


Figure 4.6 – DTM of the Attica region, Greece

5. MULTISCALE, MULTIDATA ANALYSIS OF GEO-PHYSICAL AND ENVIRONMENTAL PARAMETERS.

Work in WP3 focussed in generating, delivering and updating the basic data and information for the flood simulation system. The basic and pre-processed earth observation and GIS data was transformed into classified and usable information in order to be ingested into the simulation system. The transfer of raster based earth observation satellite information into vector based annotated earth information was performed by means of an state of the art innovative multi-scalar and object oriented image analysis system (the eCognition system). eCognition takes the raster data input, accepts vector based GIS information and automatically generates polygonal image objects.

5.1 Development of specific images parameters for hydrological analysis

Object features were created from the geographical parameters, reflecting not only the absolute value of a certain parameter (i.e. the object height) but also the trend and direction of this parameter (i.e. the slope and the aspect of the object). Similarly, the vector capabilities of the method were enhanced to incorporate surface elevation, which is defined in vector bases hypso-lines (height-iso-line) as common in topographic mapping.

UPC defined a list of different classes of objects to be classified in the Llobregat region from the satellite image to create the land uses map among these we list:

- Urban areas:
  - City type classes
    - Dense residential
    - Scattered residential
    - Industrial
  - Vegetated spaces
  - Impervious open spaces

- Rural areas:
  - No vegetation
  - Pasture
  - Cultivated areas
  - Brush
  - Trees
  - Infrastructures

This information is essential in order to assign the hydraulic properties in the finite volume mesh for the flood simulation.

For the Attica region, AUA defined the following object classes: Roads, Urban, Semi urban, Trees, Soil, Water, Motorways, Quarries

The object oriented analysis system fuses the various native input data and generates value added information for the simulation analysis such as:

- Marked soil map (indicating the potential of certain soils to catch water)
- Land cover map (indicating sealed land areas with high water-run-off and vegetation cover areas)
- Both maps take into account the topography to better estimate the capacity for absorbing water

5.2 Development of the interfaces for the flood flow

Following the needs defined by the project partners, CIMNE adapted the existing pre and post-processor GID (www.gidhome.com) to treat the geometries of each area of study.
As a result of this work, the geometries can be easily created using different data formats via the different tools offered by GiD.

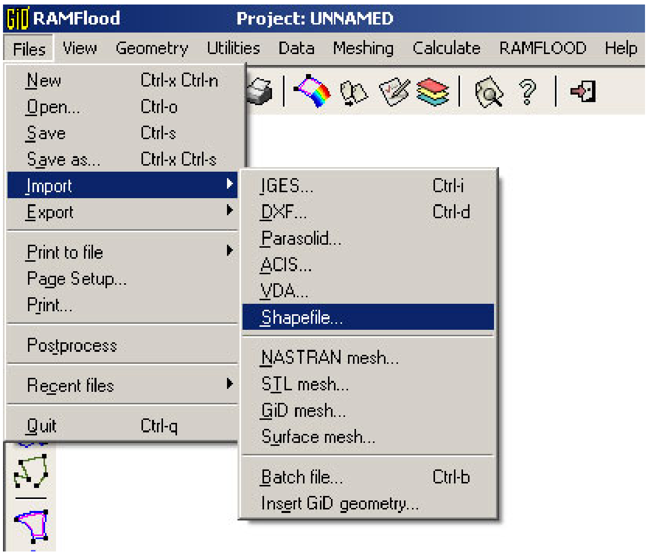


Figure 5.1 – GiD tools for importing and creating a geometry

A complete tool for reading the DTM files (digital terrain model) was also developed by CIMNE and UPC. This tool allows to import and create the geometry directly from the DTM files, as well as to process the DTM information.

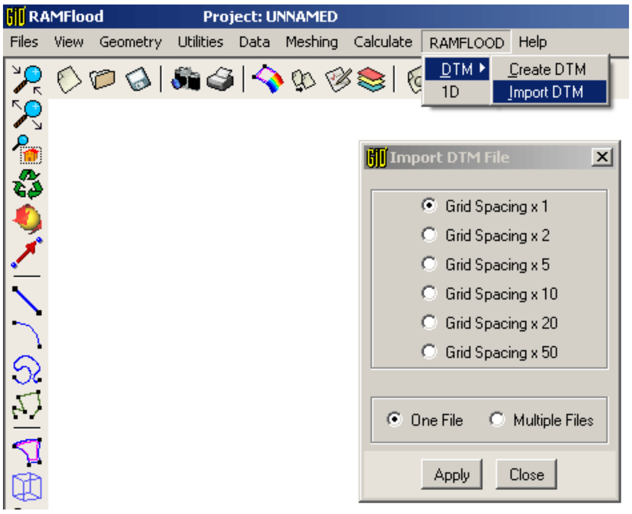


Figure 5.2

CIMNE also developed the necessary interfaces between GiD and the flood simulation code CARPA developed by UPC. The necessary GiD's interfaces to define the data for the flood simulation and to analyse the numerical results were also developed.
The following figures show some of the interfaces created within GiD:

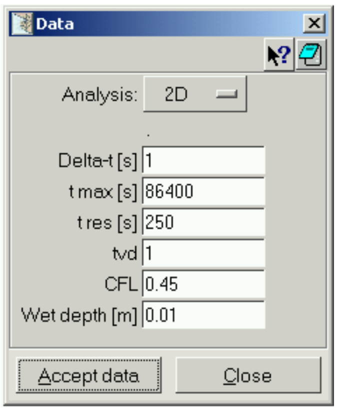


Figure 5.3

The users define the type of flood analysis and the necessary parameters from the window "data".

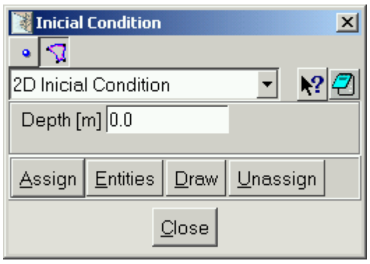


Figure 5.4

The users define the initial condition on the mesh with the window “Initial condition”.

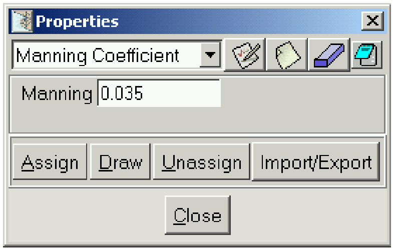


Figure 5.5

The users assign the properties on the mesh with the window “Properties” (roughness). This task can be done either manually, or directly from the land uses map associated at the area of study (database files).

The users define the boundary condition on the mesh with the window “2D and 1D Analysis” (roughness). In this task the user needs to define the “Inlet condition” and de “Outlet condition”

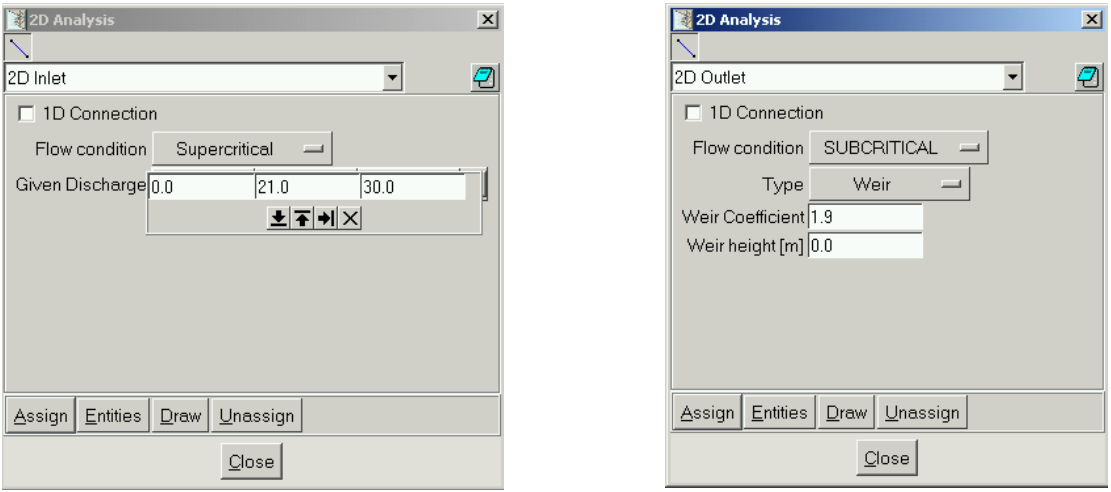


Figure 5.6 – Main window to define the boundary condition on the mesh

By using the view results menu of GiD, the user can access to the results.

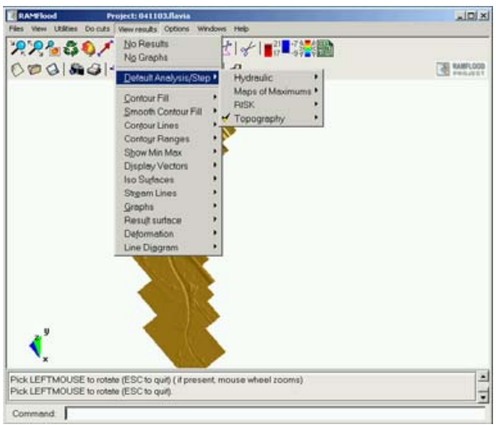
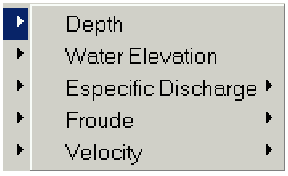


Figure 5.7 – View Results of GiD

In order to group better the post-processing information, the following groups of results and interfaces were created:

Hydraulic



Maps of Maximums

RISK

Topography

An example of the post-processing result is shown in the following figure:

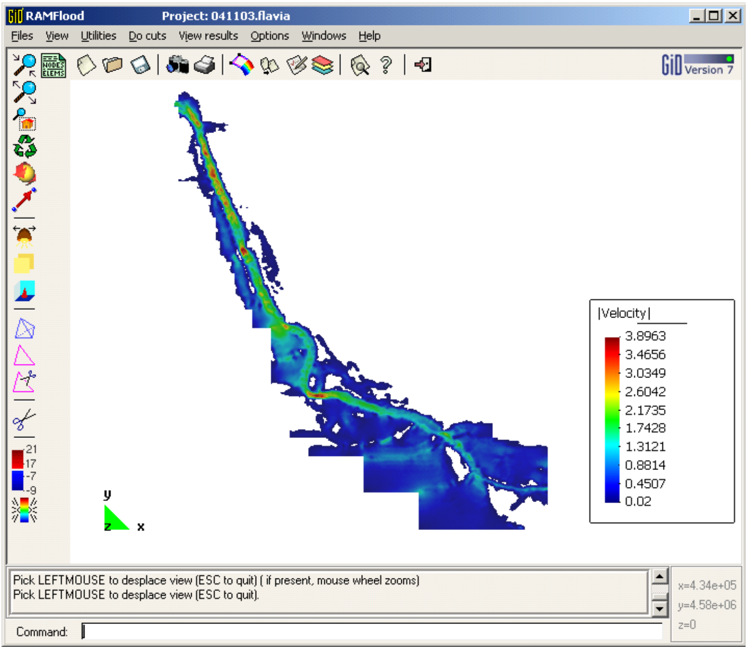


Figure 5.8 – Example of flood simulations output (velocity image) display by the post-processor of GiD

5.3 Development of interfaces for the management of the RAMFLOOD DDS

CIMNE created the Ramflood DSS's interfaces following guidelines from the project partners. The design of the user interface was planned as of the web site supported by numerous communication utilities written in Java and documents presented in Hypertext Markup Language (HTML).

Java utilities provide three main functions for the user interface:

- Access to, and two-directional transfer of data residing on remote web-connected clients.
- Activation of, and access to modelling tools residing on remote web-connected clients.
- Presentation of spatial information in the form of maps and other graphical tools.

Essential requirements are:

- Identification of the user level and provision of appropriate support.
- Simple intuitive design.
- Flexible design.
- Easy of use.

The following figures show two windows of the interfaces developed for the Ramflood DSS: the entrance window interface with the levels of users and the main working window of the end user level:

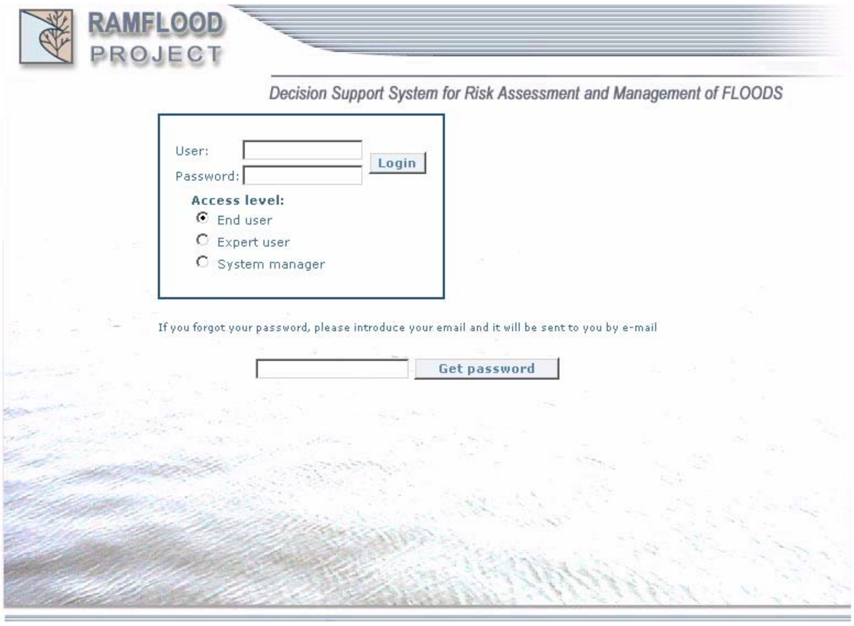


Figure 5.9 – Main window of the Ramflood DSS

Figure 5.10 – Main end-user window of the Ramflood DSS

A set of fuzzy logic rules, adaptable to specific river and geographical scenarios were developed. The aim is to assist the computer analysis of hydrological networks and more specifically to generate a soil map and land cover change maps from high resolution satellite data.
The input data are the system and user requirement and the satellite data. The results of the work was set of knowledge rules for analysing hydrological scenarios (land cover, land cover change, etc), and a rule base strategy document.

5.4 Development of land uses maps

5.4.1 Development of the Llobregat land uses map

In the Llobregat region, CIMNE used the eCognition software to develop the land uses map. The results of the objects classification were exported from eCognition. The alternatives to export data order different formats were discussed.

The final option chosen was to create two files, In the first one, written in ASCII grid format, each value number is associated with each class. The coordinates are related to the position of each number on the matrix. The second file contains the data base (class number and class name).
In the following figures an example of these files is shown:

```
ncols    629
nrows    428
xllcorner        419007.5
yllcorner        4579865
cellsize         5
NODATA_value     -9999
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11
9 9 9 9 9 9 9 9 9 9 9 9 9 5 5 5 5 5 5 5 5 5 5 5
60 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60
56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56
56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56
56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56
56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
```

Figure 5.11- ASCII grid file

```
id;Class_Names
0;Unclassified
7;residential
8;industrial
9;urban_vegetation
10;trees
12;bare_soil
13;concrete
14;brush
15;dense_vegetation
16;sparse_vegetation
19;river
20;infrastructure
21;single_buildings
```

Figure 5.12 - Reference data base file

The land uses map database was saved following a grid of 5 meters spacing between points.

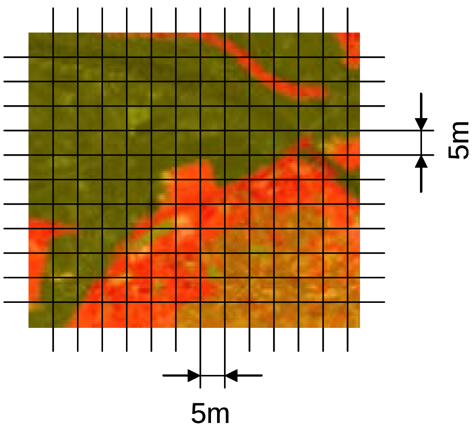


Figure 5.13 - Grid of points used to export the classification results to create the land uses map and the ASCII files

CIMNE also developed the GiD's interfaces to visualize the land uses maps. In the following figure we show the Llobregat land uses map.

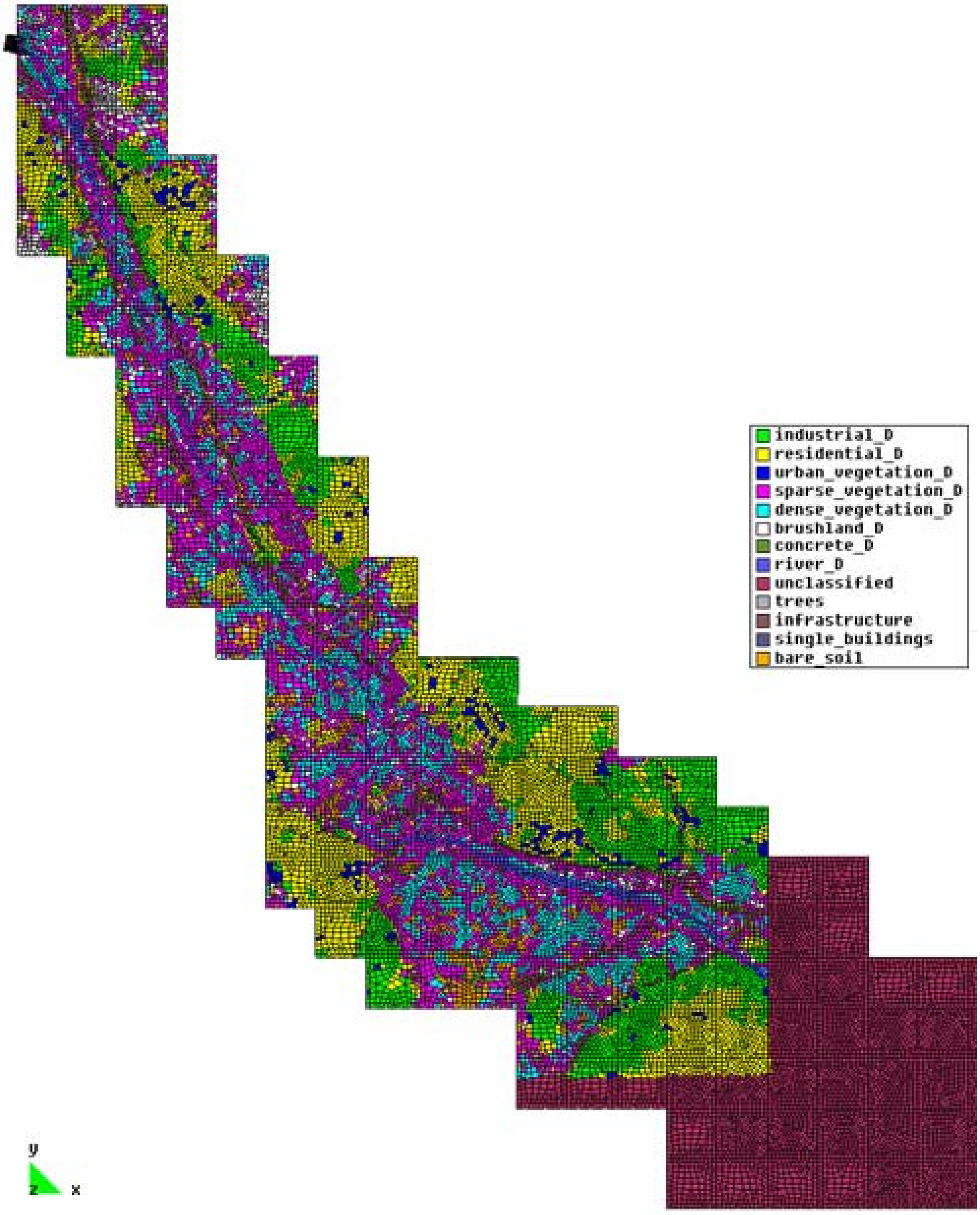
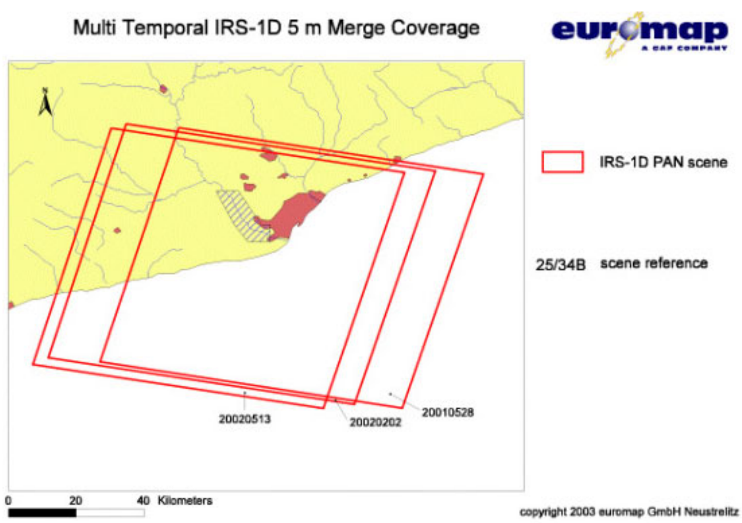


Figure 5.14 - Llobregat land uses map

EUROMAP provided the satellite images for each area of study. UPC examined the images and chose those needed in order to develop the land uses maps. This study allowed us to perform changes in the control analysis step. A selection of the satellite images provided is shown in the next page



Mission	Path	Row	Scene	Acquisition Date
1D PAN	17	40	D	20010528
1D LISS	17	40		20010528
1D PAN	17	40	D	22020202
1D LISS	17	40		20020202
1D PAN	17	40	D	20020513
1D LISS	17	40		20020513

Figure 5.15 - Selected scenes for the Barcelona area of interest

5.4.2 Development of the Attica land uses map

AUA developed the land uses map for the Attica region chosen using the PCI Focus software. The results were exported using the PCI OrthoEngine software using the same methodology than for the Llobregat area.

The following figure shows the Attica land uses map imported in the GiD pre/post-processing system.

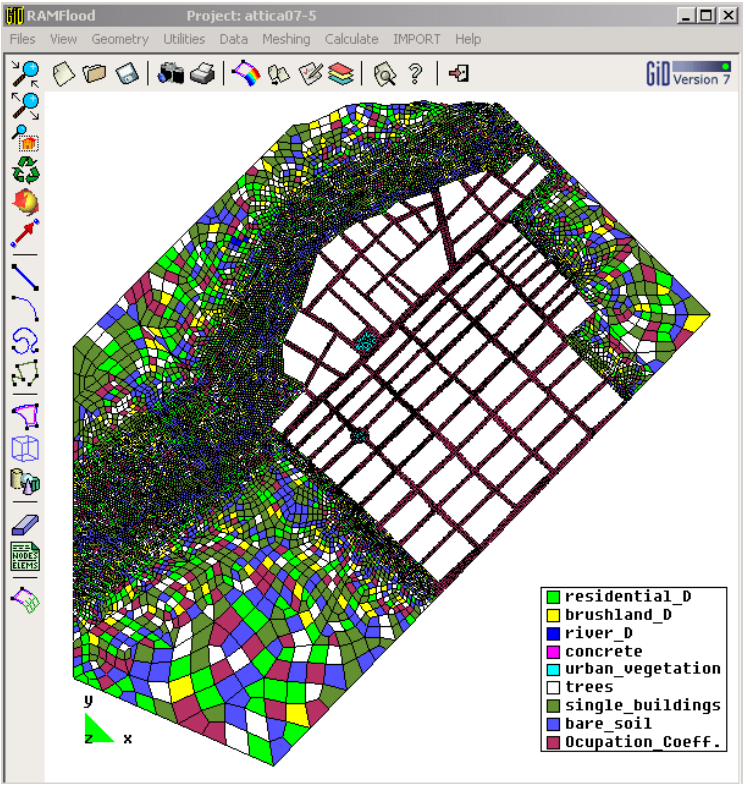
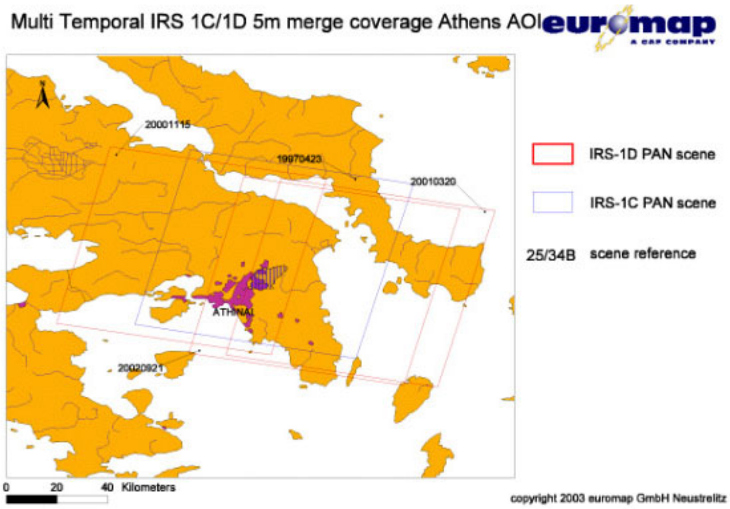


Figure 5.16 - Attica land uses map

Similarly as for the Llobregat region EUROMAP also provided sequences of satellite images for each area of study. AUA chosen the images needed for developing land uses maps.



Mission	Path	Row	Scene	Acquisition Date
1D PAN	40	43	A	20001115
1D LISS	40	43		20001115
1D PAN	40	43	B	20010320
1D LISS	40	43		20010320
1C PAN	43	43	A	19970423
1C LISS	43	43		19970423
1D PAN	40	43	B	20020921
1D LISS	40	43		20020921

Figure 5.17 - Selected scenes for the Athens area of interest

5.5 Validation of the classified land uses data

Validation process for the land uses data followed the following sequence:

- Classification of satellite images: validation of results
  - Visual validation of the classification.
  - Visual comparison between results and orthoimages.
- Import of the land uses map into GiD: verification of provided data
  - Control of unclassified zones.
  - Definition of the different classes classified and the GiD database materials.
- Hydraulic model: validation and verification of the mesh properties from the land uses map.
  - Visual comparison of resulting soil occupation maps with CREAF Landscape maps.
  - Analysis of the coherence of the imported data with the knowledge of the study area.
  - Special control of accuracy in particularly interesting areas.

The validation tasks were successfully implemented in order to validate the land uses map in the Llobregat region. In the Attica region the last task (Hydraulic model) was not performed as the land uses map database was not available.

5.5.1 Validation of land uses data for the Llobregat river area

Classification of satellite images: validation of results

A first visual validation was performed by UPC. On the basis of the differences found the land uses map was edited manually. The results obtained using the eCognition software were compared with available orthorectified data 5m natural colour mosaics. Also the classification results were compared with the satellite image.

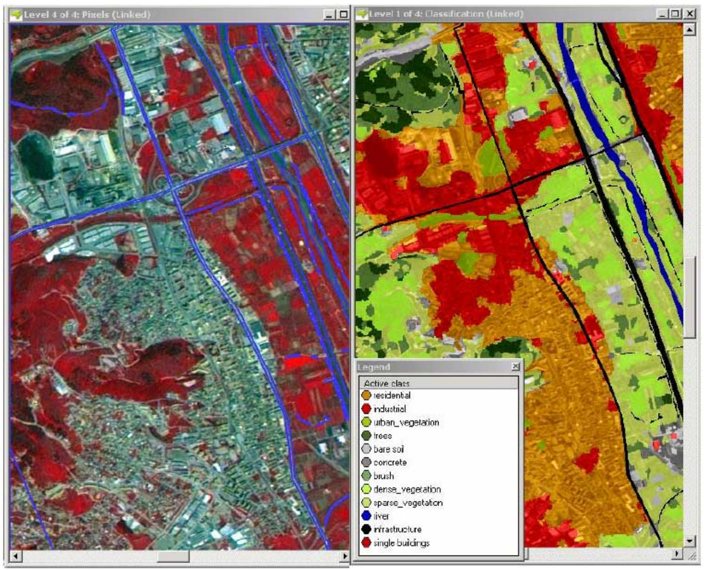


Figure 5.18 - Analysis of satellite data and classification results performed at the Llobregat region

Figure 5.19 - Orthorectified data 5m natural colour at the Llobregat region

Import of the land uses map in GiD: verification of provided data
In order to use the land uses map correctly in GiD, it is necessary to verify that the information contained in the land uses map file is homogeneous (the area of study is completely classified). The object classes used in this file (different objects classified) were stored in the GiD properties database.

The land uses map were imported and the mesh properties were automatically assigned. For this purpose, we verified that there were not unclassified areas and the different classes defined can be read by GiD.

After importing the land uses properties, a visual control was performed in order to verify the finite volume mesh and the different materials assigned to it. The objective of this step was to find possible mistakes, such as areas without any class assigned or unclassified points inside the study area. This control was performed using the GiD tools.
The following figure shows the different materials assigned on the finite volume mesh.

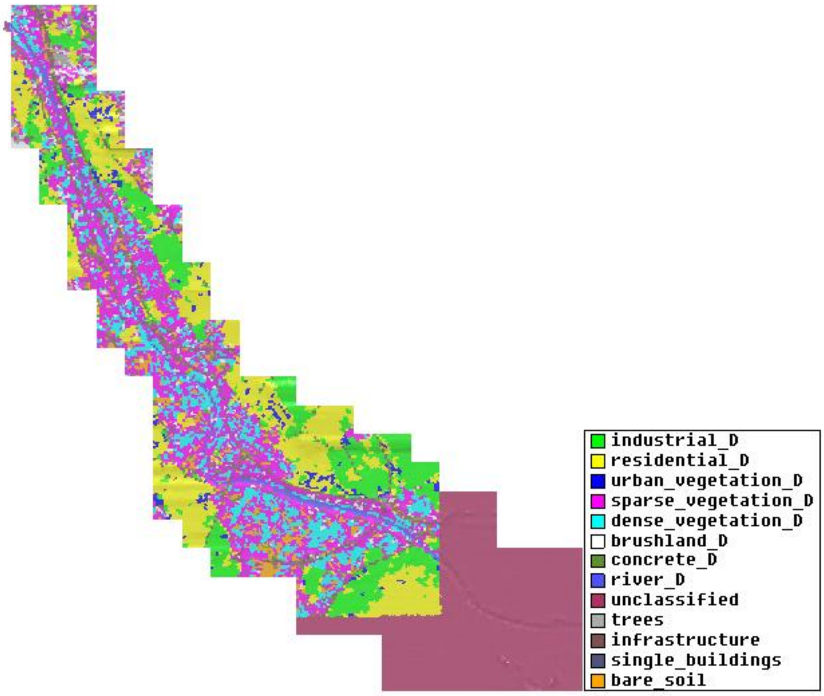


Figure 5.20 - Soil occupation classification applied into the mesh

Hydraulic model: validation and verification of the mesh properties defined from the land uses map.

Validation of data for the Llobregat region was carried out using available information from the Catalonia region, where this area of interest is included. This information is a land uses map (Model de Cobertes del sol de Catalunya, MCSC). This is a high resolution thematic cartography of the main landscape uses (woods, agricultural activities, urban areas), updated in 2002 according to the last survey flight.

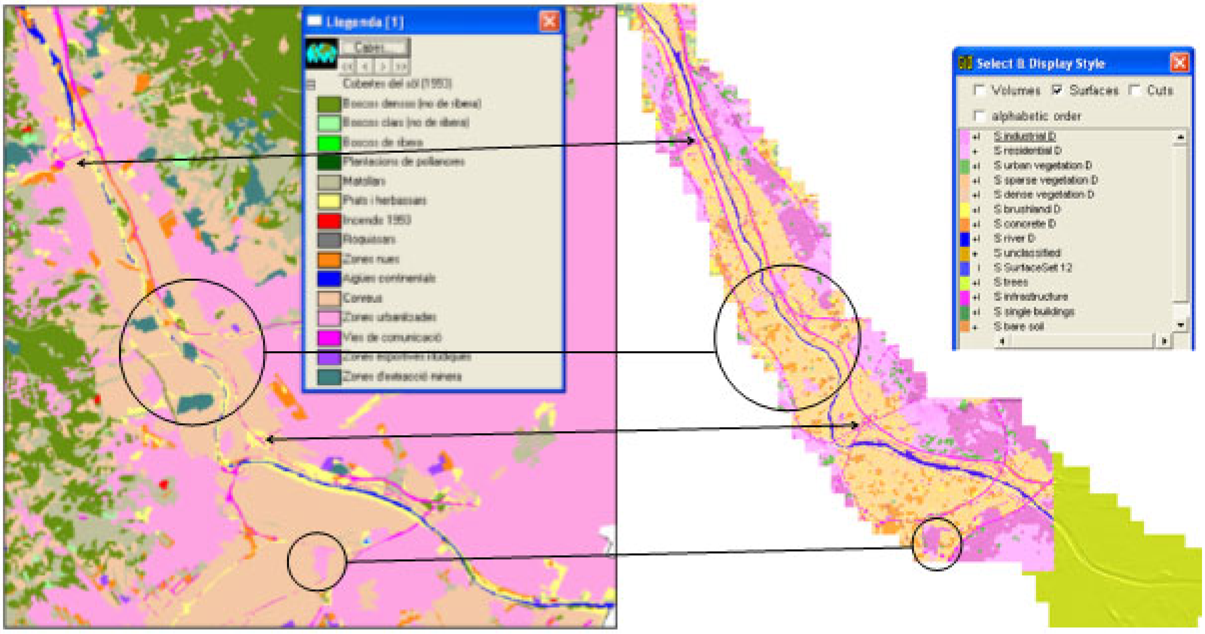
To compare the classification results we established the relationship between different classes used in each map (homogenisation of classes). From the land uses map comparison, we identified some differences between the structure of classes proposed for the Ecological and Forestry Applications Center and the one that was adopted from the eCognition software.

The classification obtained from eCognition is more detailed, as it separates better the class “urbanized zones” in three classes, “residential”, “industrial” and “urban vegetation”; classes “crops” and “grassy fields” from CREAF are sparse and dense vegetation in eCognition. The eCognition classification detected all existing infrastructures even these that are smaller than 10 m.

There were some localized incongruities in the mesh properties, but they were not significant for the correct development of the hydraulic model.

Following the complete visual comparison between the classification results obtained by CIMNE, using the eCognition system, and the available information soil occupation maps of the Catalonia region, we concluded that the land uses map created satisfied widely the 90% expected accuracy (this accuracy level was proposed by UPC).

The following figure shows each land uses map at the Llobregat river region and the main differences found.



Landscape uses map developed by CREAF Soil Classification developed by Ramflood

Figure 5.21 - Comparative analysis between classification results at the Llobregat region.

5.5.2 Validation of land uses data for the Attica region

Classification of satellite images: validation of results

The land uses map of the Attica region obtained from the satellite data was validated using the available information of the landscape uses map and an extensive field work including GPS signal collection (GARMIN GPS 12XL Personal Navigator) over certain classes and acquisition of photographic archive data (5 mega pixel images).

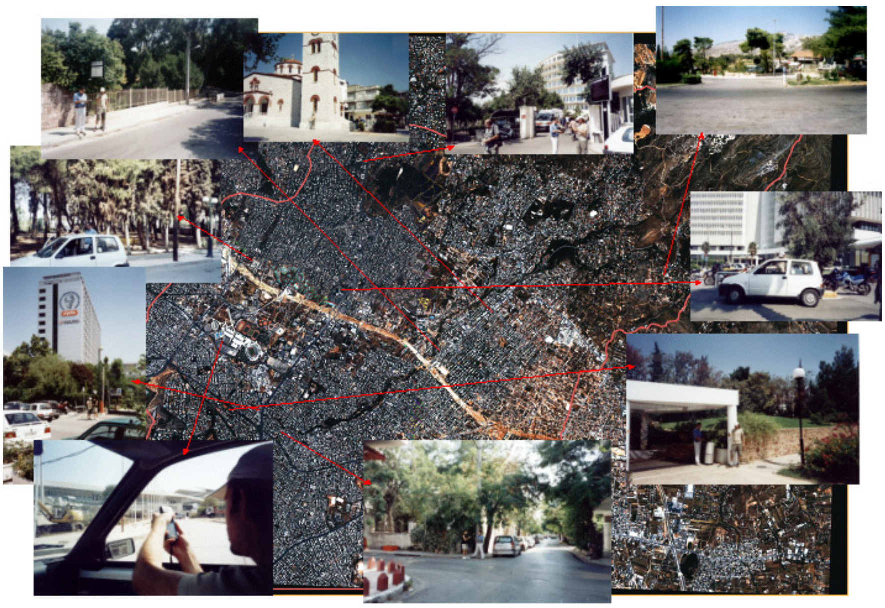


Figure 5.22 - Field validation of land covers classification for the Attica data.

Import of the land uses map in GiD: verification of provided data

The area classified from the satellite image is larger than the area defined for the hydraulic study in the Attica region, so the data applied into the mesh is only a part of the available information.

The ASCII grid file provided contained some unclassified points inside. Therefore corrections in the original land uses map file were introduced to solve this problem. The adopted strategy was to assign the nearest class.

We repeated the control task performed in the Llobregat region in order to validate the data with the support of AUA, looking for possible mistakes or inconsistent points.

Figure 5.23 shows the mesh properties defined from the land uses map automatically.

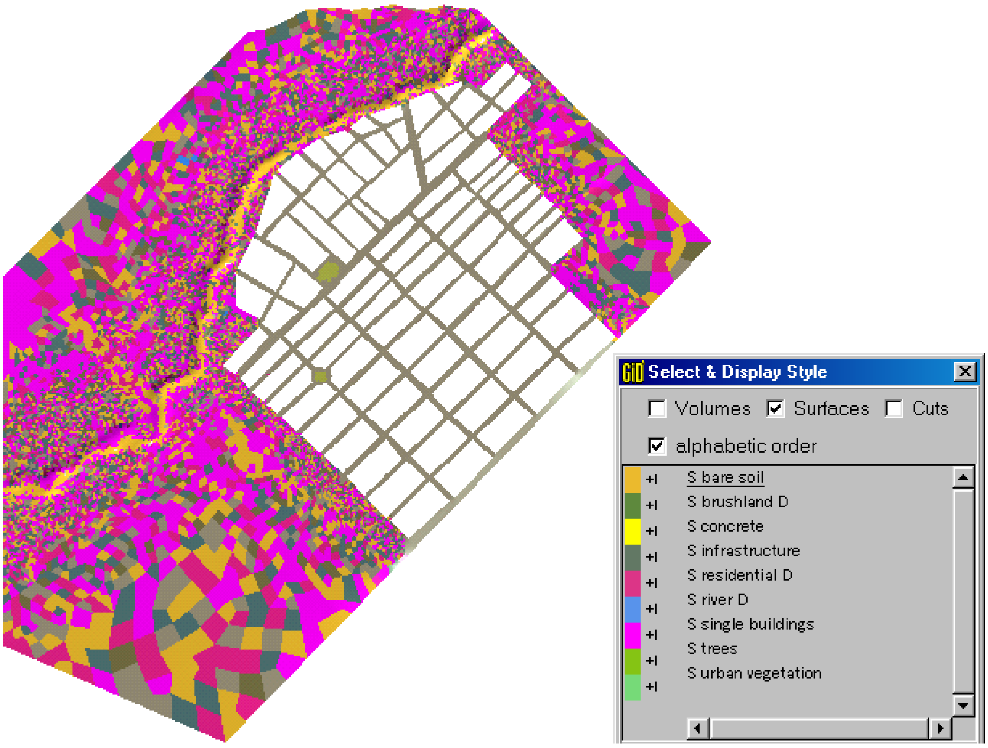


Figure 5.23 - Definition of the mesh properties in the Attica Region.

6. RISK ANALYSIS AND COMPUTER SIMULATION OF FLOOD

Work in WP4 focussed in creating a database of flood risk criteria on the basis of existing historical data and also using new results from numerical simulations obtained with 1D and 2D flood analysis models.

6.1 Definition of risk criteria

The **first risk criterion** considered is associated to human risks (flooding or dragging) in terms of critical water levels, velocities or combination of both parameters. According to these criteria, a risk database was developed. The following three different risk levels were considered:

High Risk: Associated to water levels greater than 1 m, or velocities greater than 1 m/s or product number (water depth and velocity) greater than 0.5 m2/s

Moderate Risk: Associated to water levels greater than 0.4 m and lower than 1 m, or velocities greater than 0.4 m/s and lower than 1 m/s or product number (water depth and velocity) greater than 0.08 and lower than 0.5 m2/s

No Risk: Associated to water levels lower than 0.4 m, or velocities lower than 0.4 m/s or product number (water depth and velocity) lower than 0.08 m2/s

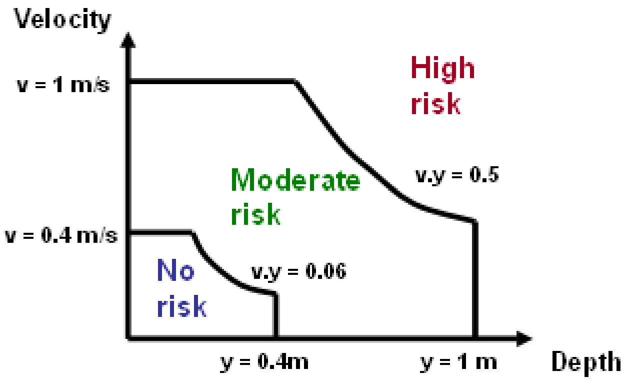


Figure 6.1 – Levels of risk criteria combining water velocities and depths

The **second risk criterion** considered is associated to maximum flooding time. This criterion has been implemented in rural areas in agriculture zones.

High Risk: Associated to maximum flooding time greater than 24 hs.

Moderate Risk: Associated to maximum flooding time greater than 2 hs and lower than 24 hs.

No Risk: Associated to maximum flooding time lower than 2 hs.

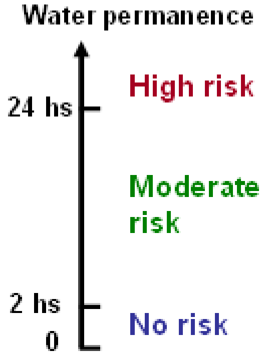


Figure 6.2 – Risk criteria based on flooding time

6.2 Computer simulation of floods

Flood propagation was simulated by means of the numerical model developed by UPC. The model named CARPA (Cálculo en alta resolución de propagación de avenidas) has been specifically adapted to RAMFLOOD for the simulation of unsteady free surface flows in one (1D) and two dimensions (2D) domains. The CARPA code solves the full Saint-Venat equations in 1D and 2D domains using the finite volume method. Unstructured meshes of quadrilateral domains were used for the 2D solution.

Work included the implementation, integration and calibration of the 1D and 2D models and codes for flood analysis available to UPC and AUA with the pre/post-processing system GiD developed by CIMNE. This included the validation of the interfaces developed in GiD to define on the finite element mesh in the 1D and 2D domains, as well as the interfaces to define the hydraulic analysis (data, initial, inlet and outlet conditions).

7. INTEGRATION OF THE RAMFLOOD DSS

7.1 Definition of use cases

The use cases which the Ramflood DSS can deal with are named: Hazard Assessment, Flood Management, Project Development, Project Management and System Maintenance.

Use case: **Hazard Assessment**.
Actors: User.
Description: The user enters into the Ramflood Web site and logs in. The system displays a set of dialog boxes and forms for operation. The user then chooses the area of interest and starts an hydrological analysis by introducing some parameters. The system does the necessary operations to evaluate in real time the hazard assessment on that area for given parameters. Hazard assessment is displayed as hazard maps for four variables: water velocity, the product of water level and water velocity level and the soil wet time.

Use case: **Flood Management**.
Actors: User.
Description: The system evaluates the flood hazard for a study area. The user consults the additional documentation contained in the system for the area in order to design an actuation plan. The user might also use the communication tools provided by the system to help in the decision process.

Use case: **Project Development**.
Actors: Expert user.
Description: The expert user creates new projects for new study areas. This actor is in charge of all the different tasks needed for that purpose and has all the necessary tools at his/her disposal. He/she defines new areas of study which can be flooded; then constructs an hydrological model for the area and finally trains a neural network to emulate the model. After each task has been validated, the expert user provides the system manager with the whole project to be included into the Ramflood DSS. The task of developing a new project is performed by following a well defined work protocol, and using software tools created for that purpose. The expert user can also update or delete any information related to a project.

Use case: **Project Management**.
Actors: System manager.
Description: The system manager includes, updates or deletes projects in the Ramflood DSS. This involves tasks such as making necessary changes in some dialog boxes, forms or in the user interface. This is always performed by following a defined work protocol and it is performed after a request from the system developer (the expert user).

Use case: **System Maintenance**.
Actors: System manager.
Description: The whole Ramflood DSS is maintained by the System manager. This task also involves verifying that the Web server is working properly at all times, or making some changes in the Ramflood Web site.

7.2 Virtual database

The virtual database was developed taking into consideration the needs and capabilities of the data providers and the data users, as well as the seamless integration of the database with other components of the RAMFLOOD DSS. The virtual database can be used in the following three modes:

- Planning and design for flood protection.
- Real time flood emergency.
- Flood recovery.

Technical requirements for the virtual database are not unique. This is due to the fact that geophysical and environmental databases, as well as numerical simulation databases, will be developed in the future at other sites by different water management agencies.

The main structure of the virtual database is the following:

- Geophysical and environmental data
    - Topography data
    - Satellite images
    - Soil and land cover data
    - Historical references of floods
- Numerical simulation data
    - Historical floods
    - Design floods
- Maps (each region)
    - Soil and land cover map
    - Risk maps
    - Topography maps
- Risk criteria
    - Technical information (description of the risk criteria to be used and the risk scales)
    - Experimental results:
        - Obtained in laboratory
        - Numerical results obtained in the computer simulation of flood
- Software (GiD, CARPA, etc)
- Another information (legal and sociological aspects, etc.)

7.3 Computer model database

The CARPA 1D and 2D finite volume analysis models and codes were integrated into the Ramflood modelbase (both 1D and 2D finite element models) with the GiD pre/post-processing system. Each code was calibrated using its own technical requirements.

In order to provide a wider spectrum of future applications, the GiD software was used to integrate the simulation flood models in the Ramflood modelbase. New flood simulation codes can be easily integrated in the Ramflood DSS simply by specifying the pre/post-processing data requirement of the new code. Therefore, the Ramflood DSS provides a seamless communication between different models and codes, between the codes and the databases, and between the models and the visualization utilities.

7.4 Decision module

Work in this task focused in implementing the Artificial Neural Network (ANN) module. CIMNE studied how resolve each part of the ANN module and the way of integrate it within the user interface.

The following definitions are useful to understand the scope of the RAMFLOOD DSS:

Study Area: Is a geographical region in which floods can be produced.

Hydraulic Model: It provides an hydrological analysis of the study area for a defined set of conditions. In the current version of the RAMFLOOD DSS it is based on the finite volume method.

Artificial Intelligent Module: It is able to emulate the hydraulic model in real time. It is based on Artificial Neural Networks.

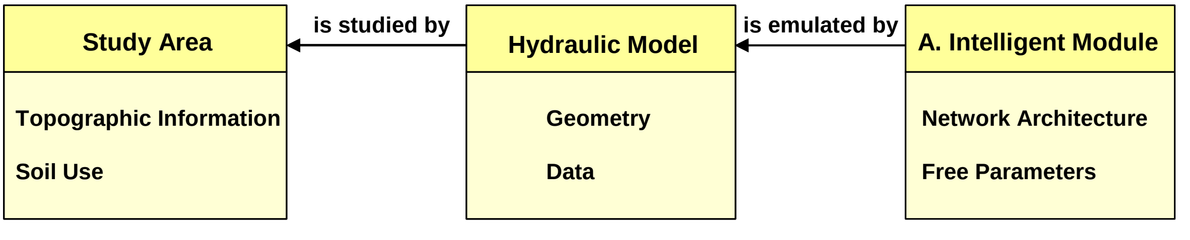


Figure 7.1 - Conceptual model with associations and attributes of the Ramflood System.

7.5 About the ANN method used

The ANN module provides accurate results for a flood analysis scenario in a few seconds. This approach is necessary for the Ramflood DSS, as flood scenarios require fast management. Also ANN's fast computation makes the Ramflood Decision Support System able to be Web based, which allows efficient risk assessment and management of emergency scenarios due to severe floods by different users at any location.

A multilayer perceptron architecture was chosen for the ANN.
This is defined as:

- A group of sensorial nodes x_1, …, x_n which form the input layer.
- One or more hidden layers of neurons.
- A group of neurons y_1, …, y_m which form the output layer.

The following figure shows the chosen ANN architecture.

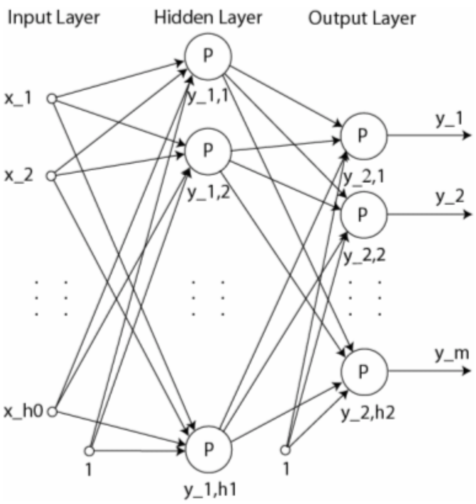


Figure 7.2 - Multilayer perceptron architecture

Commonly the multilayer perceptron is trained so that a particular input leads to a specific target output. This is a function approximation problem. The multilayer perceptron is capable of approximating any function with a desired accuracy.

The number of inputs to the network is constrained by the problem, and the number of neurons in the output layer is constrained by the number of outputs required by the problem. However, the number of layers between network inputs and the output layer and the sizes of the layers are up to the designer.

The inputs to the network must characterize a typical water flow increase in a head point of the river. For the Ramflood project this water flow is represented by 3 parameters: flood peak time (in seconds) peak flow rate (in m^3/s) and base time of the flooding (in seconds). These three parameters are chosen to be the inputs to the network:

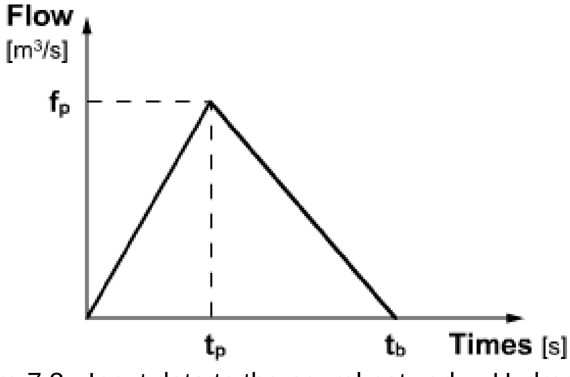


Figure 7.3 - Input data to the neural network – Hydrograph

The ANN must provide the information needed to plot the risk maps. For this propose four neurons were chosen in the output layer, one for each flood risk map considered; i.e.

- Maximum water velocity risk map.
- Maximum water height risk map.
- Maximum water velocity-height product risk map.
- Total wet time risk map.

In order to build the ANN module for the Ramflood Project we followed four steps:

- Generate the training data
- Pre-process the data
- Create and train the ANN structure
- Validate the results

7.5.1 Generation of the ANN training data

There are four steps in the training data generation process:

- Assign random values to the input variables. This step is associated with the data selection process, i.e., choosing which data provides the most important information.
- Obtain the flood simulation results using the flood model (CARPA) with the specified input values.
- Collect the input data and the numerical results and in a data file.
- Repeat steps 1, 2 and 3 until the size of the training data set is enough to map the flood model with a set accuracy. The size of the training data set is an important issue, since the more flood scenarios we analyse the more accurate the ANN results will be.

To define the input variables for the flood simulation analysis we used the Montecarlo method.
The following figure shows the training loop.

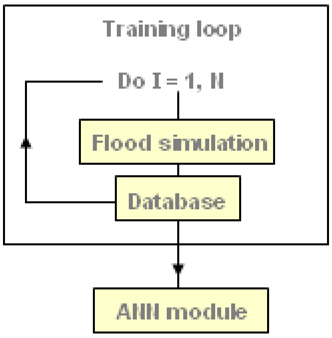


Figure 7.4 - Training loop of the ANN

The number of flood simulation runs depends on the accuracy required for the ANN. The greater the number of simulations, the greater the accuracy of the ANN for predicting on specific flood situation.
Previous experiences in the use of ANN for flood simulations in rural and urban areas lead to the conclusion that at lead 250 simulations runs were required for creating the training data base.
The training data base was therefore divided into two groups: **Group 1** including approximately 75 % of the data base, to be used for the training of the ANN.
Group 2 including approximately 25 % of the data base. This information was used for validation of the ANN.
This validation task serves for assessing capability of the ANN to emulate correctly the CARPA code. If this is not the case, the number of flood simulation runs of the training data base must be increased.

7.5.2 Pre-processing of the ANN training data

In practice it is always advantageous to apply pre-processing transformations to the input data before it is presented to the ANN. Similarly, the outputs of the network are then post-processed to give the required output values. One of the most common forms of pre-processing consists of a simple linear rescaling of the data. An approach for scaling the network inputs and targets is to normalize the mean and the standard deviation of the training set so that they will have zero mean and unity standard deviation. This pre-processing forces the input variables to have similar ranges, which simplifies the network training.

7.5.3 Training of the ANN

The neural network used is a classical multilayer perceptron with 3 input variables 15 sigmoidal neurons in a single hidden layer and 1 linear neuron in the output layer for each of the output variables.
For the training of the ANN the information from the flood simulation runs stored in the data base in the **Group 1** is used.

The learning algorithm chosen is the Levenberg-Marquardt algorithm.

The performance function used is the mean squared error. Training is performed until the mean squared error reaches a goal value of 0,001.

Finally, for each node of the finite element mesh we create 4 ANNs (one ANN for each output result that we need obtain).

7.5.4 Validation of the ANN results

The objective of a forecasting validation is to determine its quality. To validate a forecasting technique we need to compare the values provided by this technique to the actually observed values.

In order to carry out the validation task the information from the flood simulation runs stored in the data base in the **Group 2** was taken as the “exact reference data”. The validation is therefore comparing the exact reference data with those of the ANN.

The performance of a ANN can be measured to some extent by the mean squared error on the training set, but it is useful to investigate the network response in more detail. One option is to perform a regression analysis between the network response and the corresponding targets for an independent test set.

This analysis leads to 3 parameters. The first two, m and b, correspond to the slope and the y-intercept of the best linear regression relating targets to ANN outputs. If we had a perfect fit (outputs exactly equal to targets), the slope would be 1, and the y-intercept would be 0. The third parameter is the correlation coefficient (R-value) between the outputs and targets. If this number is equal to 1, then there is perfect correlation between targets and outputs.

To perform this analysis of the ANN response we put a test data set through the ANN and perform a linear regression between the network outputs and the corresponding targets.

The following figures illustrate a typical graphical output provided by this post-training analysis. A training data set with 3 input variables, 1 output variable and 1000 samples has been used. The data set has been split into 750 samples for training and 250 samples for testing. Both input and target data range from 0 to 1. Regression analysis is performed using data which has not been used for training, i.e., testing data. The fit here is good, since the error of the regression parameters m, b and R with respect to those for a perfect fit is less than 0.001 in all cases. ANN outputs are plotted versus targets as open circles. A dashed line indicates the best linear fit. A solid line indicates the perfect fit (output equal to targets).

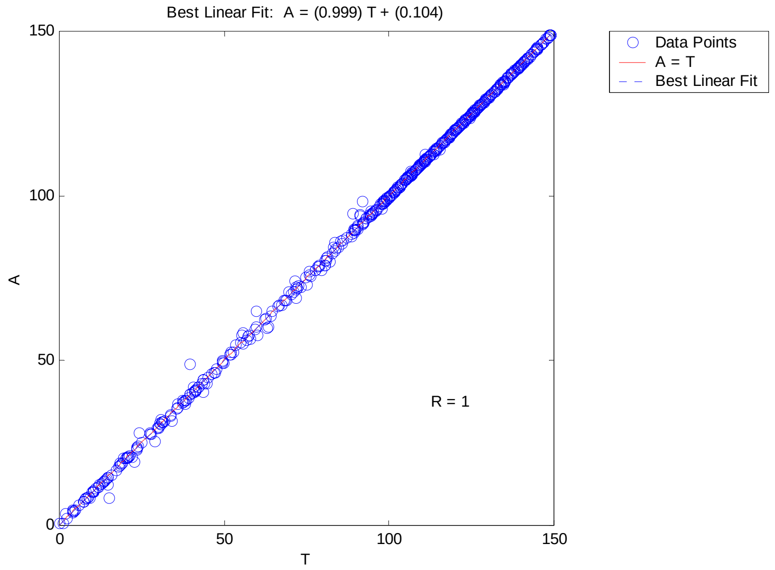


Figure 7.5 - Typical regression analysis. The figure represents ANN outputs versus targets.

The validation process of the ANN in the RAMFLOOD DSS can be depicted in a state diagram. State diagrams show states and transitions. They describe the behaviour of a system. Figure 7.6 shows the State Diagram for the validation of the ANN in the RAMFLOOD DSS.

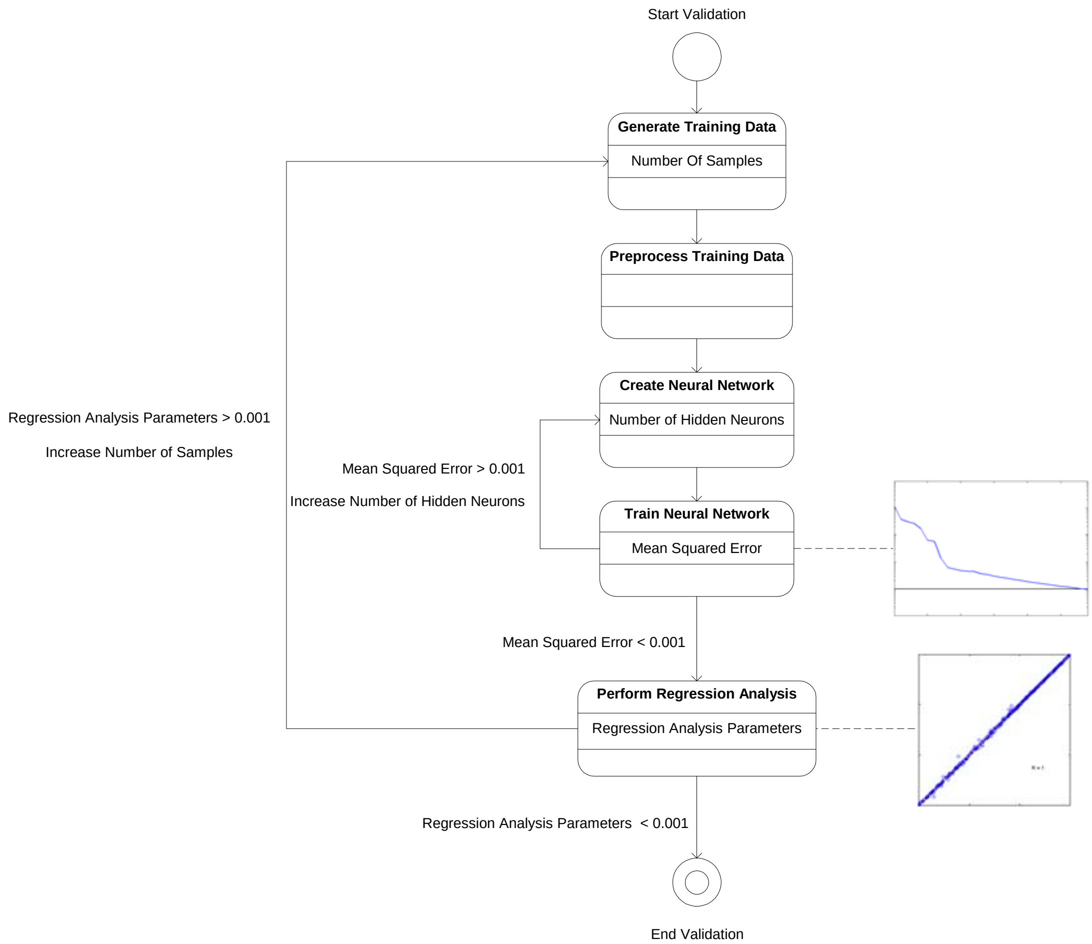


Figure 7.6. State Diagram for the validation of the ANN in the RAMFLOOD DSS.

Next we describe in detail the different tasks depicted in Figure 7.6 needed to be performed in order to validate the ANN in the RAMFLOOD DSS. The criteria used here will yield a relative error of the order of 0.001 in the hydraulic and flood risk maps, when compared to those provided by the hydraulic model CARPA.

We start by generating a training data set (of the order of 100 samples). Then the data is pre-processed so that the mean is 0 and the standard deviation is 1. From this data set a few of the elements (of the order of 25 elements) are separated for validation. The resulting training data set is then divided into training and test subsets. Normally three fourths of the samples are used for training and the rest for test.

Once the training data set is ready a multilayer perceptron with a certain number of neurons in the hidden layer (of the order of 10 neurons) is created for each element considered. The networks are assigned a performance function to be the mean squared error. The learning algorithm is based on the conjugate gradient method. Then we set the performance goal to be a mean squared error of 0.001.

The multilayer perceptrons are trained so that they reach the performance goal. If they do not, the number of neurons in the hidden layer is increased in a small number (of the order of 2 neurons) and the ANN are trained again.

When the multilayer perceptron for each validation element reaches the performance goal a regression analysis to check their generalization properties is performed. We set the goal regression analysis parameters to be $m = 0.001$, $b = 0.001$ and $R = 0.001$.

If the regression parameters got are below their goal for all the multilayer perceptrons then the number of samples in the training data set is enough and the number of hidden neurons in the ANN is right. If the value of the regression analysis parameters is greater than their goal more samples are needed in the training data set. The procedure then is to generate more training data (of the order of 50 samples) and repeat the whole process until the validation for all the elements considered is successful.

Once all the elements considered are validated we are ready to take the whole training data set for training. A network of multilayer perceptrons for each element in the geometry and each output variable is then created with the same number of hidden neurons as that used in the validation step. The ANN are assigned a performance function to be the mean squared error. The performance function, the learning algorithm and the performance goal are chosen to be the same as in the validation phase. The resulting ANN is trained until all the multilayer perceptrons reach the performance goal. The ANN is then ready to be used for hydraulic and flood risk maps forecasting in the RAMFLOOD DSS.

8. INTEGRATED RAMFLOOD DSS

The final integration of the different modules of the Ramflood DSS and the release of a first prototype was performed in WP5. A user-friendly and flexible interface to facilitate the use of the Ramflood system for different types of users was developed and tested. Particular care was taken in the development of flexible interfaces allowing the integration of alternative tools in the DSS in future applications (i.e. new data collection system, alternative flood simulation codes, new AI modules, etc.). The necessary user's documentation was produced. The prototype Ramflood DSS was installed at the premises of the end user partners ACA and SPAP.

CIMNE created the Ramflood DSS's interfaces following the guidelines agreed by the project partners. The design of the user interface has the form of a web site supported by many communication utilities written in Java and documents presented in Hypertext Markup Language (HTML).

Essential requirements for the effective uses of the Ramflood DSS are:

- Identification of the user level and provision of appropriate support.
- Simple intuitive design.
- Flexible design.
- Easy of use.

To access the Ramflood DSS, the users can click on the button "Ramflood DSS" in the Web page of the Ramflood project (http://www.cimne.com/ramflood/)

Figure 8.1

The following three levels of users were defined to access to the Ramflood DSS: End User, Expert User, System Manager.
The main features associated to each user level are described next.

End User

End Users can access the Ramflood DSS to obtain the risk maps associated to the study area as provided by the ANN. Also, the users can access to the database with the complementary information.
To complete this level the following tools to improve the communication between users were developed: forum, documentation, chat, videoconference, calendar and user's list.
The image below shows the main working window of the end user level:

Figure 8.2 – Main window of the End user level

The following figures show the DSS windows where the end user will fill in the hydraulic data ("Input Data") to obtain the risk maps in real time ("Output Data").

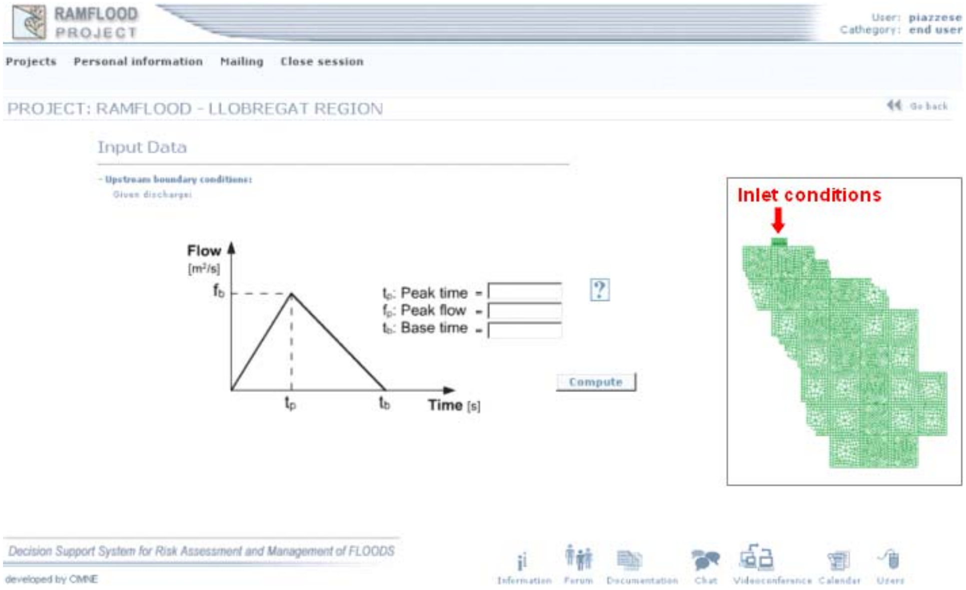


Figure 8.3 - Input Data window

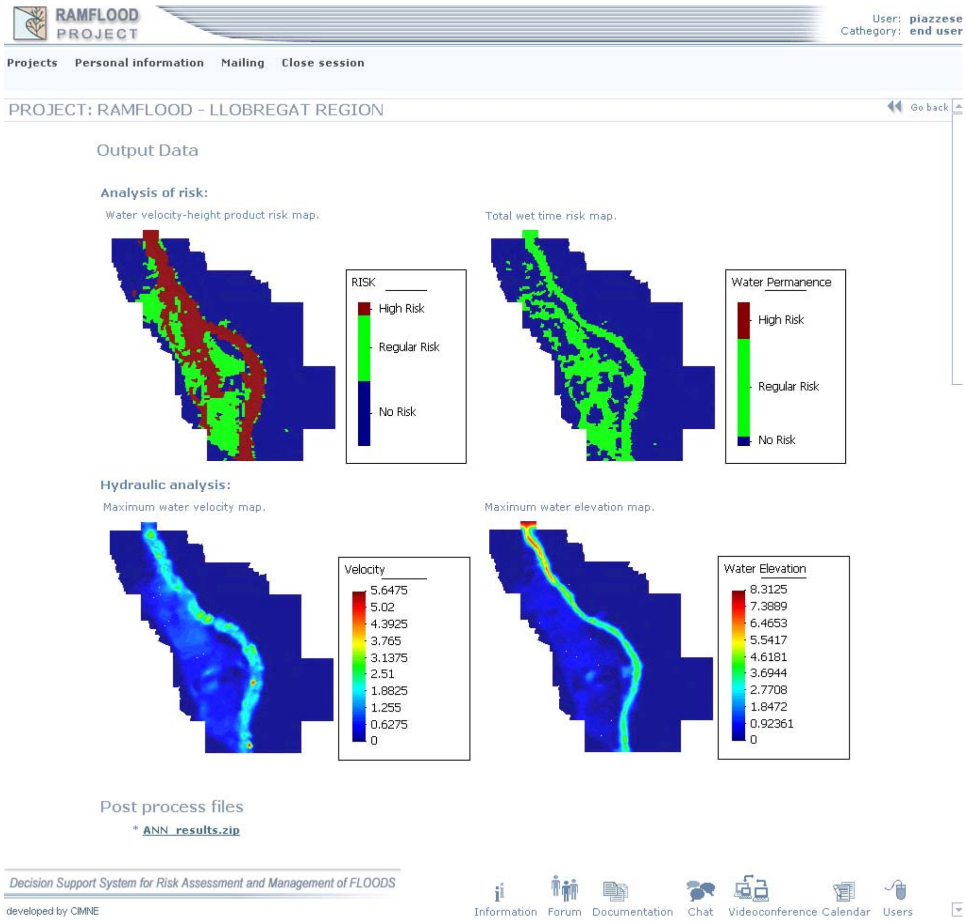


Figure 8.4 - Risk maps provided by the ANN module

In this "Output" window the end user can see the results obtained from the ANN analysis:

- Risk maps for: (a) the water velocity, and water height product and (b) Total wet time.
- Hydraulic analysis: maximum water velocity map and maximum water elevation map.

Also the End User can download the files to visualize the results using the GiD post processor (ANN-results.zip).

Expert user
This level includes the following sections: Ramflood DSS, Database and the Workflow. The Ramflood DSS and Database sections are similar to the End User level. The Expert User can access to the Workflow of the project with the information necessary to develop newly each part of the Ramflood DSS.

Also the following communication tools: forum, documentation, chat, videoconference, calendar and users (user's list) were included.

The image below shows the main working window of the Expert User level:

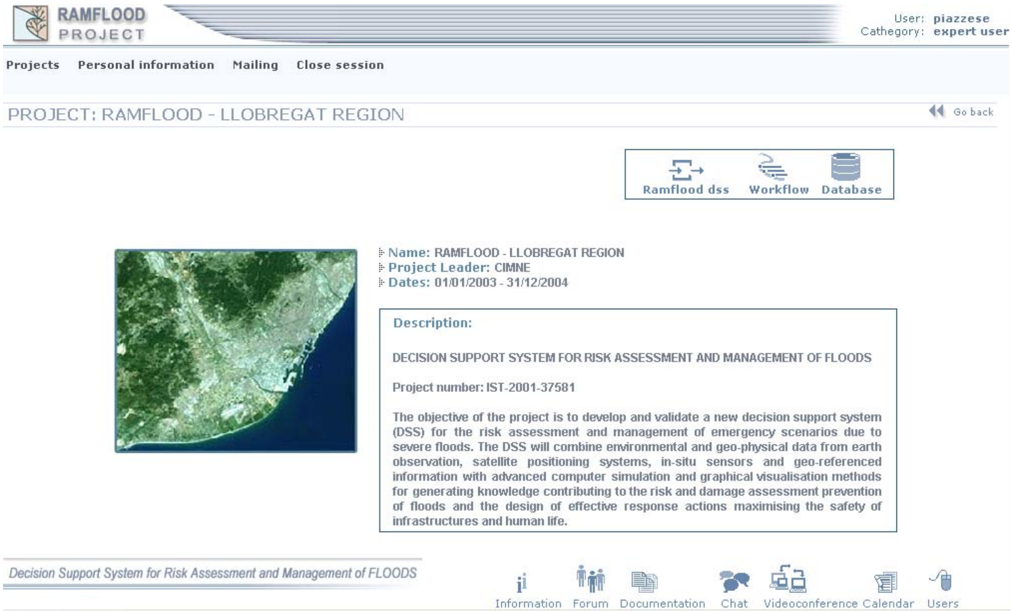


Figure 8.5 – Main working window of the Expert User level

System Manager
The System Manager can create new projects, create new users, modify and delete information of each project, modify and delete users, access to the mailing system to send emails, etc.

In the System Manager level, the users can also access to the available projects and the following sections: Ramflood DSS, Database and the Workflow (similar to the Expert user). Also the following communication tools: forum, documentation, chat, videoconference, calendar and users (user's list) were included.

The image below shows the main working window of the System Manager level:

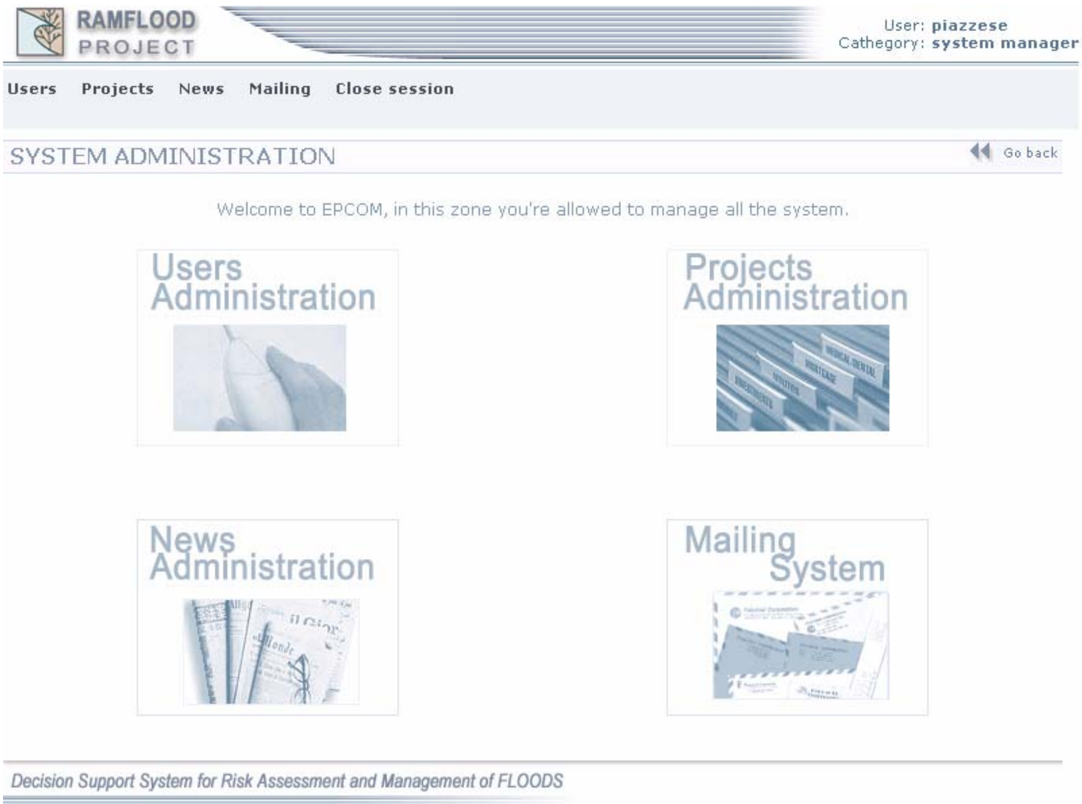


Figure 8.6 - Main working window of the System Manager

8.1 Ramflood DSS wizard tool

A computer tool (a wizard) has been created to automate the different steps for the creation of the artificial neural networks. The wizard is extremely useful for the future application of the Ramflood DSS to other areas of study.

The objective of the Ramflood wizard tool is to emulate, by means of a neural network, a hydrological model for flood forecasting. The main advantage of the neural network over the hydrological model is the higher speed that the neural network takes to perform a numerical simulation. Indeed, while the hydrological model might take several hours to complete a certain simulation, the neural network needs just seconds or minutes.

Thus, the Ramflood wizard tool includes all the necessary utilities to develop a neural network for the fast computation of flood risk maps. That maps include:

1. Total wet time map during a flood.
2. Maximum water velocity map.
3. Maximum water height map.
4. Maximum water velocity-water height product map.

Roughly speaking, the neural network works as follows: A set of flood risk maps with their corresponding initial and boundary conditions are presented to the network. The network is then trained in order to analyze new problems with different initial and boundary conditions.

When the Ramflood wizard tool is opened, the main window is displayed. The main window allows to interact with all the functionalities in the Ramflood Tool that is, from creating a project to performing a simulation with the ANN.

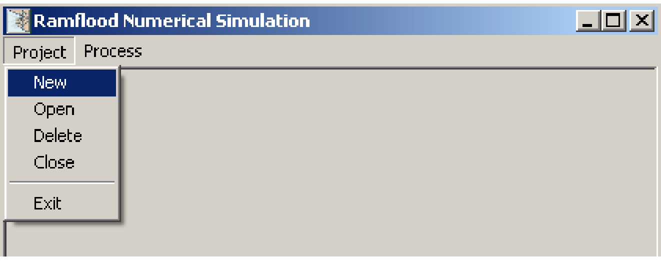


Figure 8.7 - The Ramflood wizard tool main window.

The next sections provide a detailed explanation of how to develop an ANN for the fast simulation of flood risk maps.

Create a New Project

In order to develop an ANN for simulation of flood risk maps, a project for the specific area of study must be created. To do that, just click “New” in the menu “Project” and select a name and a location for the project. In this example we create a new project called “Llobregat” in the location “C:\Ramflood\RamfloodWizard”.

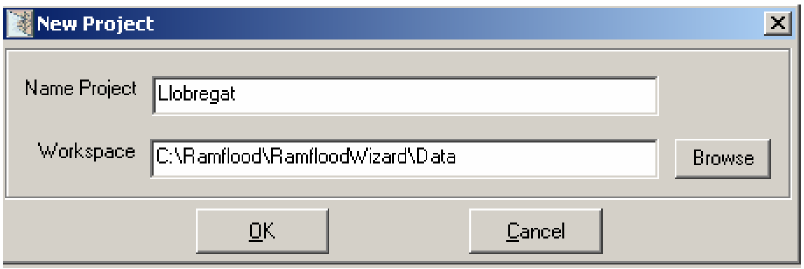


Figure 8.8 - Create a new project window.

Once a new project has been created we can open it at any time to do any work with that area of study.

At this point, we can start developing the neural network.

8.1.1 Generate the Training Data

The first step in developing the neural network is to generate the training data with which we will train the network. For that purpose we use the model for flood forecasting CARPA.

The inputs to the network must characterize a typical water flow increase in a head point of the river. The form of this hydrograph is determined by the analysis of hydrological studies and statistical data from the region of study.

For the Llobregat river basin, the hydrograph is represented by 3 parameters, which are chosen to be the inputs to the network:

1. Peak time, tp.
2. Peak flow, fp.
3. Base time, tb.

Figure 8.9 shows this flow peak in a certain point of the river which can produce a flood down bed.

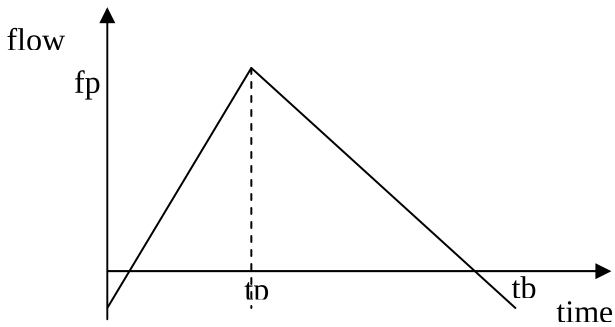


Figure 8.9 - Inputs to the neural network.

Once the form of the hydrograph has been chosen as input for the program CARPA, the hydraulic simulation can be performed. The simulation provides, among other information, that needed to generate the flood maps, that is, wet time, maximum velocity, maximum height and maximum velocity-height product for each element in the mesh. Table 1 shows the format of the file maxims.rep, which is the output file from CARPA.

Element	Wet time (s)	Max. velocity (m/s)	Max. height (m)	Max. velocity*height (m^2/s)
1	28800	2	0.5	1.2
2	43200	3.5	0.25	1
...	...	...	...	...
1000	0	0	0	0

Table 1. Format of file maxims.rep.

This information is used, together with the geometry information, to plot the four risk maps chosen.

In order to generate the training data set the following input files for the program CARPA, are needed "Carpa1DTemplate.dat" and "Carpa2DTemplate.dat". The "Carpa1DTemplate.dat" file contains information related to 1D's geometry and boundary conditions. The "Carpa2DTemplate.dat" file contains useful information about the 2D geometry and the boundary conditions. A "Variable.dat" file is also needed. This file contains a summary of parameters that are used for the Ramflood Tool. These three data files are created by an adequate GiD problem type.

Once the input data files "Carpa1DTemplate.dat", "Carpa2DTemplate.dat" and "Variables.dat" have been created the Ramflood DSS is needed to generate a training data set for the ANN. For that purpose, we open the project in question, and click on "Generate Training Data" in the menu "Process". Then, we need to specify

1. The location of the Carpa1DTemplate.dat data file.
2. The location of the Carpa2DTemplate.dat data file.
3. The location of the Carpa.exe program.

Figure 8.10 shows the look of this process in the main window of the Ramflood Tool.

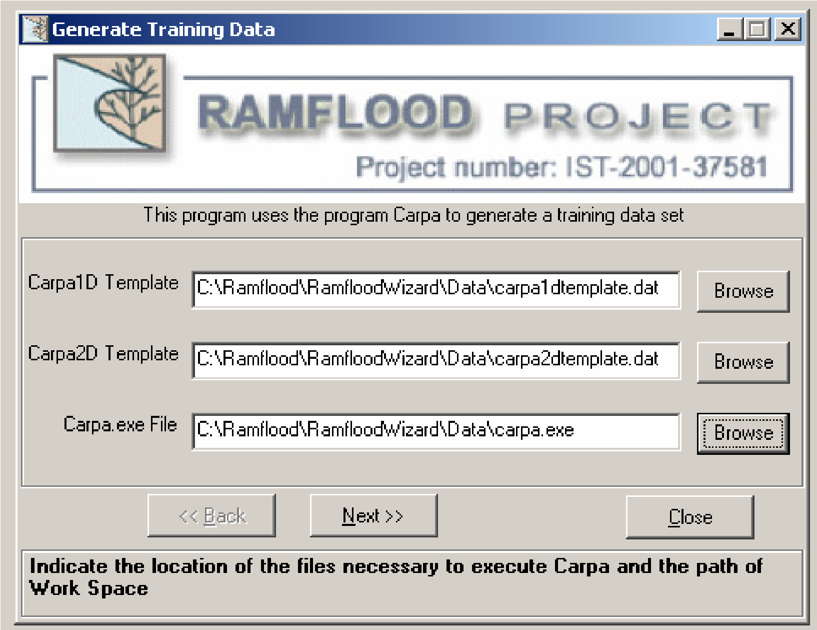


Figure 8.10 – Window shows the steps for the generation the training data for the ANN

There are four steps in the training data generation process:

1. Assign random values for the input variables. This step is associated to the data selection problem, i.e., choosing which data provides the most important information.

2. Execute the flood simulation model with that input values.

3. Collect the input data and output results from the flood simulation in a data file.

4. Repeat steps 1, 2 and 3 until the size of the training data set is enough to map the flood model with a desired accuracy.

The whole process results in four training data sets, one for each output variable: wet time, maximum velocity, maximum height and maximum velocity-height product.

In order to assign random values for the input variables their range of variation must be chosen. To do that, the Ramflood Wizard Tool provides a window for each pair of variables time-flow in the hydrogram. Write there the minimum and maximum values for each of the variables. If a variable is not to be consider as such, write the same maximum and minimum values in the corresponding boxes. That variable will then be treated as a constant. For the Llobregat example we are considering so far, the peak time (t1) varying from 10800 to 21600s, and the peak flow (q1) from 0 to 10. The starting flow (q1), for example, is always set to zero, so we write at both the minimum and maximum boxes a value of 0.

Figure 8.11 shows how the variable range assignment window appears in the Ramflood Wizard Tool.

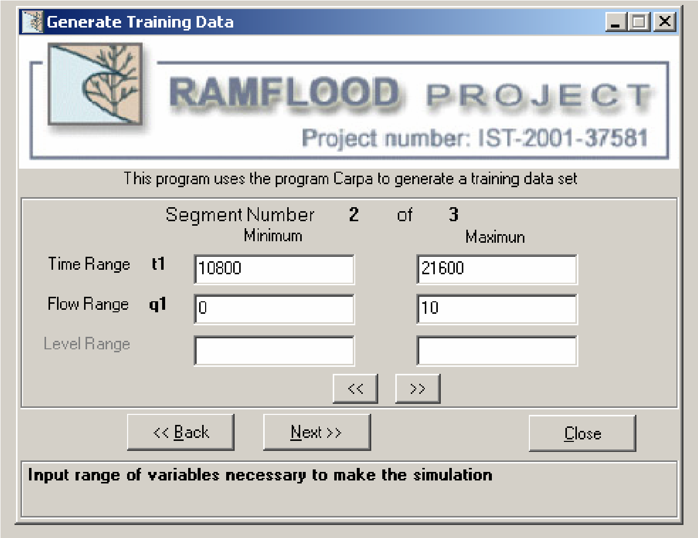


Figure 8.11 - Range variable assignment.

Once we have assigned the ranges for all the input variables, click the “Next” button. A window appears with a text box called “Cycles of Numerical Simulation”. Choose the number of flood simulations (samples) for the training data set and click the button “Generate Training Data”. Note that generating the training data set is the most time consuming process in the development of the ANN and it might take several days, or even weeks. For the Llobregat example we generate 250 samples, over two weeks.

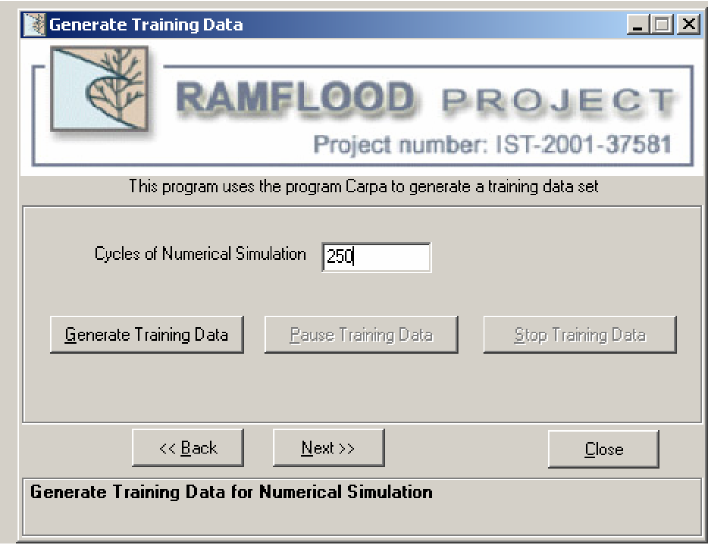


Figure 8.12 - Choose the number of samples in the training data set.

The training data is saved in a file called “traindata.dat”. The format of this file for the Llobregat example is as shown in Table 2.

Element	t2	q1	t1	v	h	Vh	T
1	8073	7	2734	3.90	0.50	0.20	22427
2	8073	7	2734	3.90	0.50	0.20	22427
3	8073	7	2734	3.90	0.50	0.20	22427

Table 2. Format of file traindata.dat file for the Llobregat river area.

The list step before proceeding to preprocess the training data. Is the splitting the file “traindata.dat” into 4 different training data files with an appropriate format, one for each output variable, that is, wet time, maximum velocity, maximum height and maximum velocity-height product. To do that, click the button “Order Data” in the Order Training Data window.

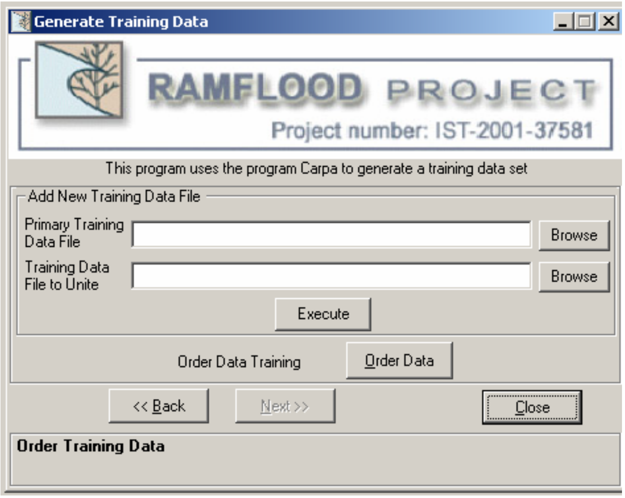


Figure 8.13 - Order Training Data Window.

The result for the training data step is a file called “traindata_v.dat”, were the suffix “v” represents the name of the variable under consideration. The format of the file “traindata_h.dat” for the Llobregat example, where the suffix “h” means that it corresponds to the height variable, is shown in Table 2.

t1 q1 t2 h			
4001 250 3 1			
Flag			
1			
8125	7.50	3680	0.5
7586	6.30	4582	0.6
6528	9.80	2865	0.3

Table 2. Format of file “traindata_h.dat”.

Here:

- “t1 q1 t2 h” indicate the names of the variables
- “4001 250 3 1” indicates the number of elements in the geometry, the number of samples in the training data set, the number of input variables and the number of output variables.
- “flag” indicates the training data set for a new element.
- “1” is the index for the element in the geometry.

8.1.2 Pre-process the Training Data

In practice it is always advantageous to pre-process the training data before it is presented to the ANN. Once the ANN has been trained, the inputs must be pre-processed to give the required input values for the ANN. Similarly, the outputs from the ANN are then post-processed to provide the user with the required output values. One of the most common forms of pre-processing consists of a simple linear rescaling of the data. An approach for scaling ANN inputs and targets is to normalize the mean and the standard deviation of the training set so that they have a zero mean value and a unit standard deviation. This forces the input variables to have similar ranges, which makes easier the training of the ANN.

Thus, this process creates, from a raw training data file, a preprocessed training data file and a mean and standard deviation of input and target variables data file.

In order to preprocess the training data we need to specify:

1. The location of the raw training data file.
2. The location of the preprocessed training data file to be created.
3. The location of the mean and standard deviation of input and target variables data file to be created.

Figure 8.14 shows how this process appears in the main window of the Ramflood Tool.

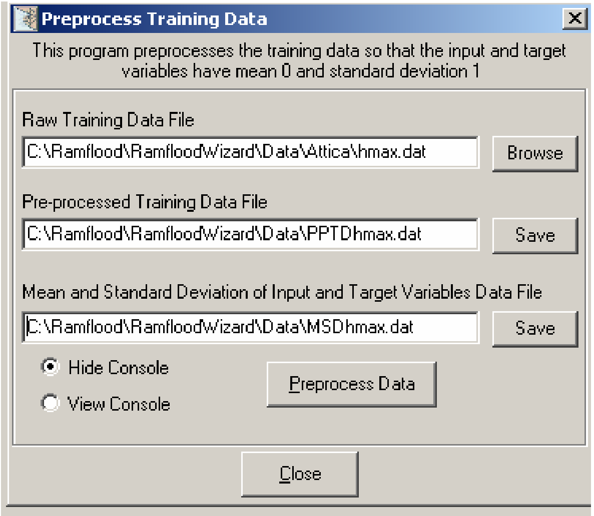


Figure 8.14 - Preprocess Training Data.

Once the location of all input and output data files has been specified, click the button "Preprocess Data" in order to preprocess the data. You can turn on the View Console radio button for information on the actual process.

This must be repeated for each of the four output variables. Thus, the whole process will result in four pre-processed training data files and four mean and standard deviation data files, one for each output variable: wet time, maximum velocity, maximum height and maximum velocity-height product.

8.1.3 Create the Neural Network

Once the training data file has been created and pre-processed, we are ready to create the ANN structure. This consists of a data file containing the size, architecture and free parameters of the ANN.

An artificial neural network of the type multilayer perceptron with a hidden layer of sigmoid neurons and an output layer of linear neurons can approximate any function. For a multilayer perceptron, the number of neurons in the hidden layer is the only design parameter, being the others (number of inputs and number of outputs) constrained by the problem. The number of neurons in the hidden layer depends on two things: the number of inputs to the network and the complexity of the output. The more inputs to the network the more neurons in the hidden layer we need. Similarly, the more complex we believe the output is, the more neurons in the hidden layer we might need.

In this way, an ANN structure consists of a vector of neural networks of the type multilayer perceptron with size equal to the number of elements in the geometry of the area of study. The number of inputs of each multilayer perceptron is equal to the number of parameters which represent the hydrograph considered. The number of outputs of each multilayer perceptron is one. As mentioned above, the decision on the number of hidden neurons is up to the designer.

In the example of the Llobregat basin considered, the mesh had 4001 finite volumes, the number of inputs is 3, the chosen number of hidden neurons is 12 and the number of outputs is 1. Four neural network structures of this type are needed, one for each output variable: wet time, maximum velocity, maximum height and maximum velocity-height product. Therefore 16004 ANNs were created,

To create a ANN structure with the Ramflood Tool, click "Create Neural Network" in the menu "Process". Then, specify

1. The location of the raw training data file. This file contains the variables name, the size of the neural network we need and the number of input and output variables.
2. The number of neurons in the hidden layer.
3. The location of the neural network data file to be created.

Figure 8.15 shows how this process appears in the main window of the Ramflood Tool.

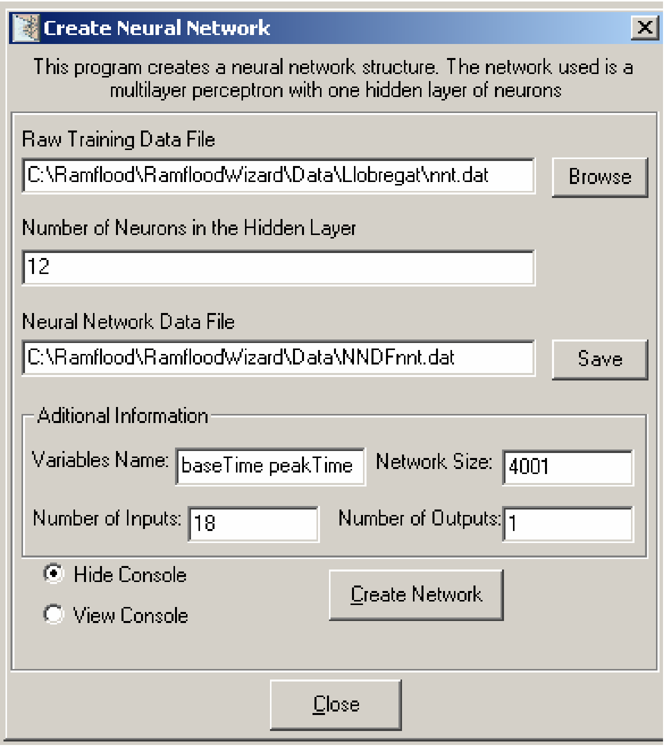


Figure 8.15 - Create Neural Network.

When the location of the raw training data set is specified, the Ramflood wizard tool reads the additional information from it and writes this information in the dialog box.

Once the location of the raw training data file, the number of neurons in the hidden layer of each multilayer perceptron and the location of the neural network data file have been specified, click the “Create Network” button to proceed. You can turn on the “View Console” radio button for information on the actual process.

This must be repeated for each of the four output variables. Thus, the whole process will result in four neural network data files, one for each output variable: wet time, maximum velocity, maximum height and maximum velocity-height product.

8.1.4 Train the Neural Network

After an ANN is created it must be assigned a performance function. A very common performance function used in function regression problems is the mean squared error. In order to train the neural network we must choose a learning algorithm. A very common learning algorithm for the mean squared error performance function is the conjugate gradient method.

The training of a multilayer perceptron progresses until a stopping criterium is satisfied.
The performance goal is an important stopping criterion. Here, training stops when the performance function of the network reaches a goal value. A second stopping criterion is the goal for the norm of the performance function gradient there the training stops when the norm of the performance function gradient reaches a value close to zero. A third stopping criterion is the maximum number of epochs to train the training stops when the learning algorithm reaches a maximum number of iteration. Another stopping criterion is the maximum training time. Here the training stops when the learning algorithm spends a maximum computing time.

A training parameter which is not a stopping criterion is the number of epochs between the showing progress. This training parameter is used for visualization purposes. It indicates the interval at which the information on the training process is displayed in the console.

For on the Llobregat basin considered, the stopping criterion chosen was the **performance goal**. A value of 0.01 for the mean squared error was chosen. This occurred after 100 epochs approximately. The goal for the norm of the performance function gradient was set to 0 and the maximum training time to a large number, about 600s. It might occur that not all the elements in the network structure reach the performance goal for the chosen training criterion. In this case we need to proceed to another cycle of training. In all cases it is always advisable to check the training progress to make sure that everything goes as expected. Training is a very time consuming task and it might take several days, or even weeks.

In summary to train an ANN structure with the Ramflood wizard tool, click “Train Neural Network” in the menu “Process”. Then, specify:

1. The location of the pre-processed training data file with which the neural network is to be trained.
2. The location of the neural network data file. Make sure that the training data and the neural network correspond to the same output variable.
3. The stopping criteria: Performance goal, goal for the norm of the performance function gradient, maximum number of epochs to train and maximum training time.
4. The number of epochs between the showing progress training parameter.
5. The number of cycles this training process is to be performed.

Figure 8.16 shows how the appearance of the ANN training process in the main window of the Ramflood Tool.

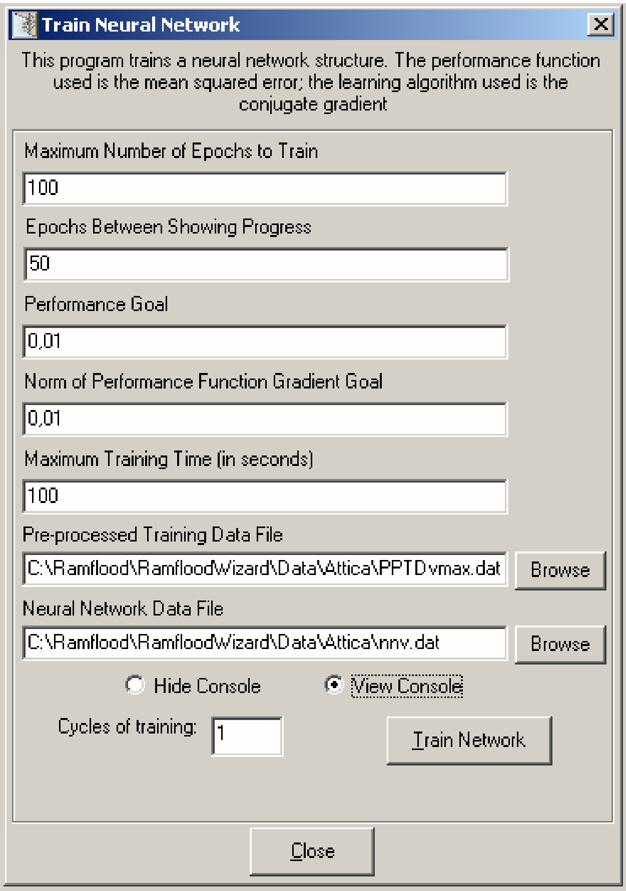


Figure 8.16 – Window specify the parameters for training the ANN.

Once the location of the training file, the location of the neural network data file and all the stopping and training criteria have been specified, click the “Train Network” button to proceed. It is important to turn on the “View Console” radio button in order to check the actual training process.

After the ANN training, its performance has to be validated. The validation form chosen here is the bound error criteria: When the mean squared error is lower than the performance goal for all the elements, the network is validated. Otherwise the network comes back to a new training cycle until the network converges.

The training progress must be repeated for each of the four output variables. Thus, the whole process will result in adjustments of all the free parameters in the four neural network data files, one for each output variable: wet time, maximum velocity, maximum height and maximum velocity-height product.

8.1.5 Check the Neural Network

The last step in the development of an ANN for simulation of flood maps is to validate the network's output. This is done by first performing a few simulations with the hydraulic model for inputs not included in the training data set, i.e., for inputs that the ANN has never seen. Then the same simulations are performed by means of the ANN. Both results should coincide within and specified tolerance. If this is not the case, one or more steps in the training process should be repeated.

To validate a single ANN structure with the Ramflood wizard tool, click "Check Neural Network" in the menu "Process". Then, specify

1. The variable for which we want to validate the network: maximum height, maximum velocity, maximum velocity-height or wet time.
2. The location of the neural network data file for that variable.
3. The location of the mean and standard deviation data file for that variable. Make sure that the neural network and the mean and standard deviation data files correspond to the same output variable.
4. The output file to be created. This file contains the results of the simulation for a single output variable.
5. The input values for the simulation.

Figure 8.17 shows how this process appears in the main window of the Ramflood Tool.

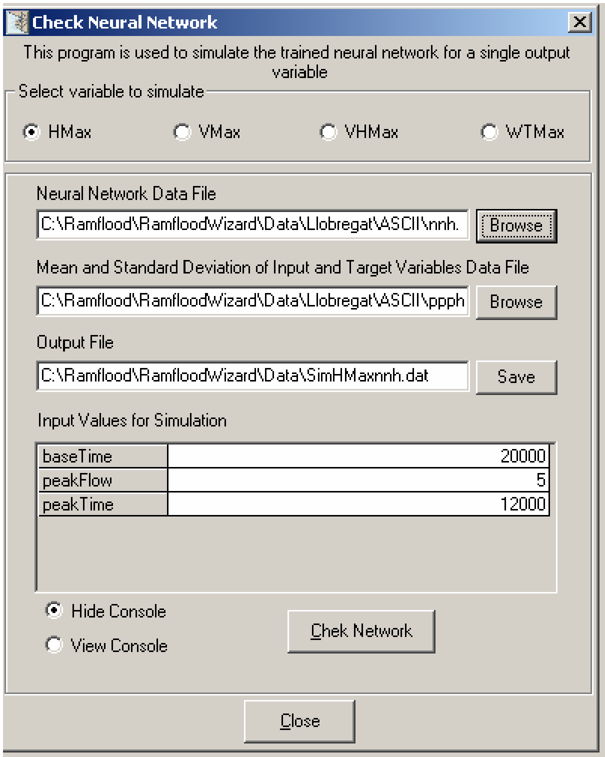


Figure 8.17 – Window for validation of the neural network.

This program is used to simulate the trained ANN for a single output variable. The program accepts two files as input (ANN data file and mean and standard deviation of input and target variables data file) and returns one files as output (output data file).

This process creates an output file. Use the program RamfloodViewResults.exe together with the data file to generate the GiD files salida.flavia.msh and salida.flavia.res.

8.1.6 Visualization of the ANN results

Once the ANN has been validated it is ready to be user. The results obtained by the ANN are post-processed for visualization. Risk or hydrological variables are plotted on a map of the region. To do this we create a results data file to be read by the pre/post-processor GiD.

This program is used to simulate the neural networks for each of the four output variables. It takes 8 files as input (ANN data file and mean and standard deviation data file for each of the four output variables) and returns 1 file as output (output data file). If the data files have a standard name, the user does not need to specify all the names. The standard names accepted by the Ramflood Tool for the neural network data files are,: “NNDFhmax.dat”, “NNDFvmax.dat”, “NNDFvhmax.dat” and “NNDFwt.dat”; the standard names accepted by the Ramflood Tool for the mean and standard deviation data files are: “PPPhmax.dat”, “PPPvmax.dat”, “PPPvhmax.dat” and “PPPwt.dat”.

Figure 8.18 shows how the graphics simulation process appears in the main window of the Ramflood wizard tool. The user has to fill in the hydraulic variables in order to obtain the specific hazard (risk) results provided by the ANN.

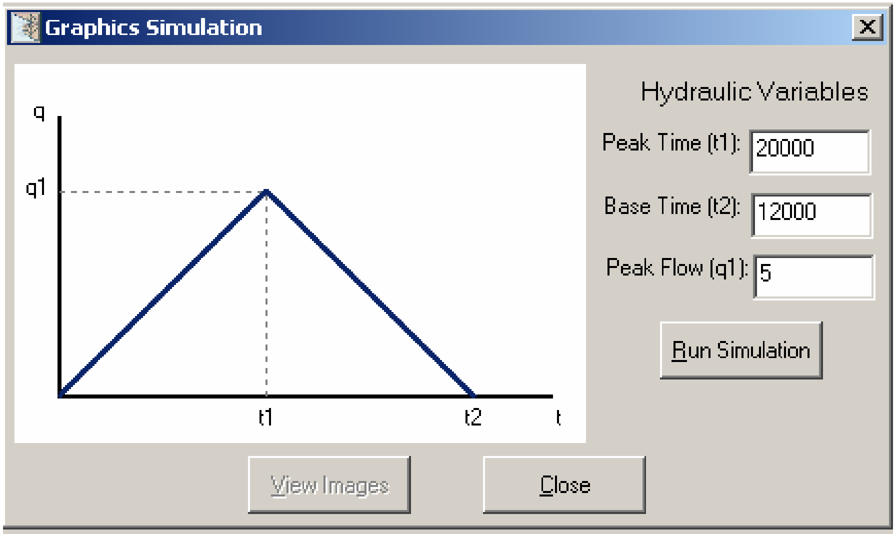


Figure 8.18 - Main window to simulate a flood using the ANN created.

Use the program RamfloodViewResults.exe together with the data file to generate the GiD files salida.flavia.msh and salida.flavia.res.

9. APPLICATION OF THE RAMFLOOD DSS TO THE LLOBREGAT RIVER DELTA AREA

9.1 Summary of the basic steps

The hydraulic simulation of the Llobregat region in Barcelona (Spain) involved the following activities:

1. Definition of the area of interest

2. Definition of the analysis data:
    - Import of DTM and creation of the surfaces
    - Creation of the finite element mesh
    - Definition of the mesh properties
    - Definition of the type of analysis (1D - 2D) on the analysis mesh
    - Definition of the mesh conditions
    - Assessment of the values range for the inlet conditions
    - Generation of the output files for the training of the ANN

3. Flood analysis of the Llobregat river basin

4. Training of the ANN for the Llobregat river basin.

5. Integration of the AI module into Ramflood DSS.

9.2 Definition of Llobregat river area selected

The area starts at the Sant Andreu de la Barca village, where the Riera de Rubi incorporation creates some local problems in this area. The Llobregat river is limited in the right and left banks by two highways until the Sant Feliu de Llobregat village, where the right bank highway disappears and a large floodplain is located, prone to be flooded by the Llobregat river. Agricultural activities are still found in this floodplain. The floodplain arrives to the Sant Boi meander, and here begins a flood protection dyke down to the mouth. The river is limited by the two lateral dykes but floodplains extends north and south. In the north area (west bank) we found two important cities: Cornellá and l'Hospitalet de Llobregat, with the urban area very close to the dykes. On the other side (right bank) we find the farming area of Sant Boi de Llobregat, one of the most important forming area of the Llobregat delta.

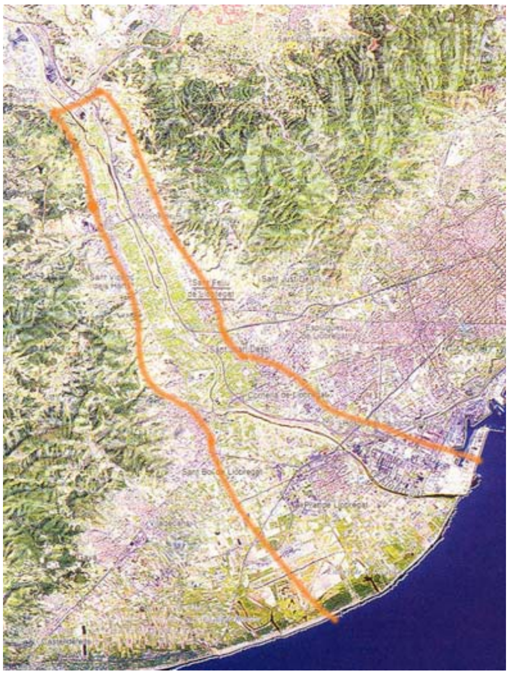


Figure 9.1 - Llobregat deltaic region

9.3 Definition of the analysis data

For the pre-processing of the computation data and the graphical visualization of numerical results we used the GiD system developed by CIMNE.

9.3.1 Import of DTM and creation of the surfaces.

In order to import the Digital Terrain Model information from Arc/Info ASCII Grid files, an auxiliary code was developed with its corresponding interface in GiD. The code read file's data and use then to create points, lines and finally the NURBS-Surfaces.

A remarkable advantage of this auxiliary code is that it allows creating from the original DTM files new files with the needed dimensions and import the data with different accuracy. The result is a group of surfaces that represent the study area.

The following images show the interface and the result of the import task.

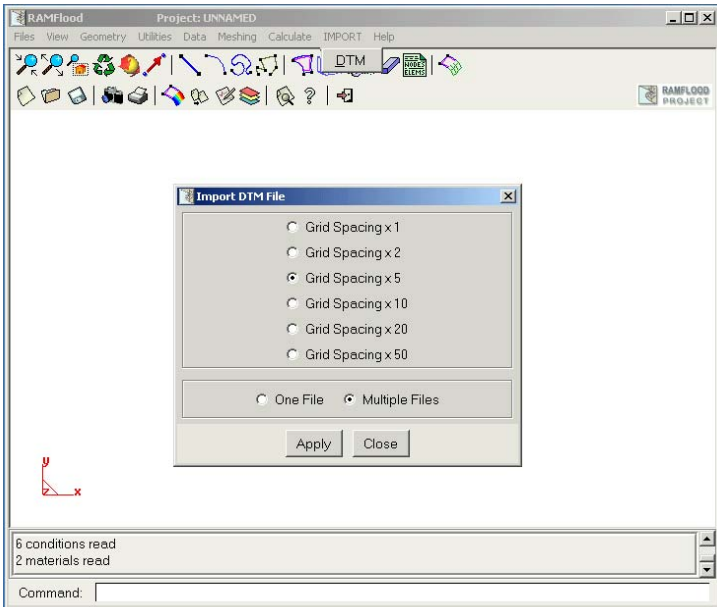


Figure 9.2 – Main window to import the DTM information

The number of surfaces is related to the number of files imported.

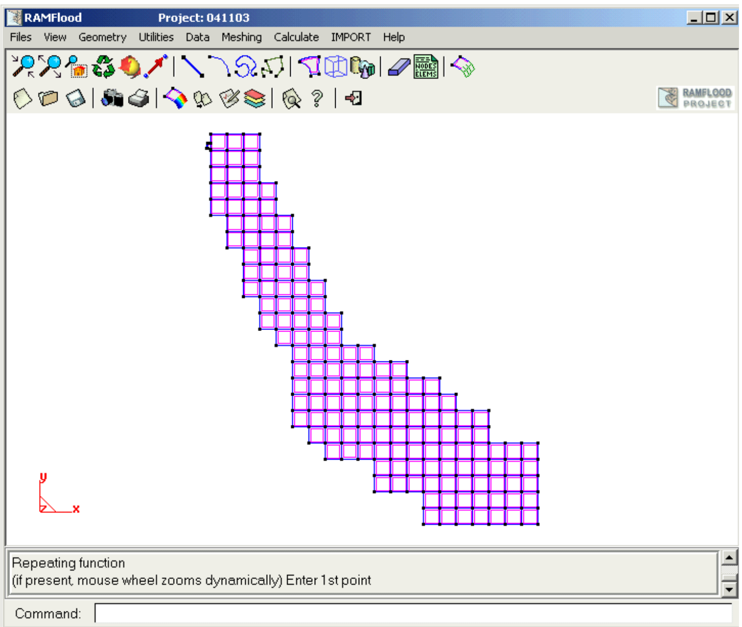


Figure 9.3 – Surfaces created in GiD from the DTM information

Next figure shows a rendered image of the study area. This tool is useful to see easily the visualization of the area.

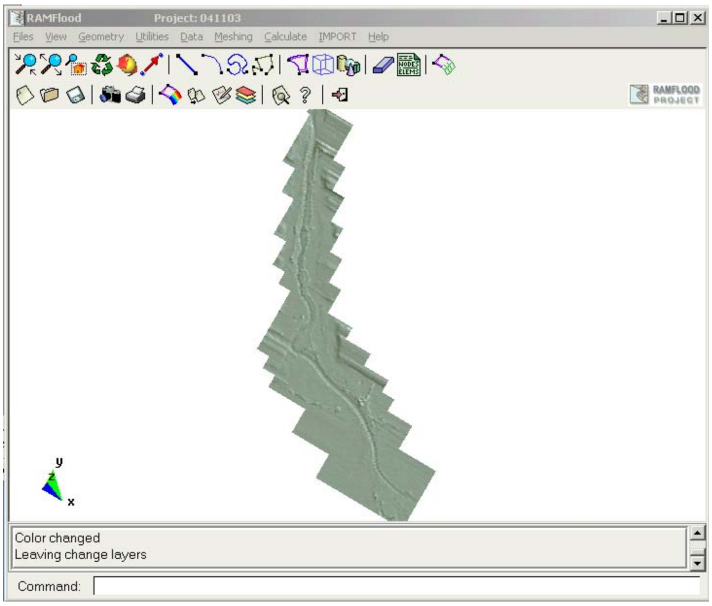


Figure 9.4 – Visualization of the Llobregat river area of study in 3D

9.3.2 *Creation of the finite elements mesh.*

The analysis mesh of 21574 quadrilateral elements was generated using GiD. The following image shows the final mesh obtained

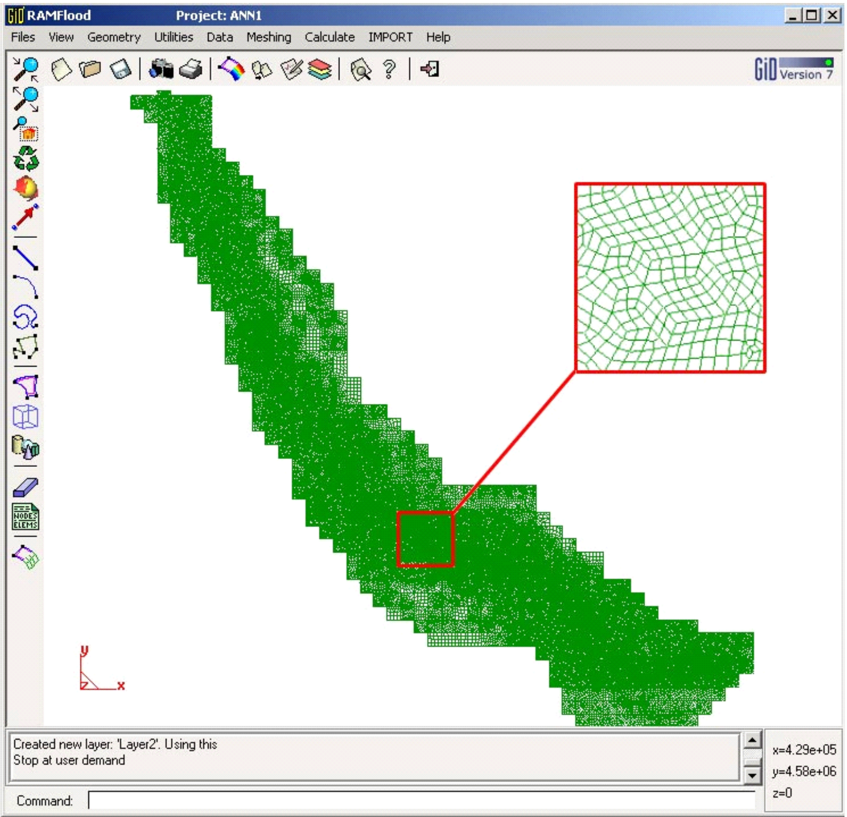


Figure 9.5 – Unstructured mesh of quadrilateral elements for the flood simulation

9.3.3 Definition of the mesh properties

The mesh properties have been defined automatically from the land uses map.

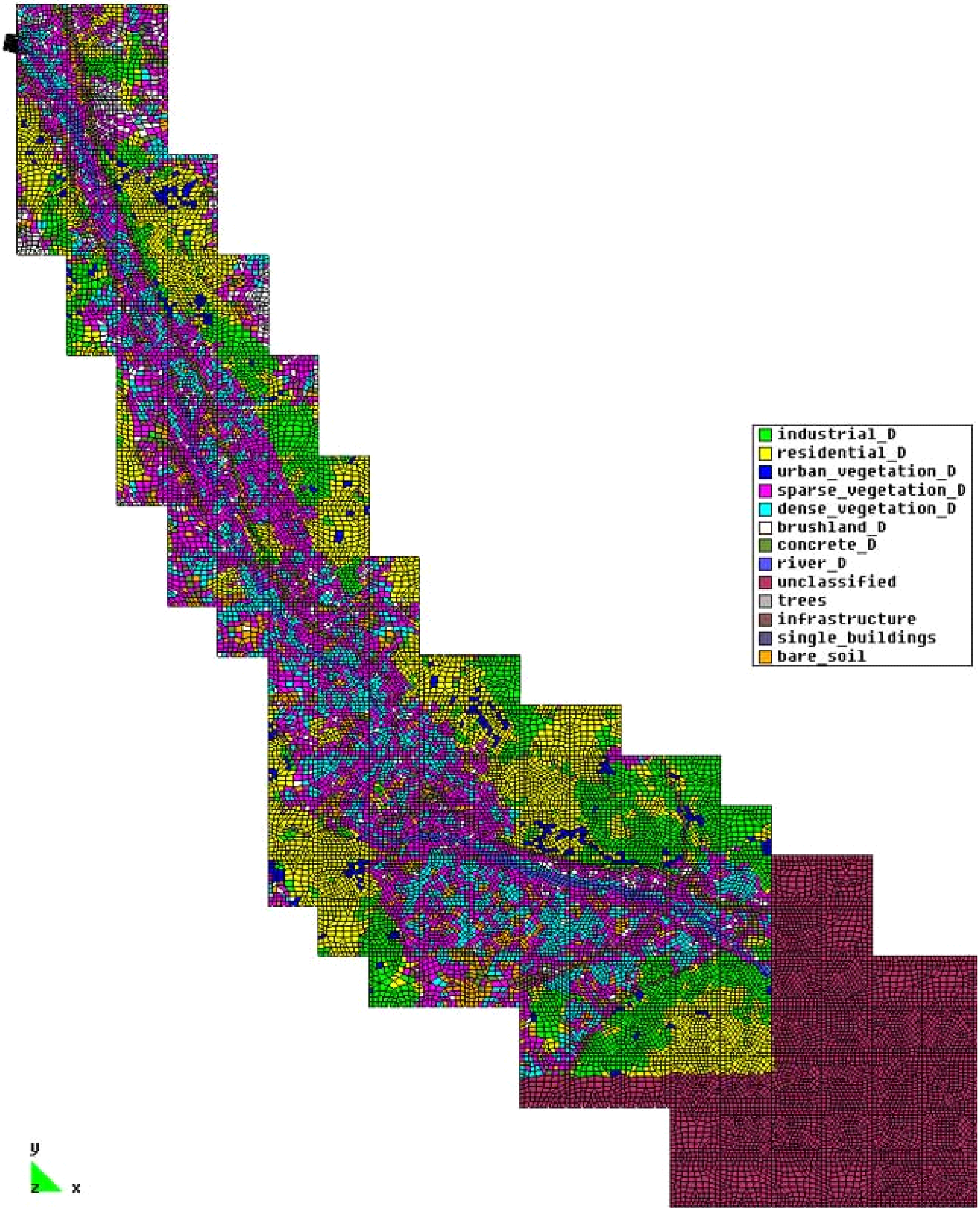


Figure 9.6 - Definition of the mesh properties over the Llobregat delta area.

9.3.4 *Definition of the type of analysis (1D - 2D) on the analysis mesh.*

The next step was to identify the different areas on the basin where the Llobregat river will be studied using the finite volume method for hydraulic analysis in 1D and 2D.

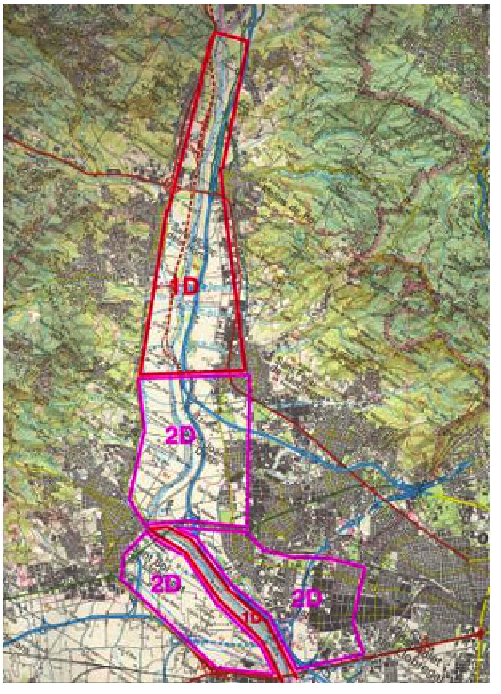


Figure 9.7 - Topographic map of the Area of Interest: Llobregat basin

Using the GiD tools we divided the Llobregat mesh in three parts (see next figure) to be studied by the 1D and 2D CARPA finite volume code.

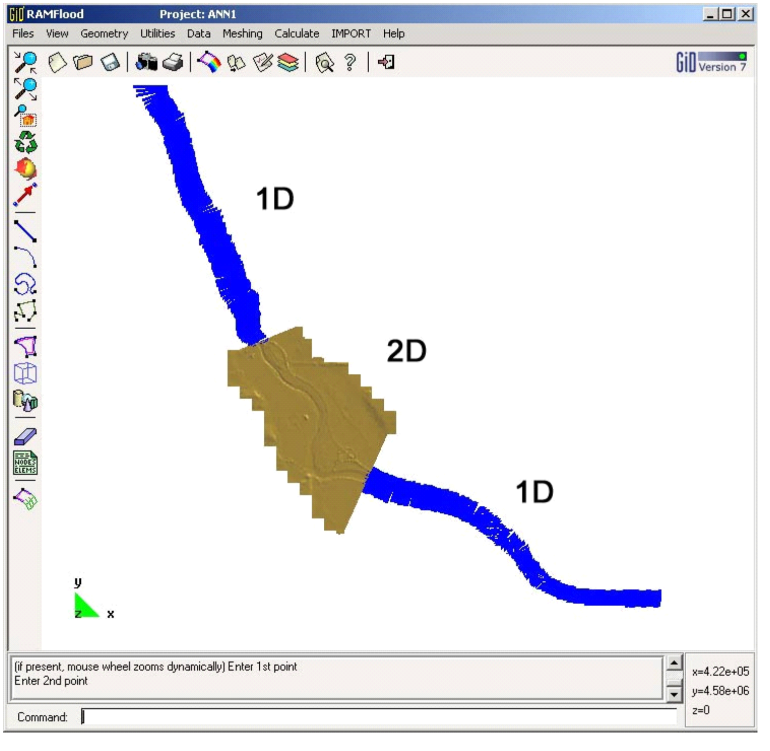


Figure 9.8 - Definition of the: 1D and 2D areas for the flood simulations

The 1D geometry is obtained from the 2D mesh. First, the 1D area is chosen, and then the river axis and the sections are defined. After that, “cuts” were performed for creating all the transversal sections (and the associated mesh).

9.3.5 Definition of the analysis conditions.

The next step is the definition of the hydraulic analysis conditions. The following GiD tools have been developed to define the initial conditions and the boundary conditions:

Initial condition: tool developed to define the initial water depth on the mesh
As the volume of base of the Llobregat River is small in comparison with the volumes that are transported after a rain, it was decided not to take it into account and a dry initial condition was assigned. Hence the initial condition was set to Wet depth (0.01 m)

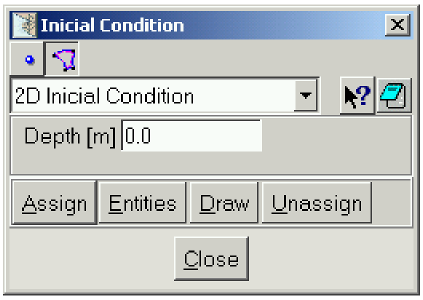


Figure 9.9 – Inlet condition window

Boundary conditions: tool developed to define the inlet condition and the outlet condition on the mesh

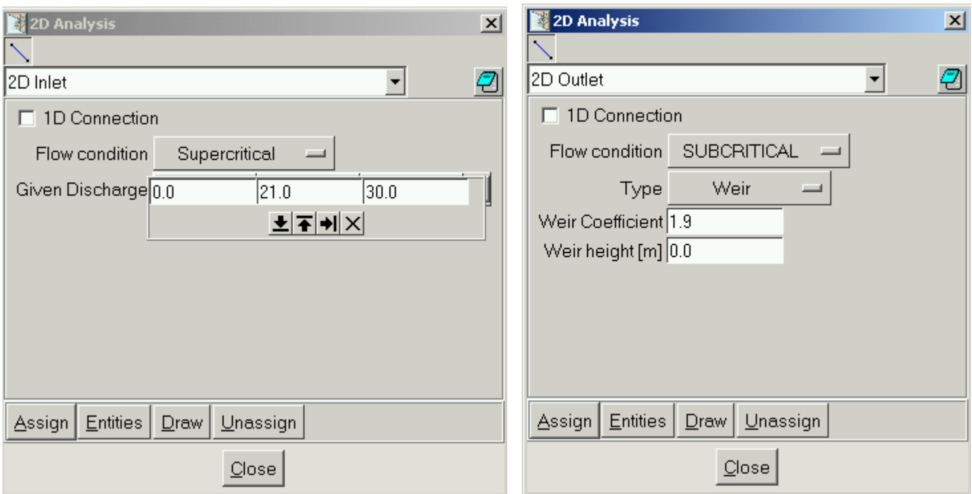


Figure 9.10 – Boundary condition windows

In the following images we can see the conditions assigned to the hydraulic analysis model.

1D inlet and outlet conditions

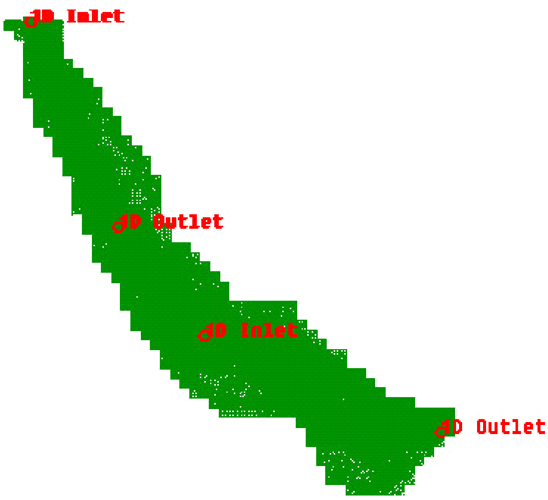


Figure 9.11 - 1D inlet and outlet conditions
2D inlet and outlet conditions

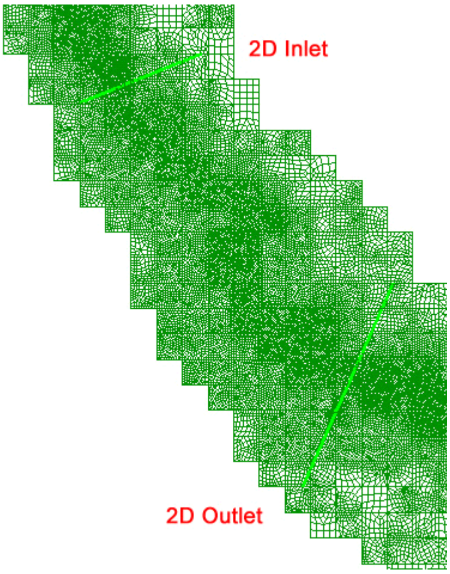


Figure 9.12 - 2D inlet and outlet conditions

9.3.6 Assessment of the values range for the inlet conditions.

In order to generate the training data for the ANN, UPC defined the values range of the inlet conditions for the Llobregat River.

The input variables of the inlet conditions are: Base time (**t_b** in seconds), Peak flow (**f_p** in m^3/s), Peak time (**t_p** in seconds)

See the following image:

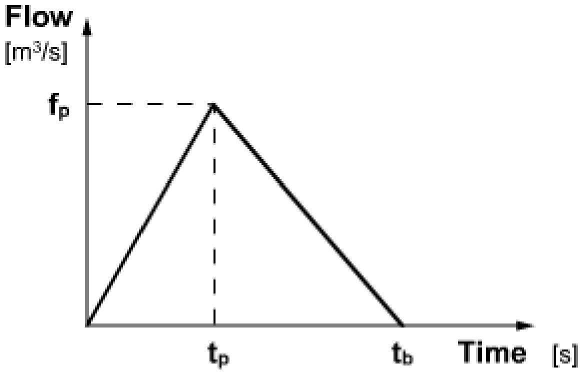


Figure 9.13 - Inlet conditions

The specific values proposed by UPC for the Llobregat river case are:

tb: 0 – 12 hours
fp: 500 m3/s –5000 m3/s
tp: ¼ - ½ of tb

9.3.7 Generation of the output files for the training of the ANN..

The next step is to define the pre-process data, to run the hydraulic simulation model and to visualize the simulation results. In the next image we can see one of the options to generate the preprocess files using the GiD system.

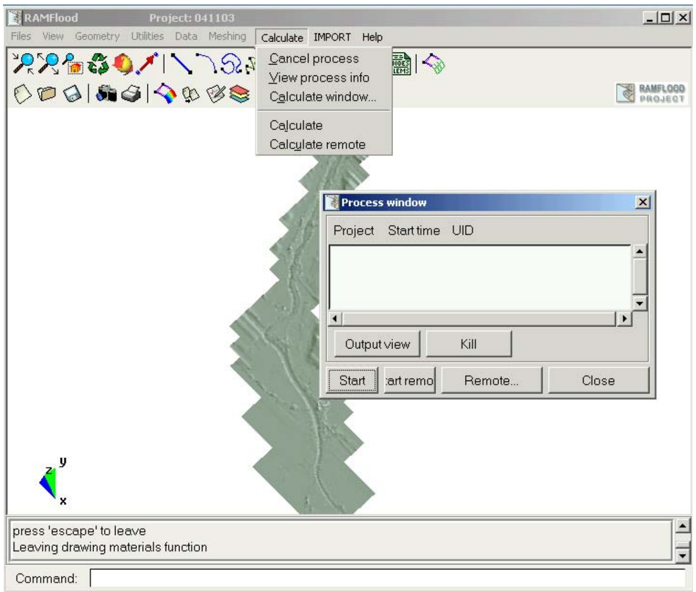


Figure 9.14 – Main window to start the flood analysis

9.4 Flood analysis of the Llobregat river basin

To validate the hydraulic analysis different studies on the basin using information available to the UPC and ACA about floods of the Llobregat River were carried out. This included the flow data, depths, velocities, floodplain, etc.

The numerical results are visualized using the post-processing facility available in the GiD.

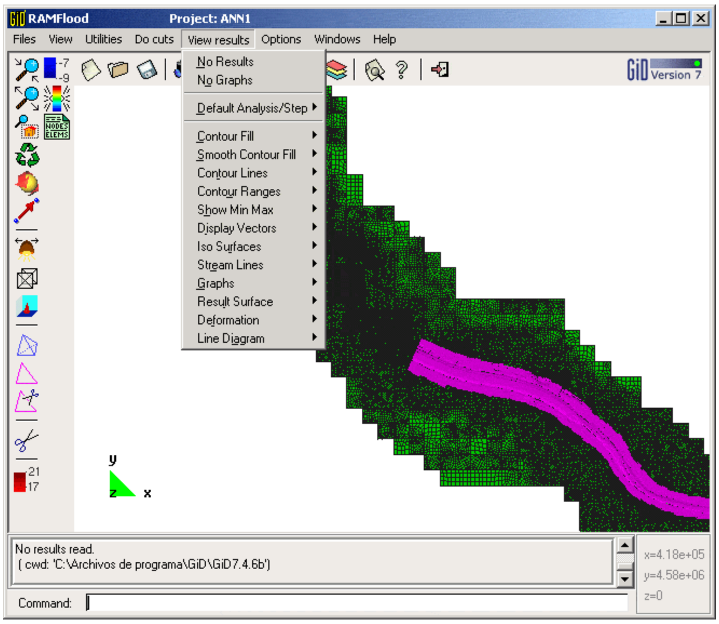
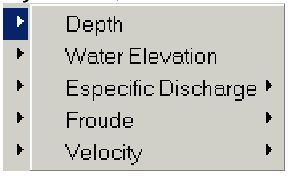


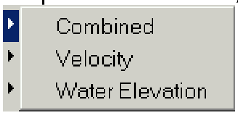
Figure 9.15 –Post-processing facilities available in the GiD

Some of the results options are listed below.

Hydraulic,



Maps of Maximums,



Topography,

Some numerical simulation results for different steps of simulation time are shown below. The following two results correspond to hydraulic results:

Depth

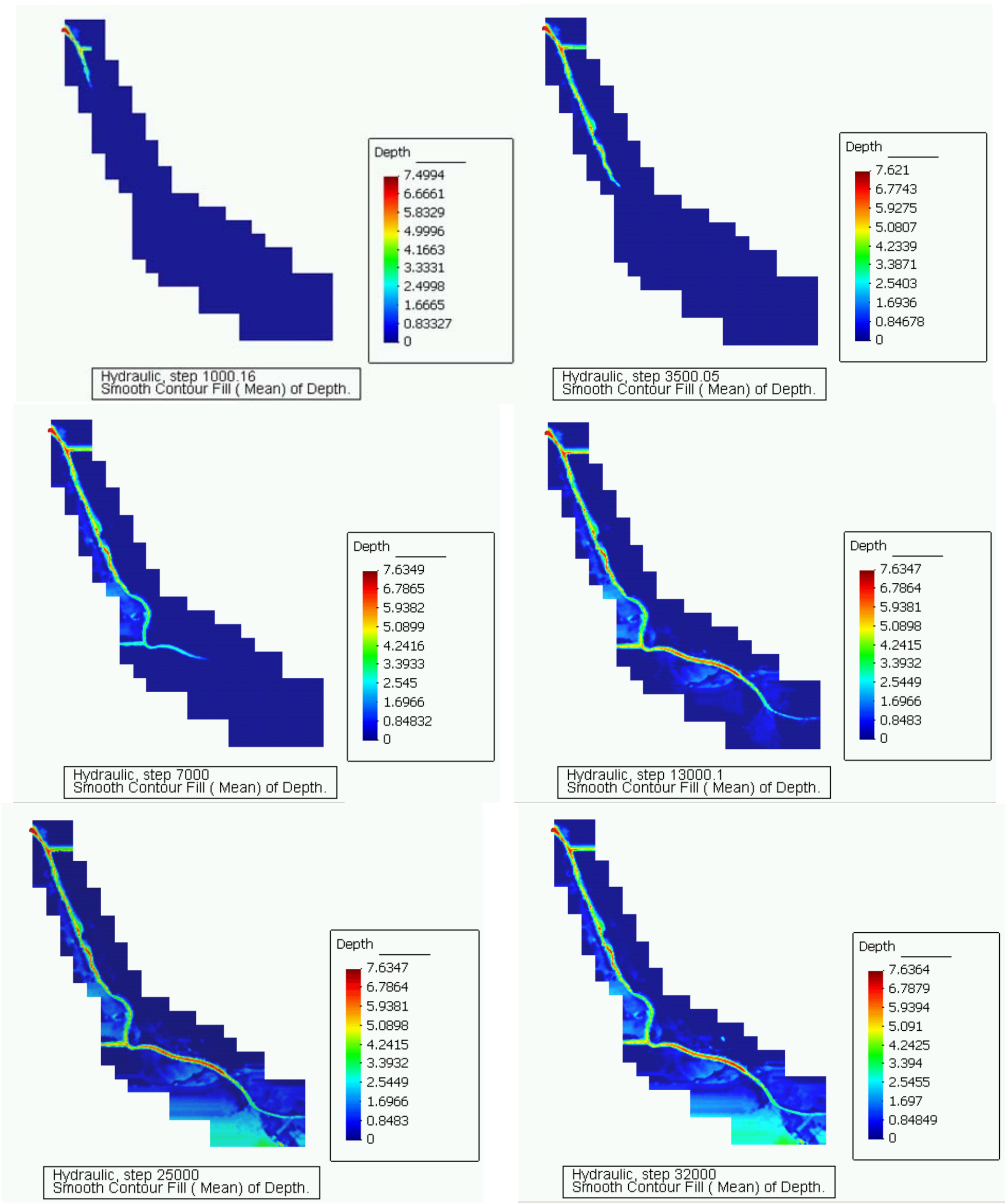


Figure 9.16 – Results of the water depth at different times for a specific simulation

Specific discharge

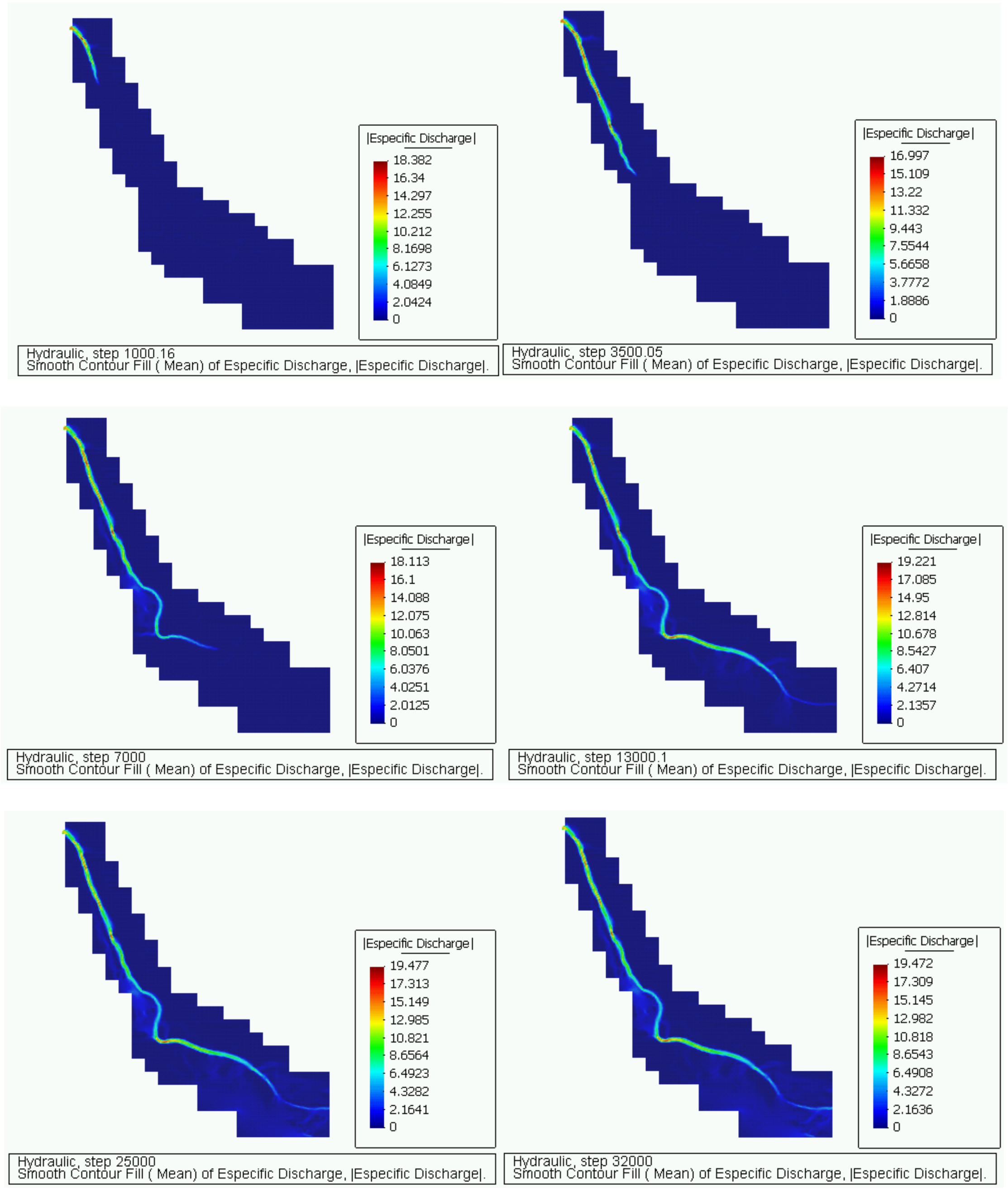


Figure 9.17 – Results of the specific discharge at different times for a flow simulation

The next three results correspond to Maps of Maximums: velocity, water elevation and water permanence.

Velocity

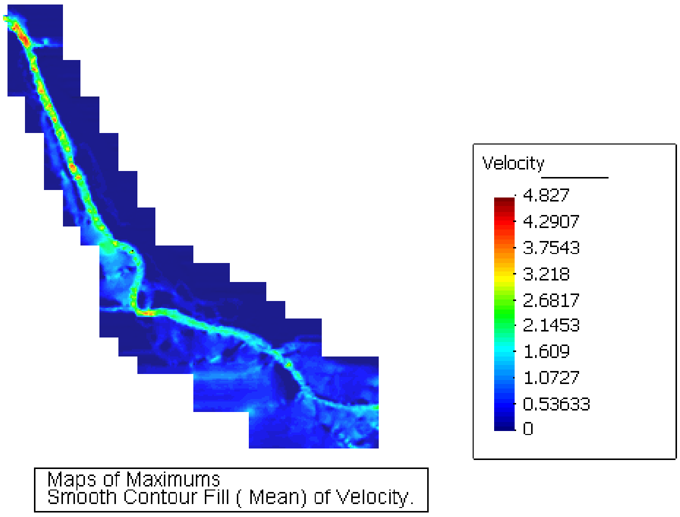


Figure 9.18 – Results of the water velocity for a specific simulation

Water Elevation

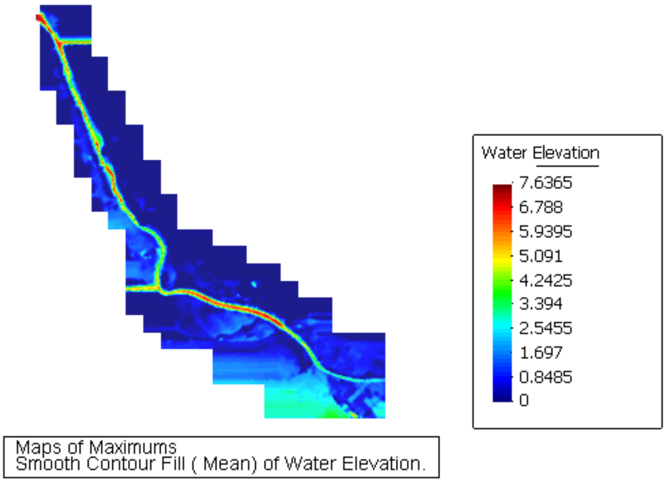


Figure 9.19 – Results of the water elevation for a specific simulation

Water Permanence

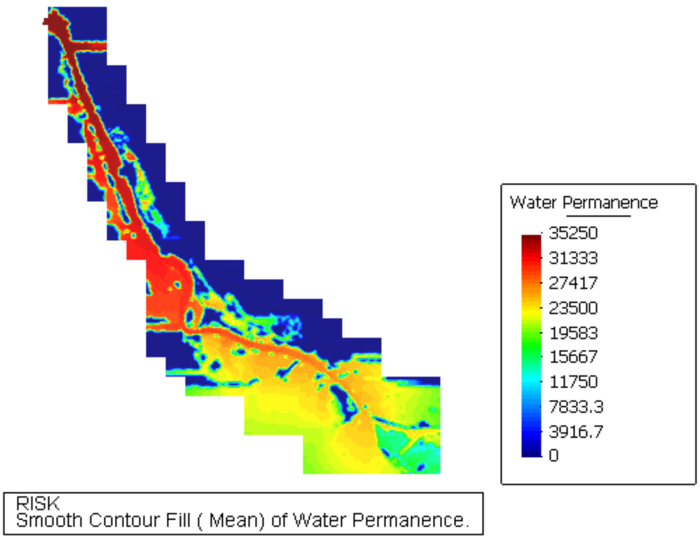


Figure 9.20 – Results of the water permanence for a specific simulation

9.4.1 Verification of the numerical results

Llobregat river drains an area of 4948.36km^2 with a river length of 156.5km. The maximum altitude of the basin is 2536m and the lowest is sea level. Its mean slope is 1.62%. The mean discharge in the historical records in the river gage of Martorell (more then 100 years of records) is 21.54m^3/s, or 679Hm^3/any. The river regime is very irregular, being the most important floods known the ones shown in the table:

Measured discharges at Martorell gage since early 1900s	
Date	Discharge (m^3/s)
21 September 1901	2700
October and November 1907	2800
30 September 1913	1500
1 October 1919	1500
18 October 1940	2200
28 April 1942	1750
25 September 1962	2100
7 November 1962	996
21 September 1971	3150
8 November 1982	1600
10 June 2000	1350

The area of interest is a very well studied reach of Llobregat river, surrounded by infrastructures, with the mentioned Martorell gage near its upstream end and the gage of Sant Joan Despí at its lower end.

Verification of the model was carried at two levels:

1. Comparison against other numerical studies.
2. Comparison with real data in flood events.

Two recent studies of Llobregat water levels were taken as reference for the validation task. These are:

- [1] DEHMA. *Estudio hidráulico del río Llobregat desde Can Bros (Abrera) hasta el azud de Sant Vicenç*. Por encargo de APIA XXI. Marzo de 1996.
- [2] ACA. *Delimitació de les zones inundables per a la redacció de l'INUNCAT*. Juny 2001

In the two studies water levels for discharges of 4000m^3/s were calculated. The first one use the CRANC model (gradually varied flow, step method). The second one use the Hec-Ras model.

The cross sections used in [1] are available to UPC,. For that reason a simulation was carried out with the same geometry and roughness coefficients. Due to the differences in modelisation approaches (gradually varied flow, versus unsteady full St. Venant equations) results can never be the same. For example, differences must exist due to the contraction and expansion energy losses used in the first, which have no direct equivalent in the second, although a similar effect on water levels is achieved with a correct approximation of the source term. An overall good concordance with both approaches was obtained.

Comparison with [2] has more uncertainties. As the exact geometry used by ACA is not available, the assumption that geometry has not changed since 2001 will be made, and comparison of water levels with CARPA and present geometry was carried out.

For comparison with real data, the flood of June 2000 was used.

In conclusion, the following tests were carried out for the validation task:

1. Comparison with other numerical modelling (1996 geometry)
2. Comparison with other numerical modelling, present geometry
3. Verification against real data. June 2000 flood.

9.4.1.1 Comparison with other numerical results. (1996 geometry)

Results of [1] were reproduced with the CARPA code. Results for both simulations are compared in 9.21, where it can be seen that there is a good agreement between both simulations.

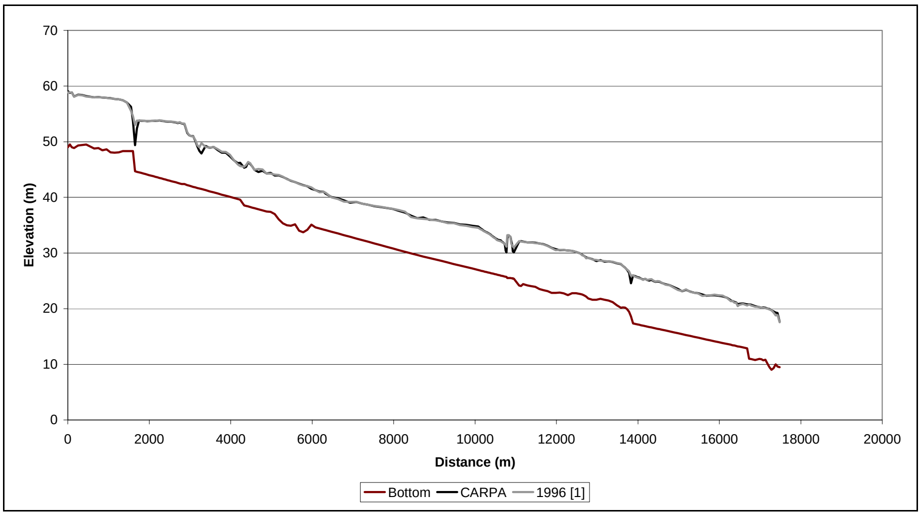


Figure 9.21 - Comparison of results with CARPA code, and 1996 simulation [1]

9.4.1.2 Comparison with other numerical results. Present geometry

The geometry provided in INUNCAT (ACA Flood Prevision Plan) in 2001 [2] was chosen for the validation. The good agreement between both simulations can be seen in Figure 9.22

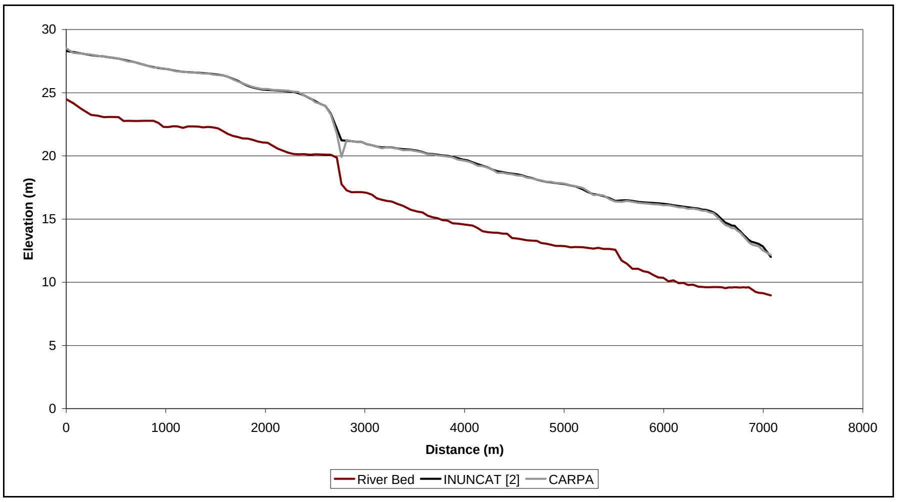


Figure 9.22 - Comparison of results with CARPA code, and INUNCAT

9.4.2 Verification within real data. June 2000 flood

The validation flood area represents an area of 21*km* long and 30km^2. An integrated simulation in one and two dimensions has been done. The reach has been divided in four parts: The upstream part between the Baix Llobregat Highway and A-7 Higway (1D), a 2D area from the Baix Llobregat Highway bridge to Sant Boi meander. A mixed !D-2D area from that point to the Catelldefels Higway Bridge, and 1D simulation downstream. In such way, there are connections in the river axis direction but also, in the third reach, a connection from a 1D reach to a 2D area through a lateral overflow of the river.

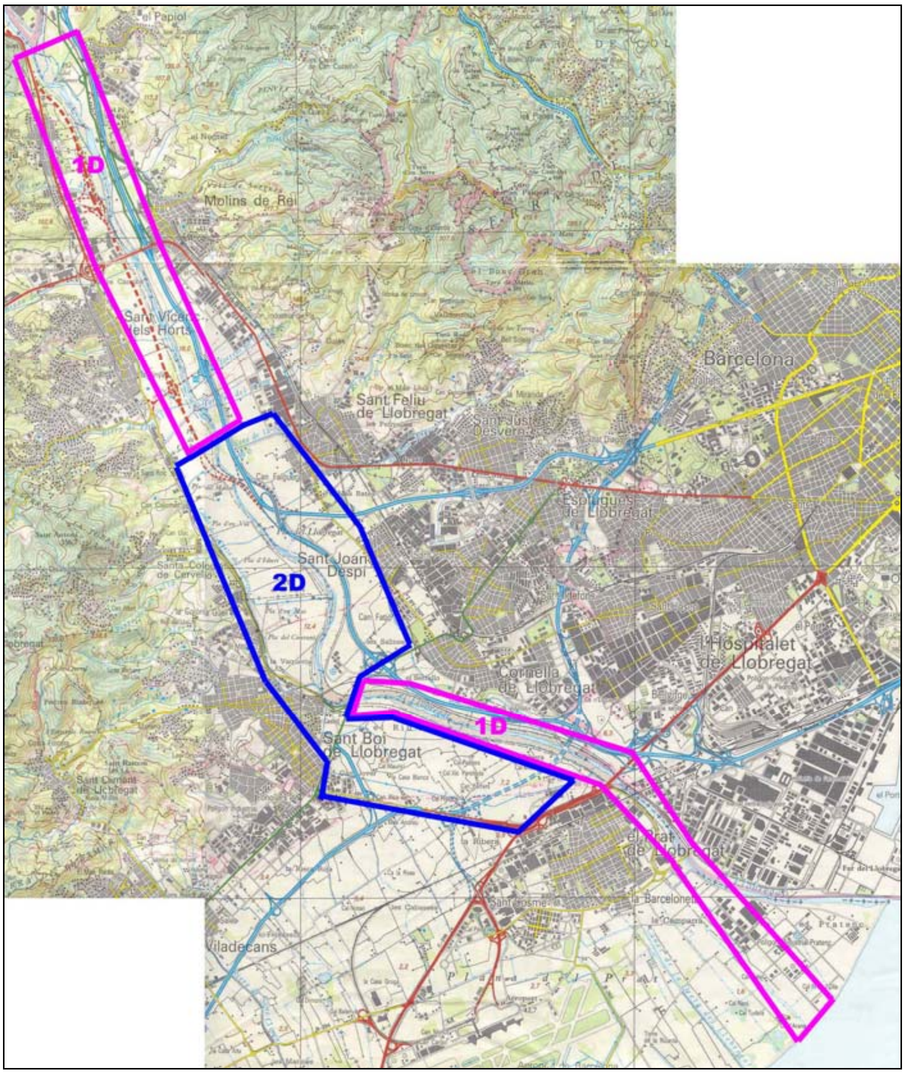


Figure 9.23 - Llobregat Region showing the areas for the 1D and 2D simulations.

From the topographic information in ARC/Info ASCII format, the geometry was imported into GiD and a global mesh was generated. Part of it was assigned as a 1D area, and cross sections were obtained by cutting the mesh. The first 1D region was discretized with 143 cross sections, while in the second one 164 cross sections were used. In the second 1D region, the upstream 43 sections can overflow to the flood plain.

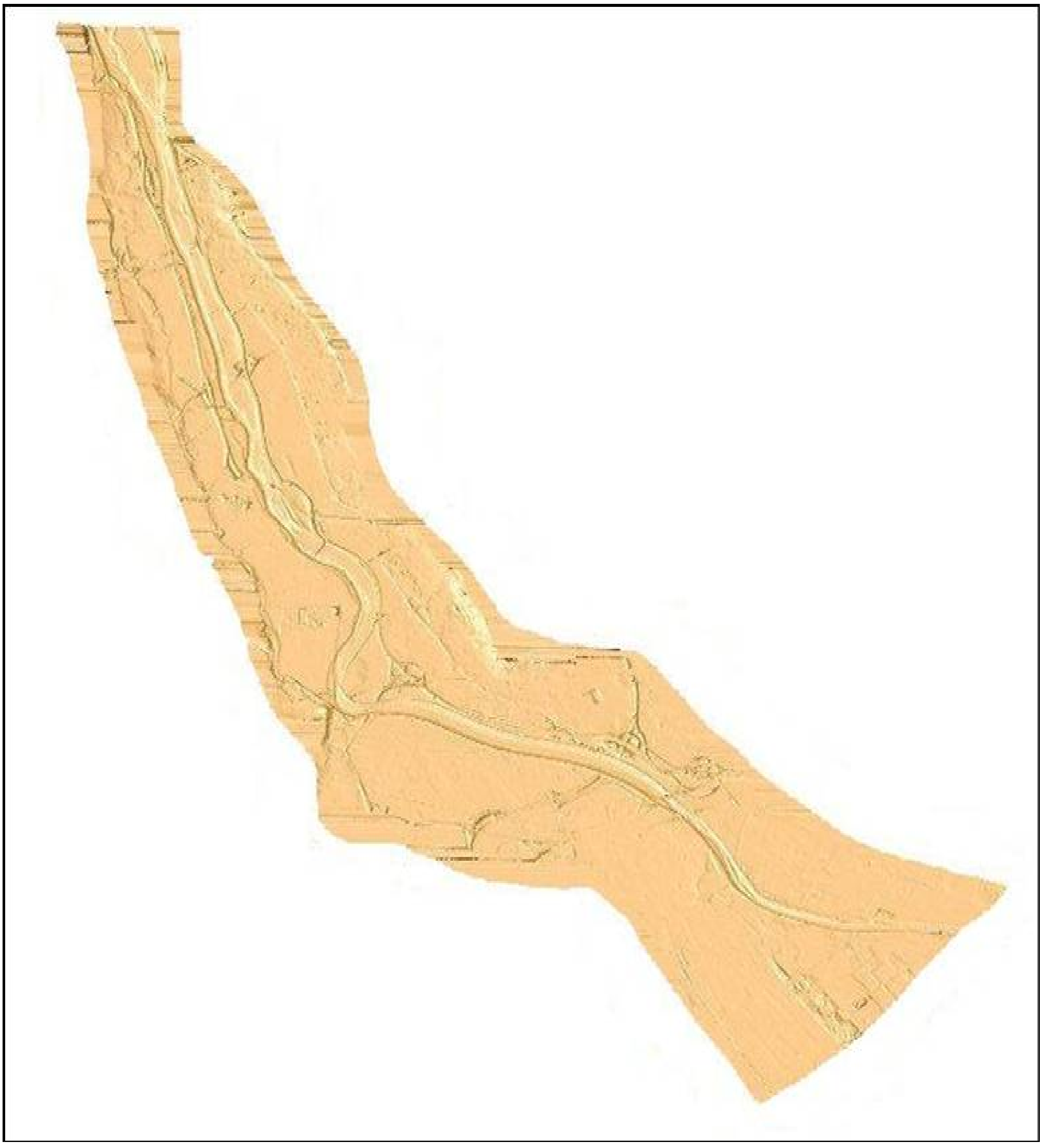


Figure 9.24 - Geometry model of the Llobregat area

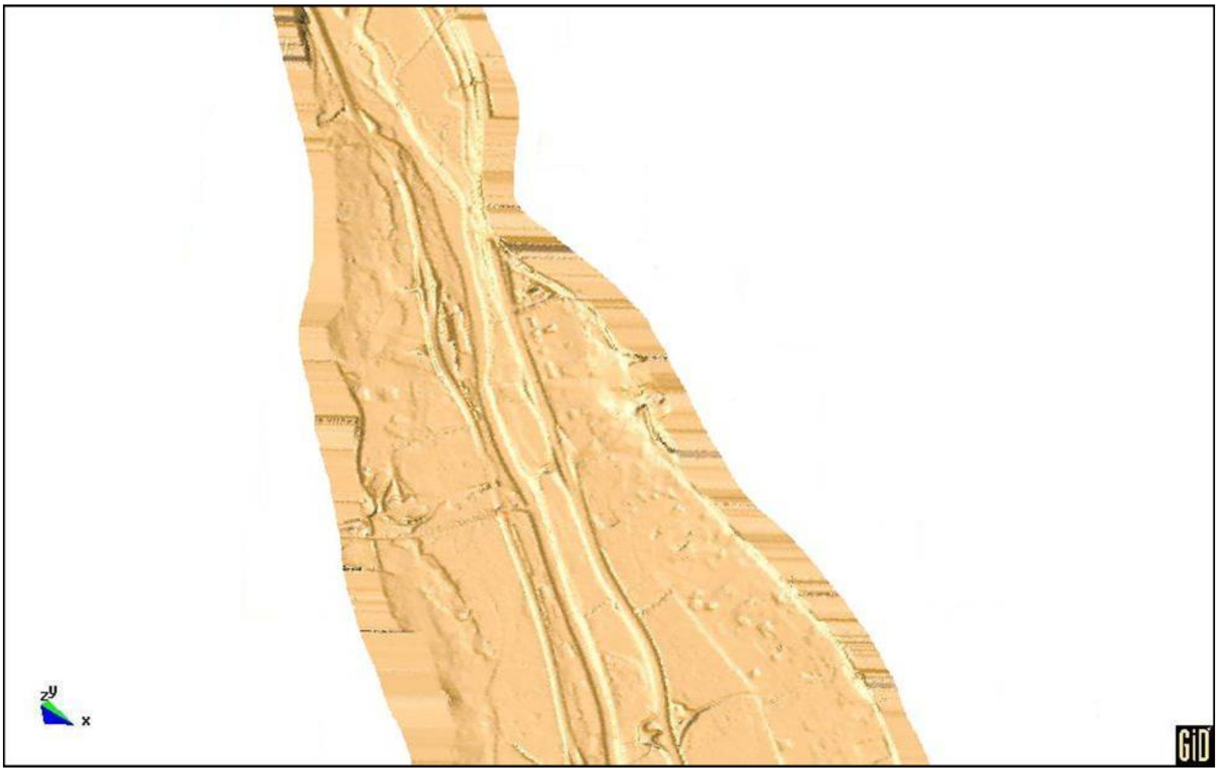


Figure 9.25 - Geometry model of the Llobregat area. Part 1

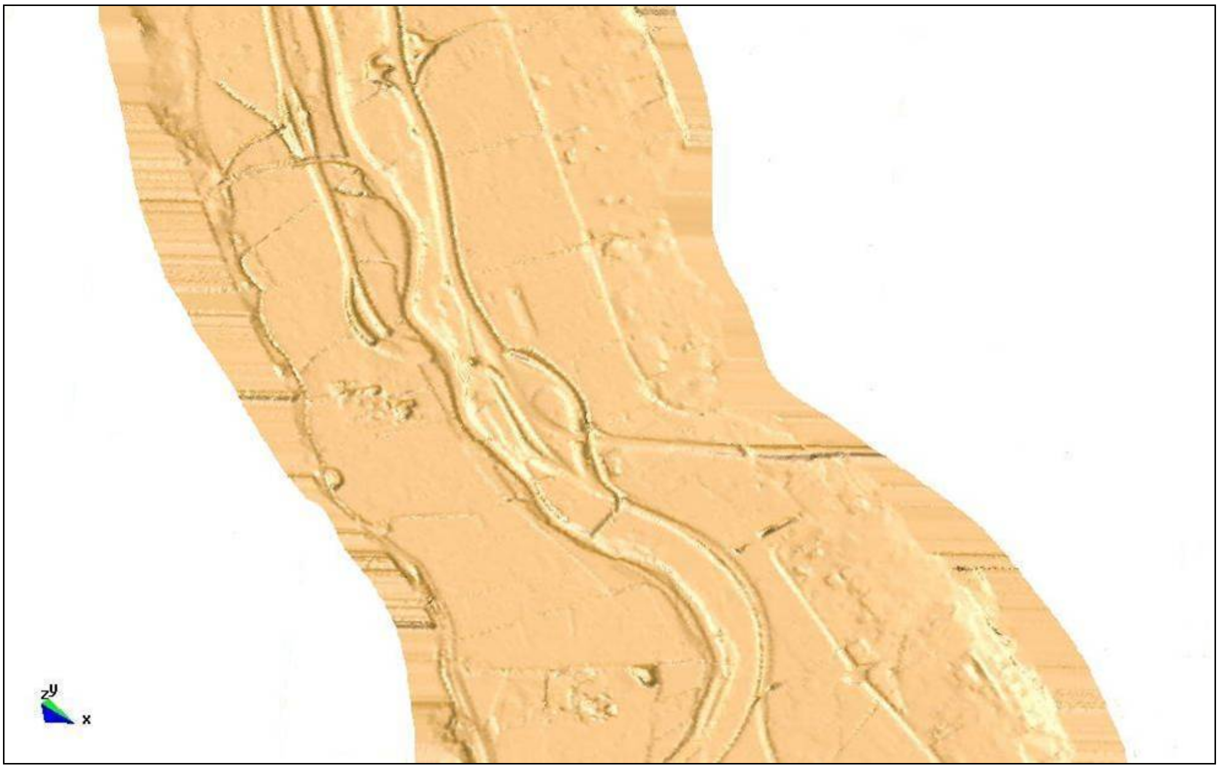


Figure 9.26 - Geometry model of the Llobregat area. Part 2

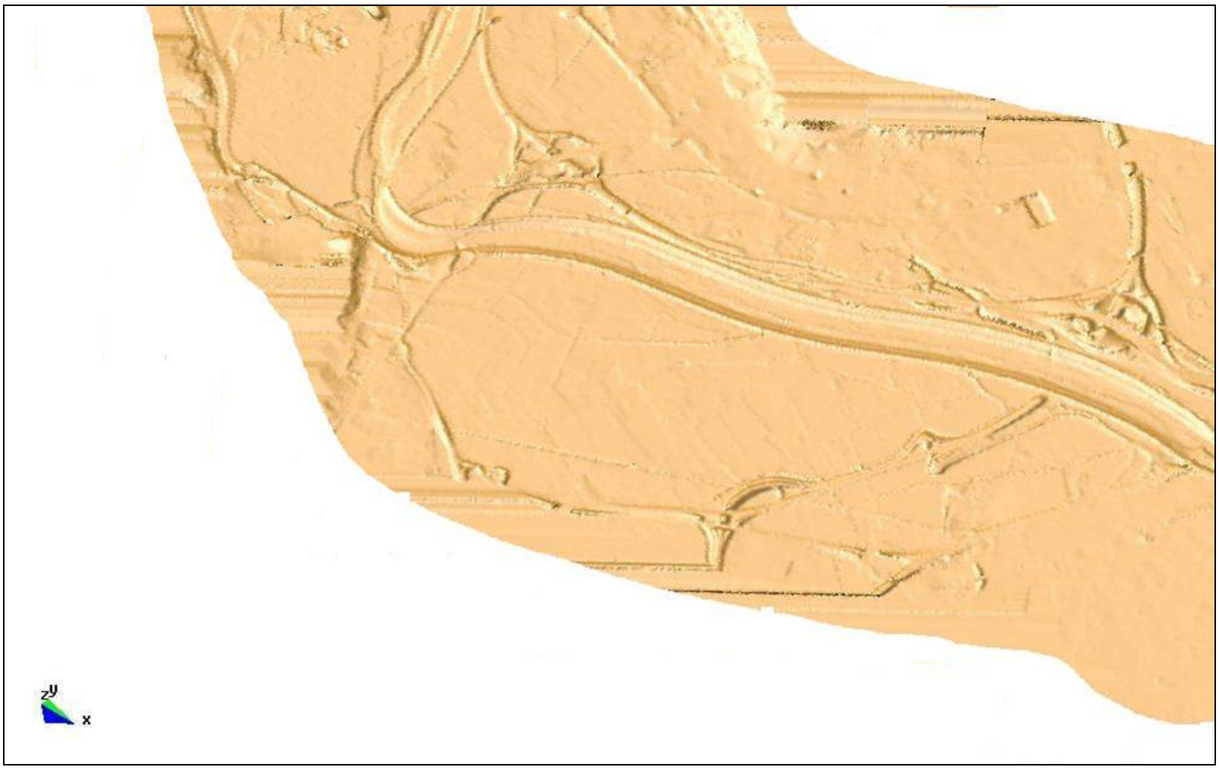


Figure 9.27 - Geometry model of the Llobregat area. Part 3

Figure 9.28 - Geometry model of the Llobregat area. Part 4

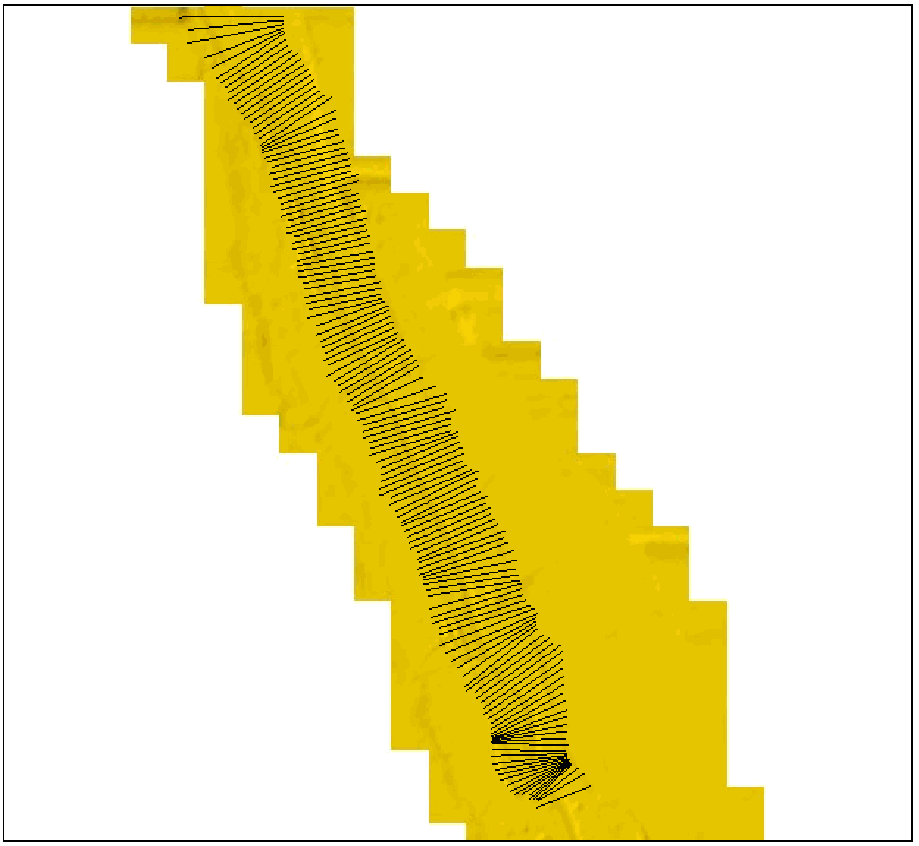


Figure 9.29 - Geometry model of the Llobregat area. Upstream 1D domain

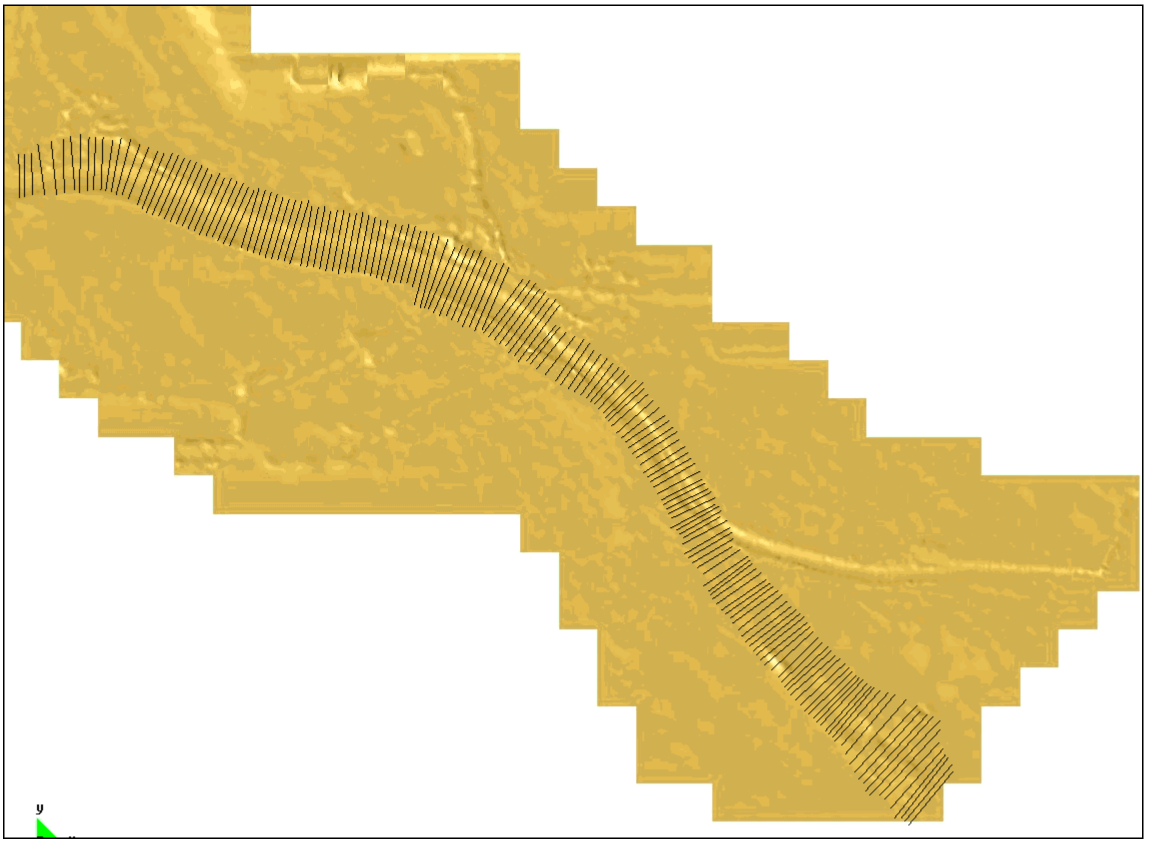


Figure 9.30 - Geometry model of the Llobregat area. Downstream 1D domain

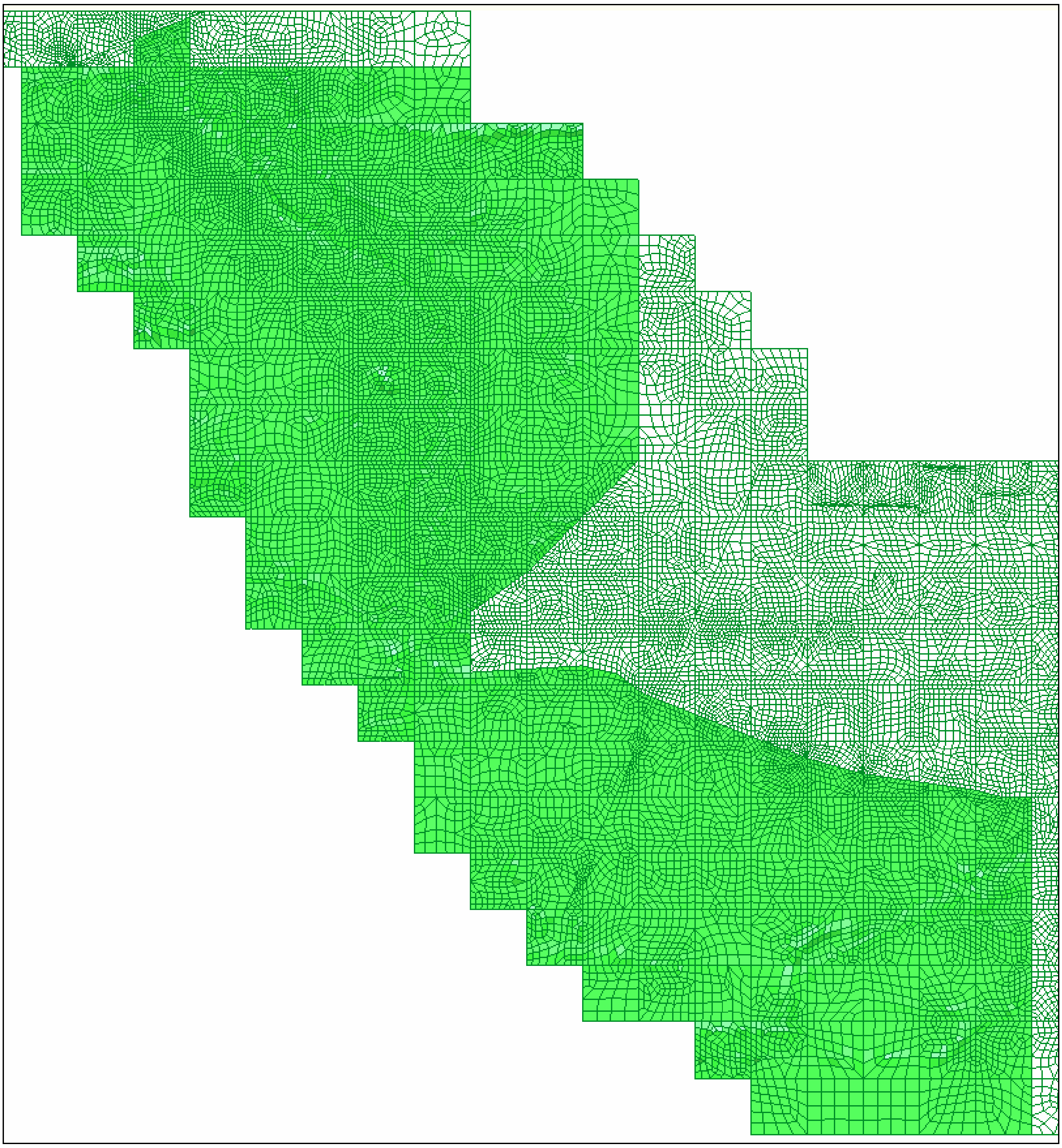


Figure 9.31 - Llobregat area. 2D mesh

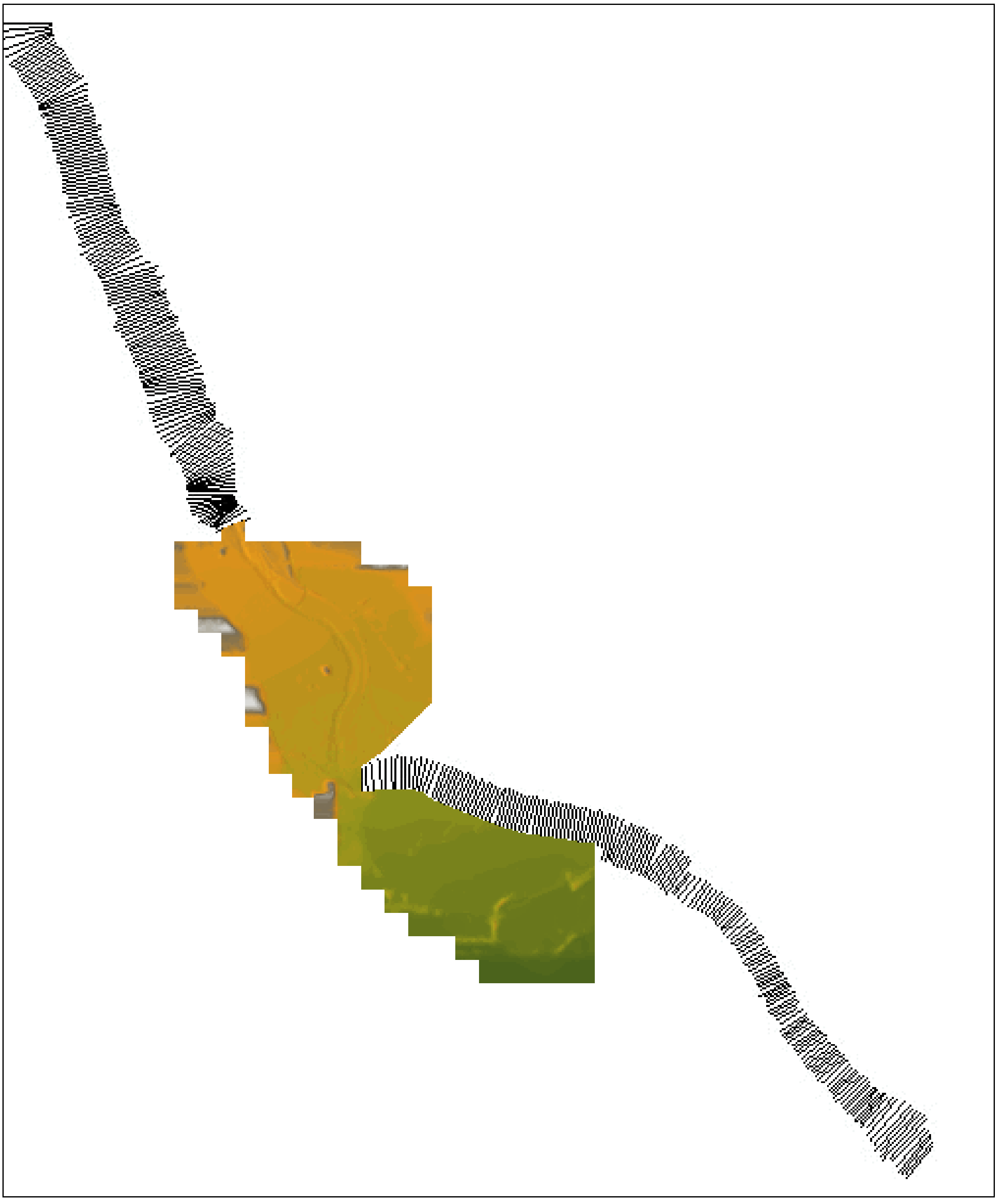


Figure 9.32 - Llobregat area. 2D region and 1D cross sections

For comparison of the numerical results with field data, ACA provided information of maximum water levels the chosen that flood, as well as a number of photographic images. In Figure 9.33 the hydrograph at Sant Joan Despí gage point is shown, This point is situated precisely at the end of the first 1D domain. Iterative tests were carried out in order to provide a hydrograph at the upstream end of the AoI consistent with the measured hydrograph at that point. In Figure 9.33 the hydrograph form is shown, while in Figure 9.34 it is compared with the results of CARPA at that point. A good calibration of the model at that point was achieved. Figure 9.35 shows the hydrograph used as boundary condition for the flood simulations.

Figure 9.36-9.43 show pictures of the actual flood used for the calibration process.

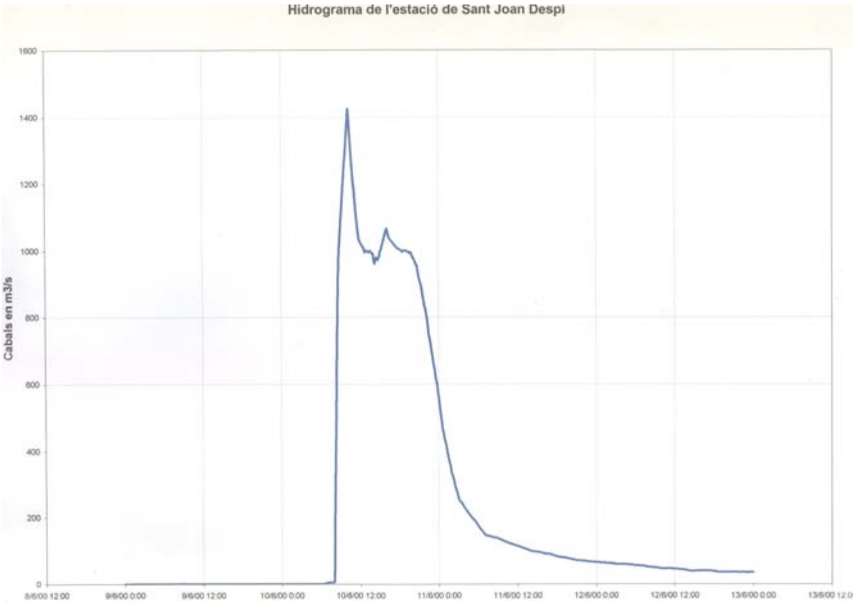


Figure 9.33 - Hydrograph of 9th June 2000 flood

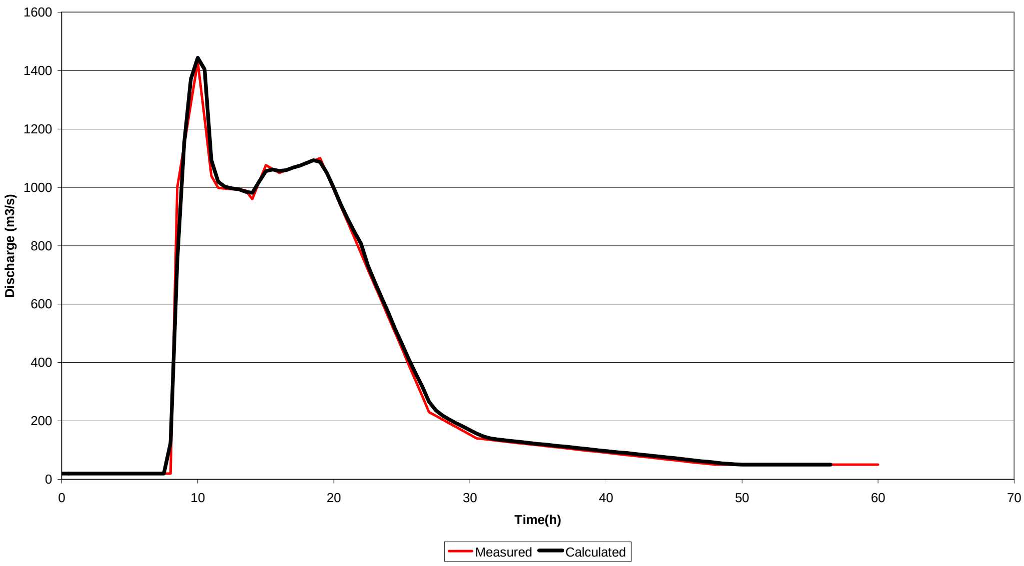


Figure 9.34 - Comparison between measured and calculated hydrograph result for the June 2000 flood

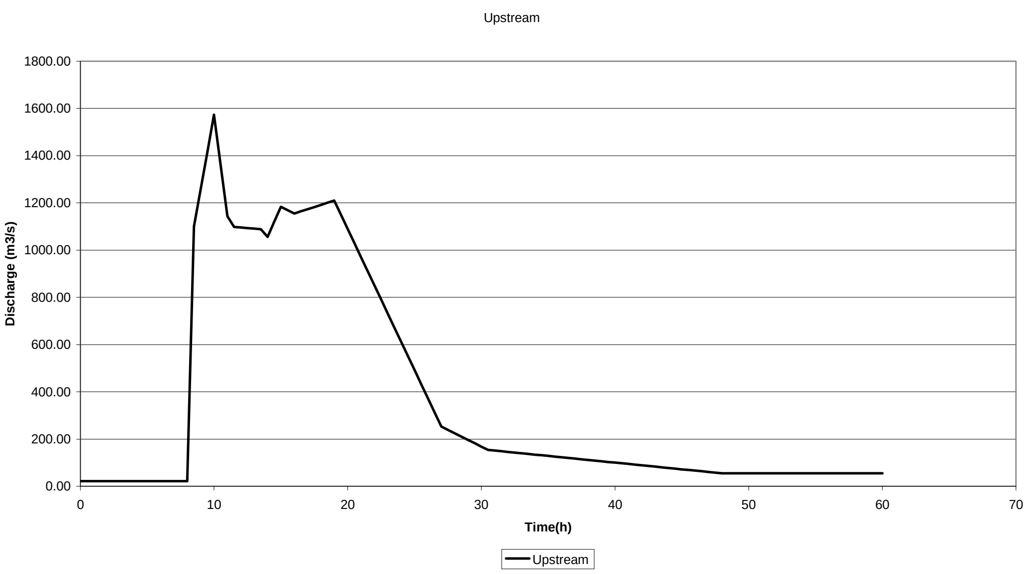


Figure 9.35 - Boundary condition upstream of the area of interest

Figure 9.36 - Llobregat river flood of 9th June 2000. Riera deRubí confluence

Figure 9.36 - Llobregat river flood of 9th June 2000. Sant Andreu de la Barca

Figure 9.37 - Llobregat river flood of 9th June 2000. View of Sant Boi from Cornellà

Figure 9.38 - Llobregat river flood of 9th June 2000. View of Sant Boi from Cornellà

Figure 9.39 - Llobregat river flood of 9th June 2000. View of Sant Boi from Cornellà

Figure 9.40 - Llobregat river flood of 9th June 2000. View of Sant Boi from Cornellà

Figure 9.41 - Llobregat river flood of 9th June 2000. View of Sant Boi bridge. Upstream

Figure 9.42 - Llobregat river flood of 9th June 2000. View of Sant Boi bridge. Downstream

Figure 9.43 - Llobregat river flood of 9th June 2000. View of Cornellà from Sant Boi

Figure 9.44 shows the position of the observed flood elevation points. In Table 1 the comparison between maximum measured elevation and maximum calculated elevation can be seen. It must be said, that the measured elevation was determined after flood signs observations once the flood was passed. Figure 9.45 - 9.49 show the calculated stage hydrographs at the measuring points, together with the stage elevation observed. The moment of the measured maximum value was unknown.

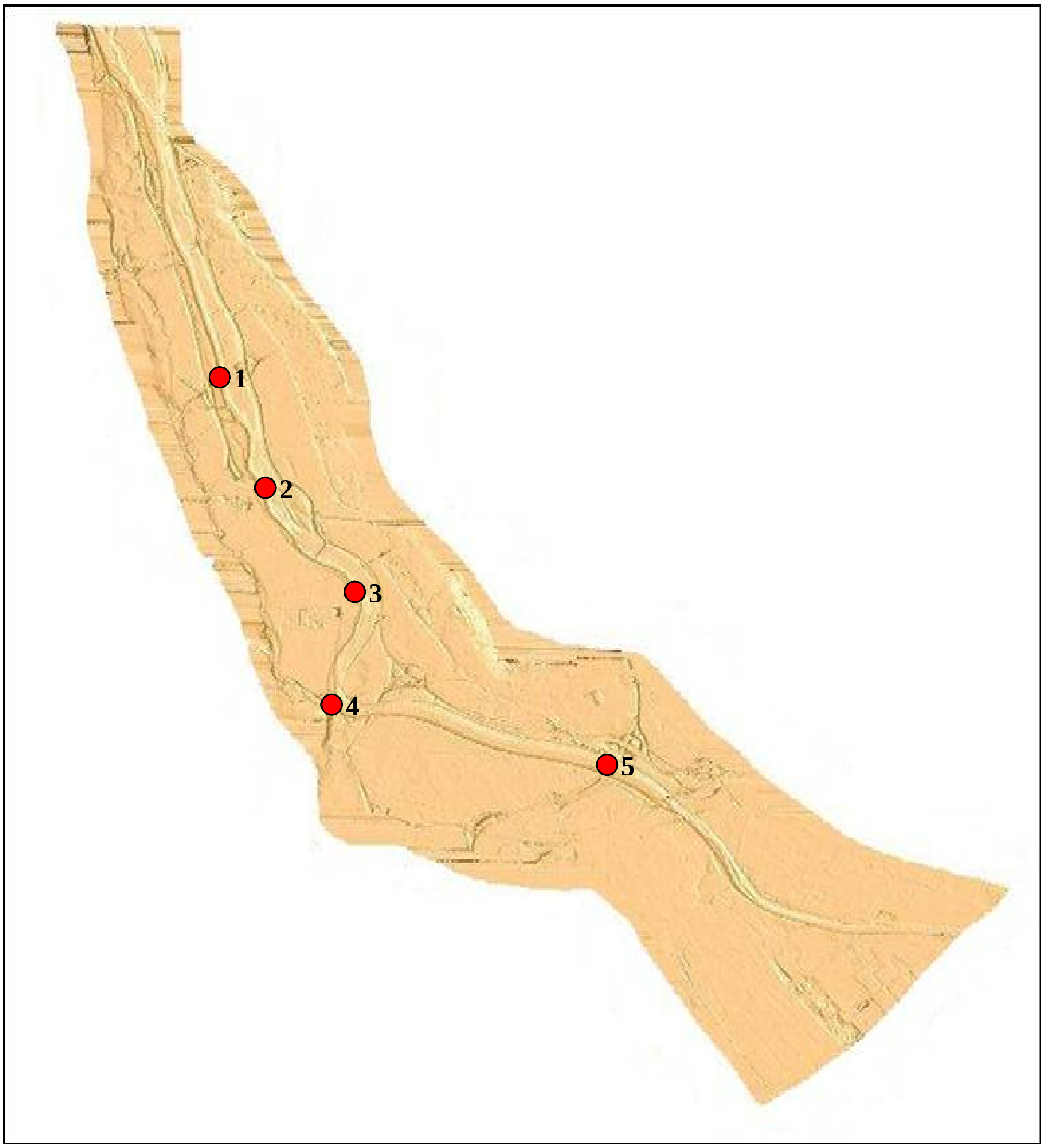


Figure 9.44 - Position of maximum flood control points

Measuring point	Observed elevation (mts)	Calculated elevation (mts)
1 Molins Bridge	22,25	22,50
2 Sant Feliu	17,10	16,88
3 Sant Boi 1	13,20	13,27
4 Sant Boi 2	9,91	10,00
5 C-32 Bridge	6,70	6,94

Table 1. Llobregat river flood of comparison observed-measured elevation at the 5 points with data

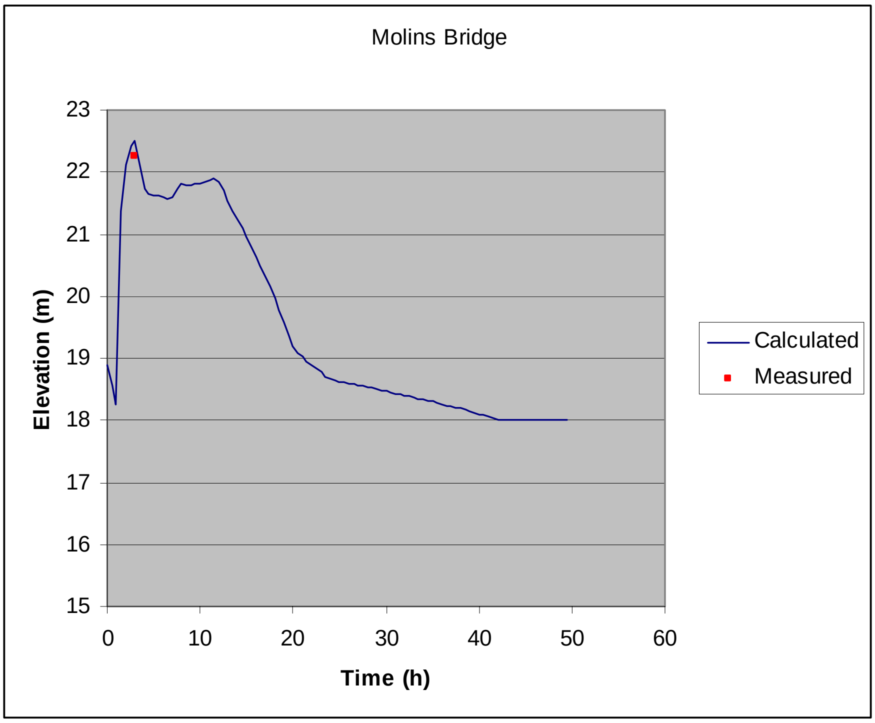


Figure 9.45 - Llobregat river flood: Comparison between measured and calculated elevations at Point 1

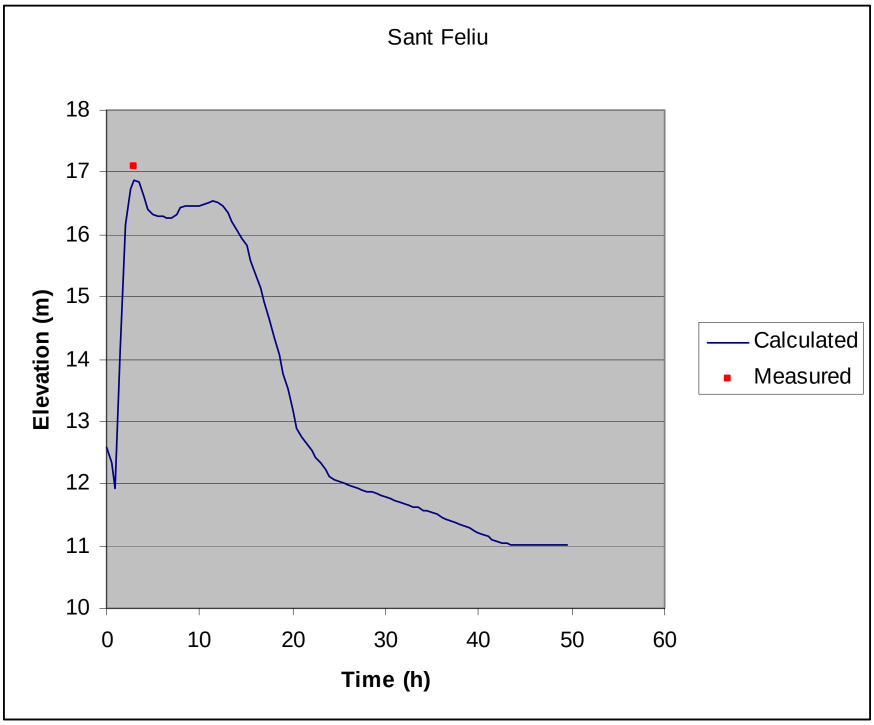


Figure 9.46 - Llobregat river flood: Comparison between measured and calculated elevations at Point 2

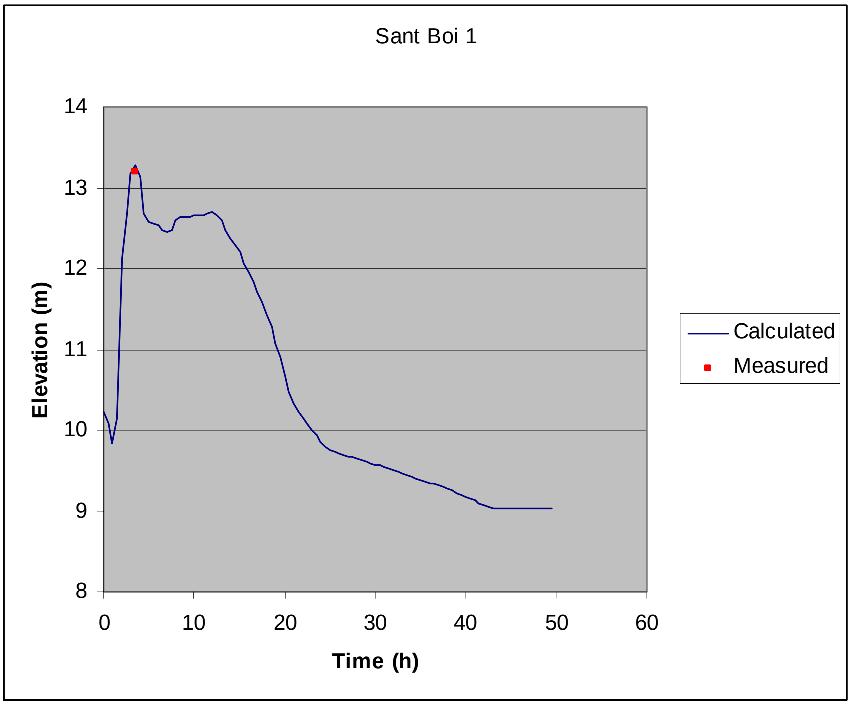


Figure 9.47 - Llobregat river flood: Comparison between measured and calculated elevations at Point 3

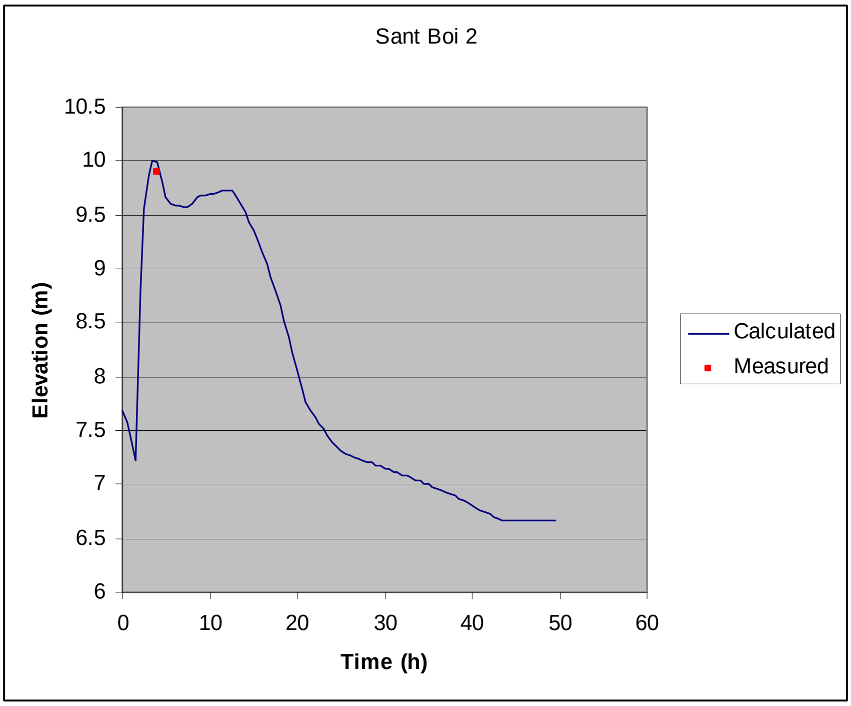


Figure 9.48 - Llobregat river flood: Comparison between measured and calculated elevations at Point 4

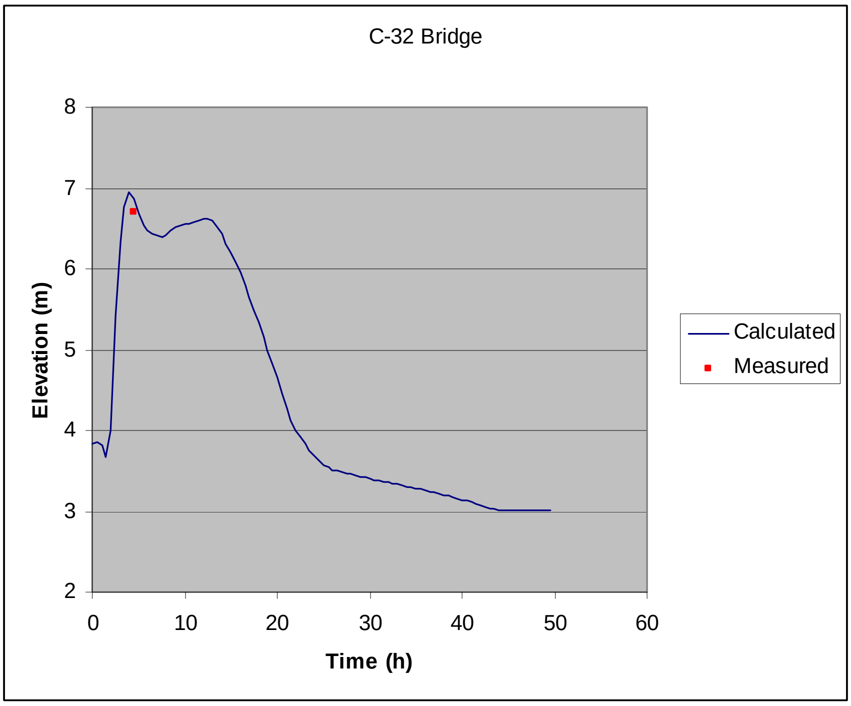


Figure 9.49 - Llobregat river flood: Comparison between measured and calculated elevations at Point 5

9.5 Training of the ANN for the Llobregat river basin

To train and build the artificial intelligent module it was necessary to generate a large number of results obtained from the hydraulic analysis of the Llobregat basin.

Using the range of the possible values of inlet conditions defined by UPC and the Montecarlo method, different combinations of the input data were analysed in order to obtain the hydraulic results at each node.

CIMNE developed a wizard tool to generate the training data. This was used to create the training database, as well as to create and validate the ANNs.

The following figure shows the main steps necessary to train the ANN:

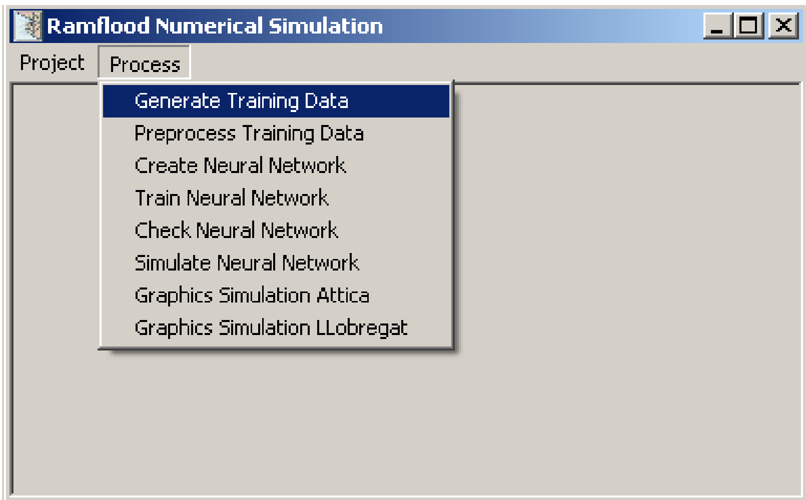


Figure 9.50 - Main steps necessary to train the ANN

9.5.1 Generate Training Data

The next figures show the first step of the training process, where the project name and the preprocessing files, as well as the CARPA code, are defined.

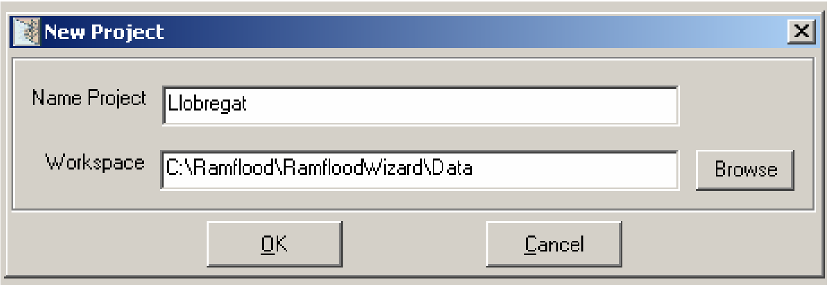


Figure 9.51 - Create a new project window.

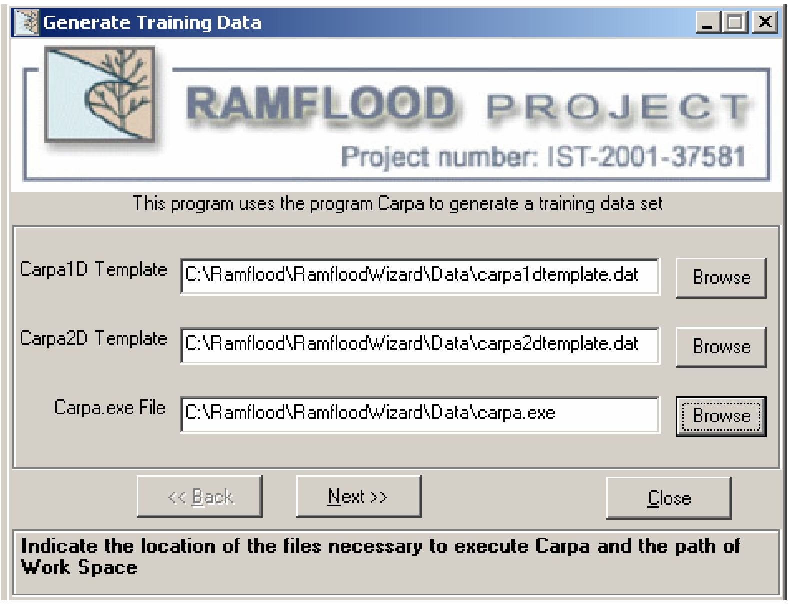


Figure 9.52 - Generate Training Data

In the second step we completed the information about the value range of the inlet conditions. See the following example, (time [s], flow [m^3/s], Level [m]):

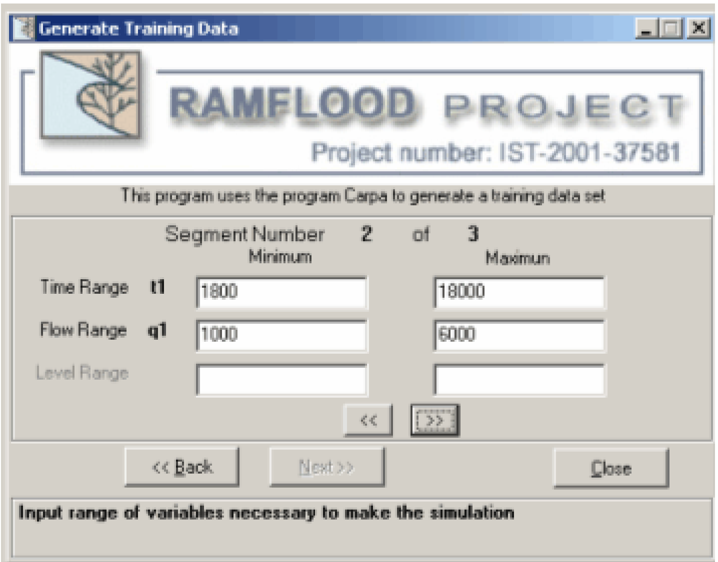


Figure 9.53 – Definition of the value range for inlet conditions

For the Llobregat region were computed 445 simulations. From the total training data, 350 simulations were used to train the ANN, and the remaining 95 simulations were used to validate the ANN created.

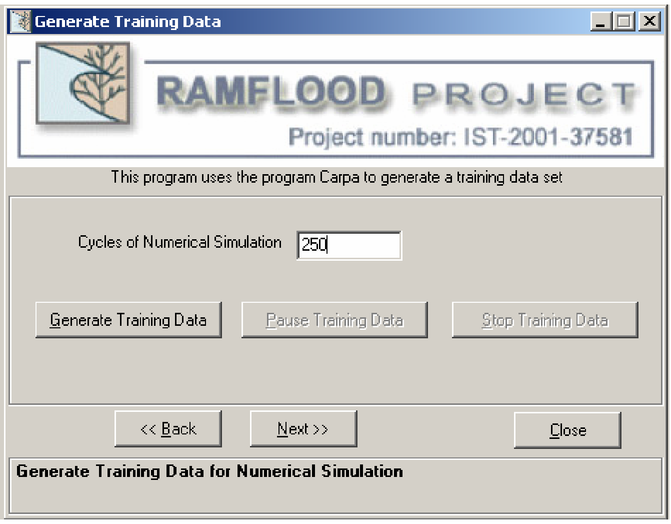


Figure 9.54 - Choose the number of samples in the training data set

Next, the training data is defined directly by a click on the button *Order Data*.

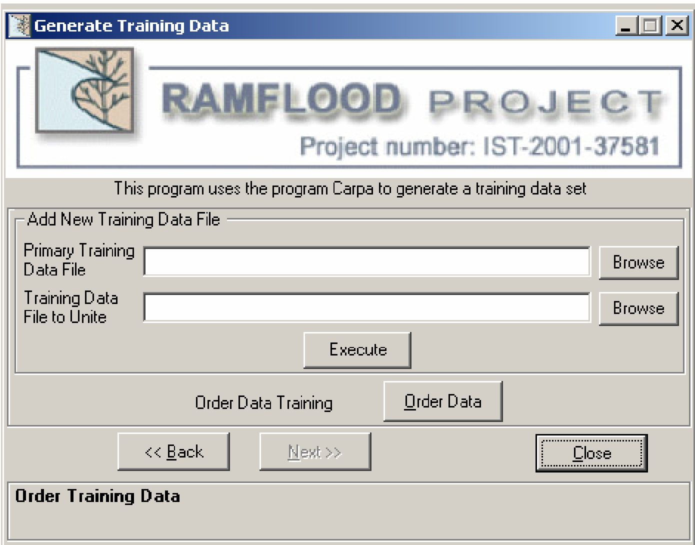


Figure 9.55 - Order Training Data Window.

9.5.2 Preprocess the Training Data

In order to preprocess the training data we specified:

- The location of the raw training data file.
- The location of the preprocessed training data file to be created.
- The location of the mean and standard deviation of the input and target variables data file to be created.

The following figure shows how this process appears in the main window of the Ramflood wizard tool.

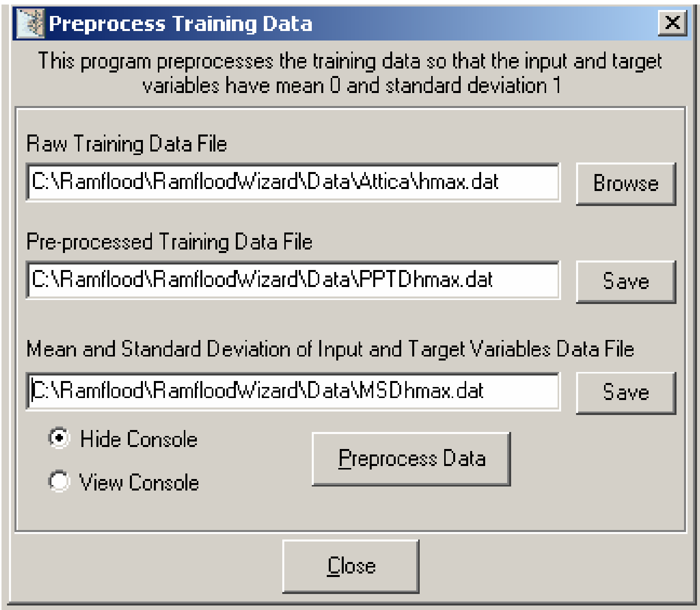


Figure 9.56 - Preprocess Training Data.

9.5.3 Create the ANN

Once the training data file has been created and pre-processed, we are ready to create the neural network structure. This consists of a data file containing the size, architecture and free parameters of the ANN.

To create the ANN structure with the Ramflood wizard tool, the following parameters are specified:

- The location of the raw training data file. This file contains useful information, such as the variables name as the size of the ANN and the number of input and output variables.
- The number of neurons in the hidden layer.
- The location of the ANN data file to be created.

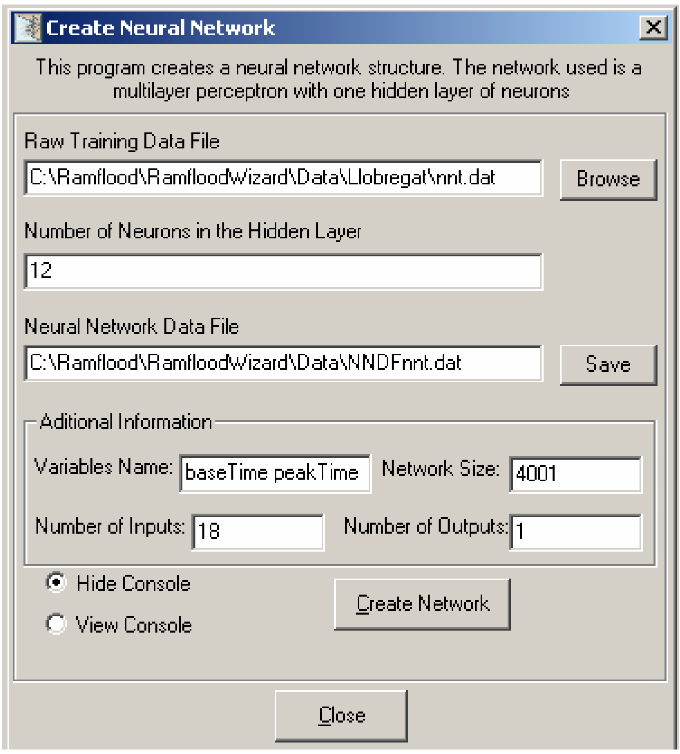


Figure 8.57 - Create ANN window.

9.5.4 *Train the ANN*

From the total training data file, we used 350 hydraulic simulations.
The ANN were trained with the help of the Ramflood wizard tool by specifying the following parameters:

- The location of the pre-processed training data file with which the neural network is to be trained.
- The location of the neural network data file. Case must be taken that the training data and the neural network correspond to the same output variable.
- The stopping criteria: Performance goal, goal for the norm of the performance function gradient, maximum number of epochs to train and maximum training time.
- The number of epochs between the showing progress training parameter.
- The number of cycles this training process is to be performed.

The following figure shows how this process appears in the main window of the Ramflood wizard tool.

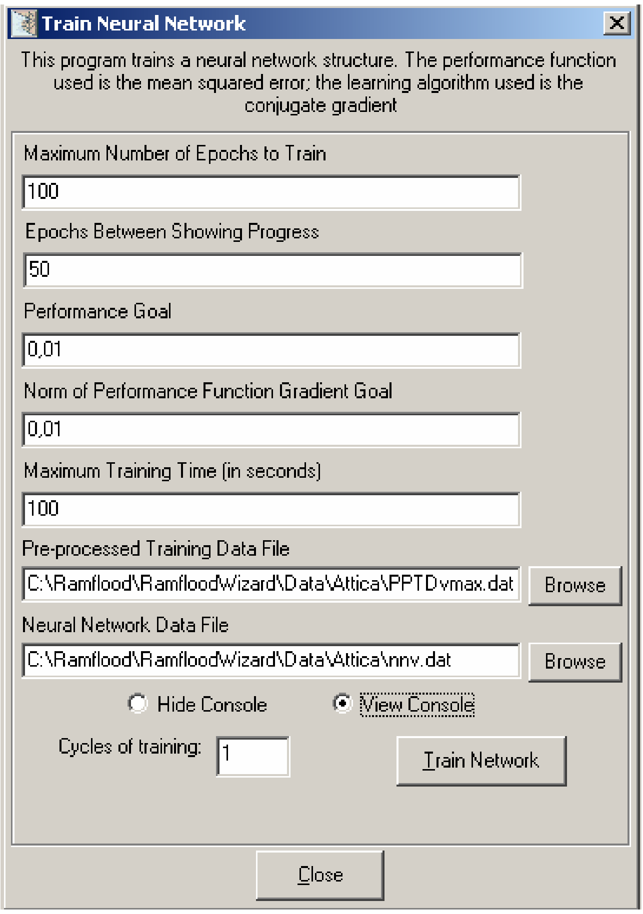


Figure 9.58 - Train the ANN window.

9.5.5 *Check the ANN*

From the total training data file, we used the remaining 95 hydraulic simulations in this step.
To validate a single neural network structure we specified the following parameters:

- The variable for which we want to validate the ANN: maximum height, maximum velocity, maximum velocity-height or wet time.
- The location of the ANN data file for that variable.
- The location of the mean and standard deviation data file for that variable. Make sure that the ANN and the mean and standard deviation data files correspond to the same output variable.
- The output file to be created. This file contains the results of the simulation for a single output variable.
- The input values for simulation.

The following figure shows how this process appears in the main window of the Ramflood wizard tool.

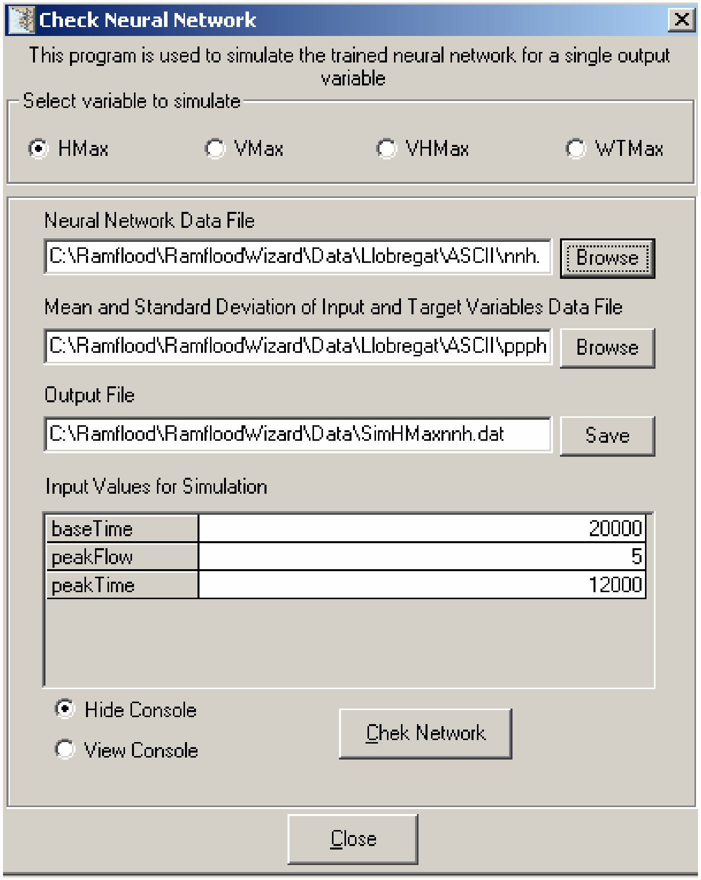


Figure 9.59 - Check neural network window.

Once the ANN has been validated it is ready to be used. The results obtained by the ANN are post-processed for visualization. Risk or hydrological variables are plotted on a map of the area of interest chosen. To do this we create a results data file to be read by the GiD pre and postprocessing system.

9.6 Integration of the ANN for the Llobregat river basin into the RAMFLOOD DSS

Once the AI module of the Llobregat region was developed, a new project in the Ramflood DSS is created and including the AI module.

If we enter into the Ramflood System as an end user, we find the following interfaces:

Figure 9.60 – Main work window for the end user level

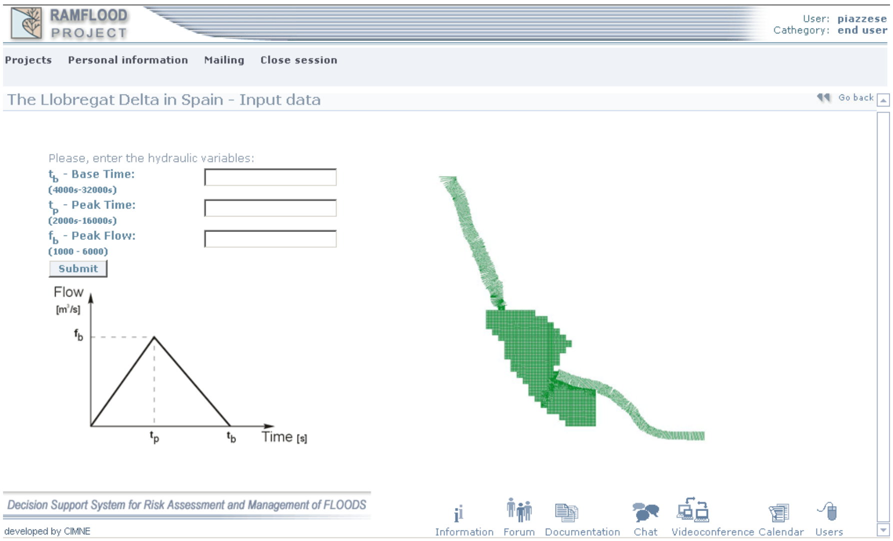


Figure 9.61 – Input data window

End users introduce the specific hydraulic parameters for which the map will be produced. We recall that these parameters are the flood base time, the peak flood time and the peak flood flow.
Figures 9.62-9.65 show maps provided by the Ramflood DSS in “quasi” real time (aprox. 20 seconds)

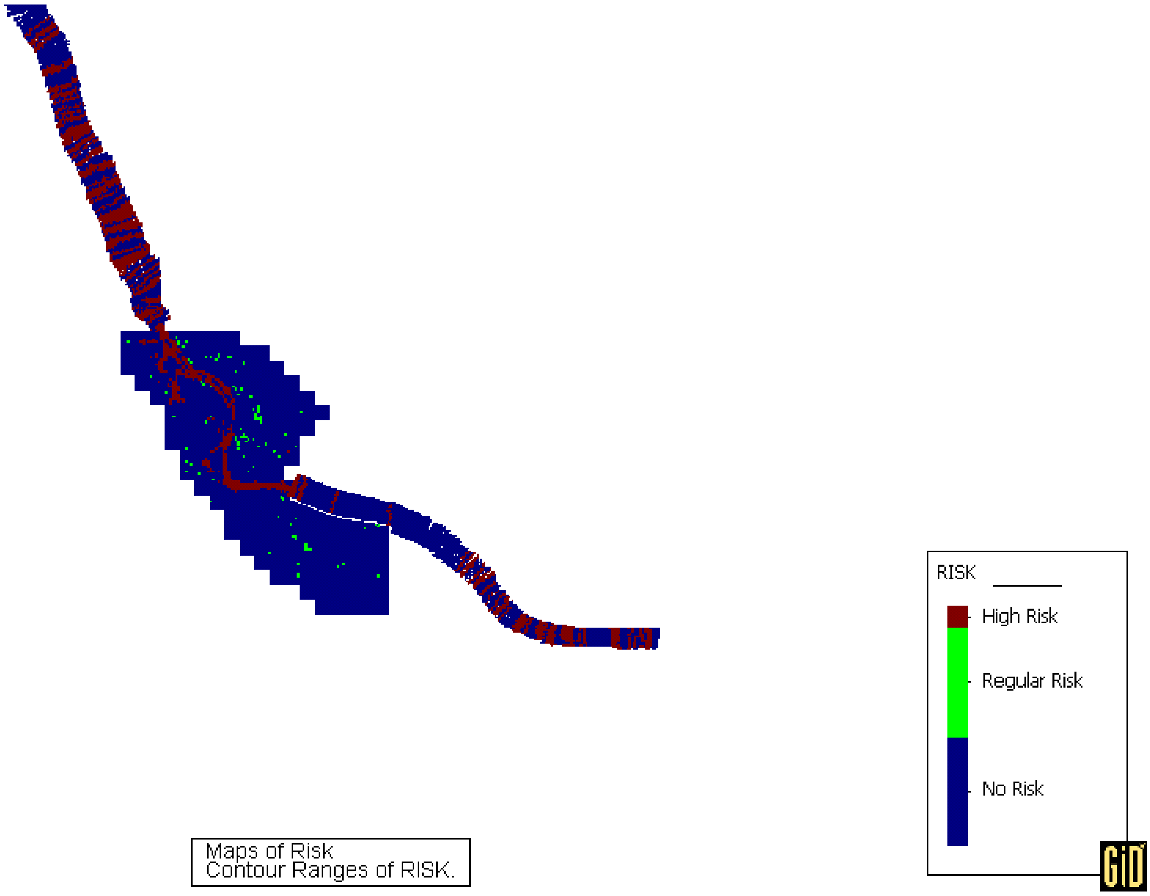


Figure 9.62 – Llobregat river basin risk map provided by the ANN

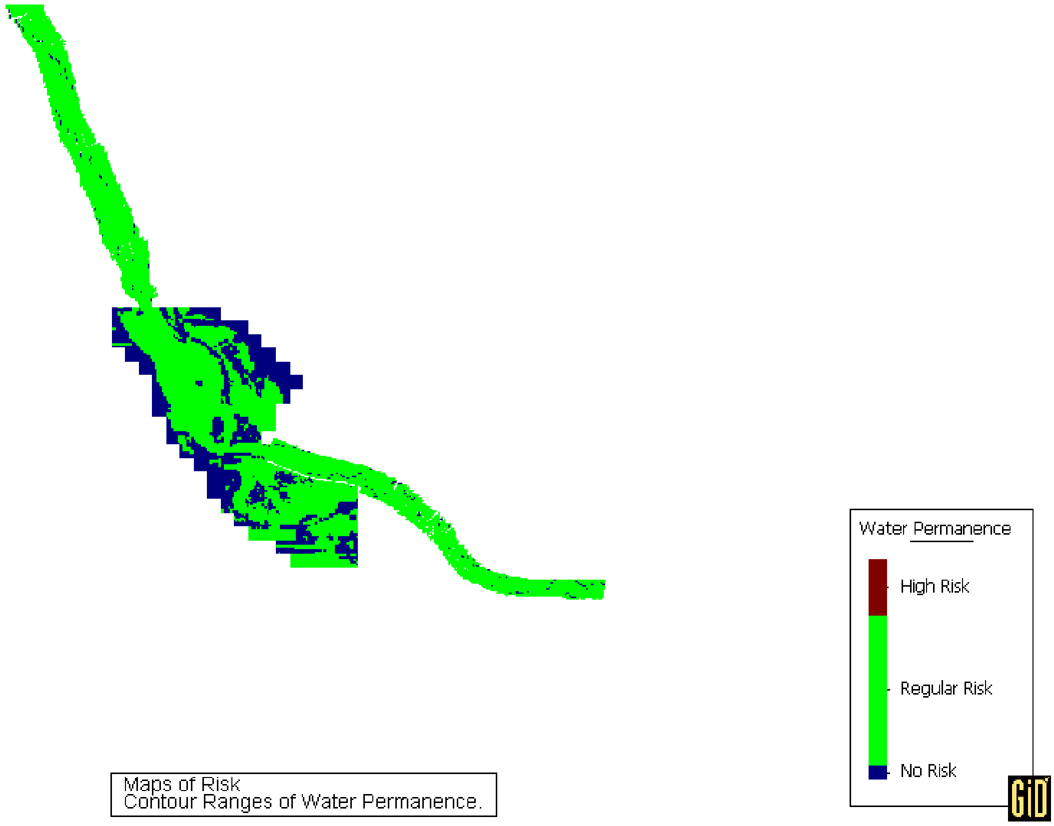


Figure 9.63 – Llobregat river basin water permanence map provided by the ANN

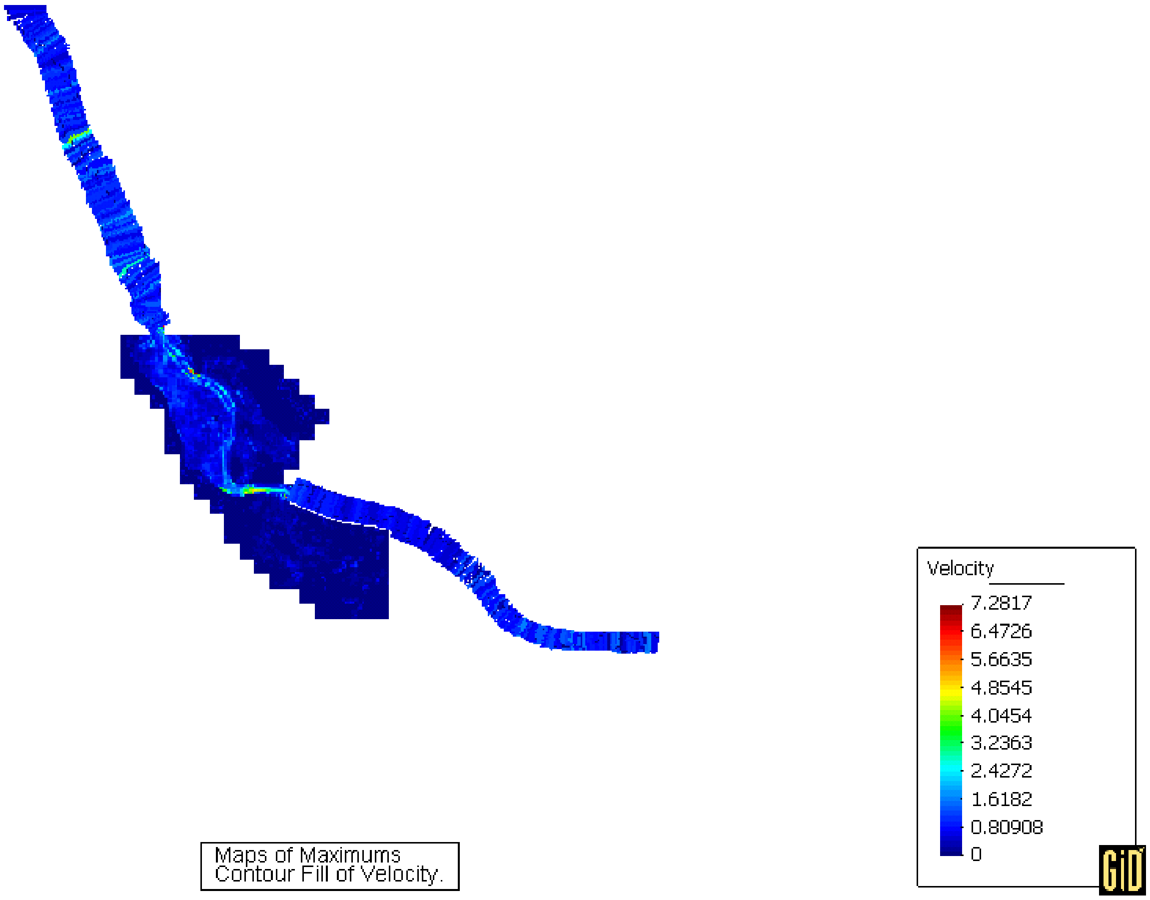


Figure 9.64 – Llobregat river basin velocity map provided by the ANN

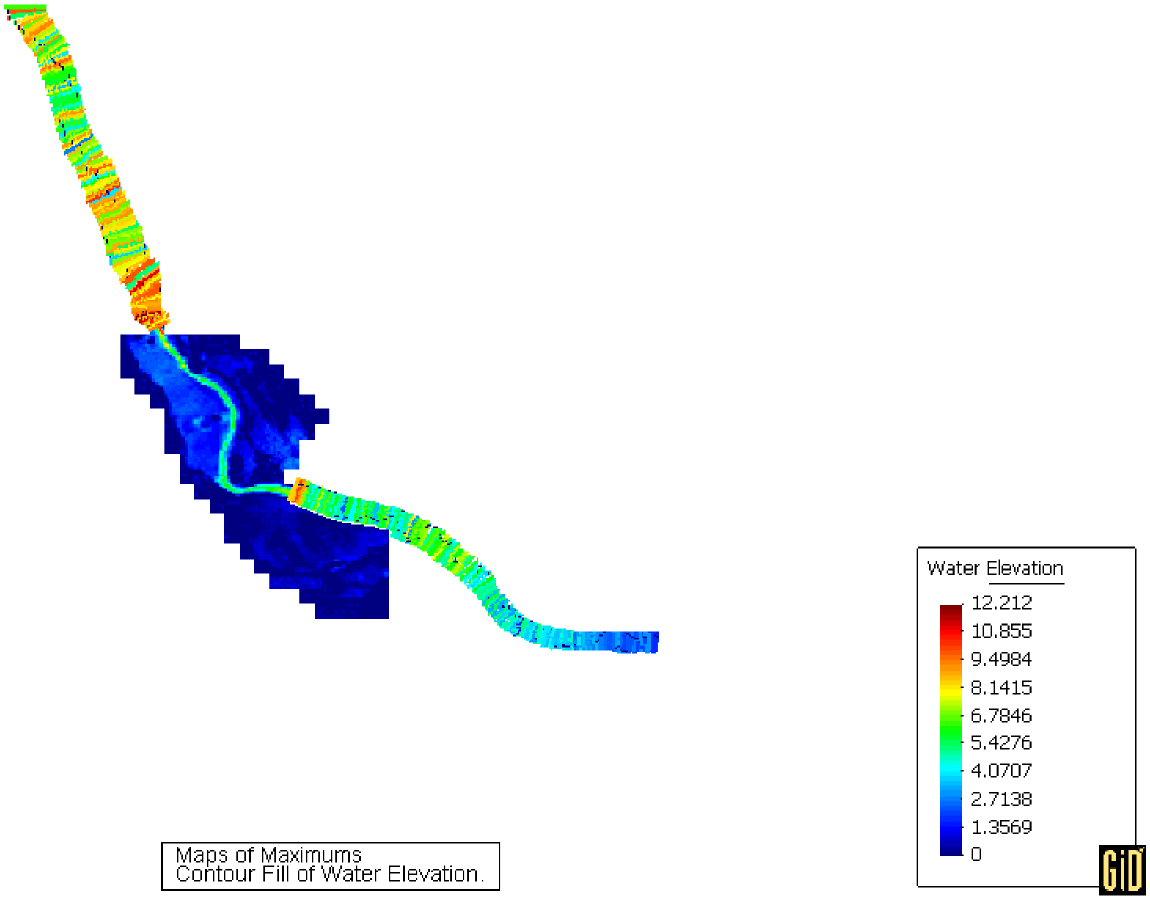


Figure 9.65 – Llobregat river basin water elevation map provided by the ANN

10. APPLICATION OF THE RAMFLOOD DSS TO THE ATTICA REGION IN GREECE

10.1 Summary of the basic steps

The validation of the Ramflood DSS in the Attica region in Greece included the following activities:

1. Definition of the area of interest

2. Definition of the analysis data:
    - Import of DTM and creation of the surfaces
    - Creation of the finite element mesh
    - Definition of the mesh properties
    - Definition of the type of analysis (2D) on the finite elements mesh
    - Definition of the mesh conditions
    - Assessment of the values range for the inlet conditions
    - Generation of the output files for the training of the ANN

3. Flood analysis of the Llobregat river basin

4. Training of the ANN for the Llobregat river basin.

5. Integration of the AI module into Ramflood DSS.

10.2 Definition of Attica area selected

The area of interest is defined as semi-urban. It is located at the border of Halandri and Brilissia municipalities, at the northern part of the city of Athens. The area has major socio-economic interest, as it is close to the Olympic Centre of Athens and there are several buildings of social importance within the area (stadiums, hospitals, schools etc.). Halandri river which is coming down from Penteli mountain, crosses the area from north-east to south-west. At the east river side the city is constructed in building blocks, while at the west side there are sparse buildings and vegetation.
The main road that crosses the area is the Penteli Avenue, which is directed parallel to the river. Also, at the southern-west of the area there is the recently constructed “Attiki Odos” motorway.

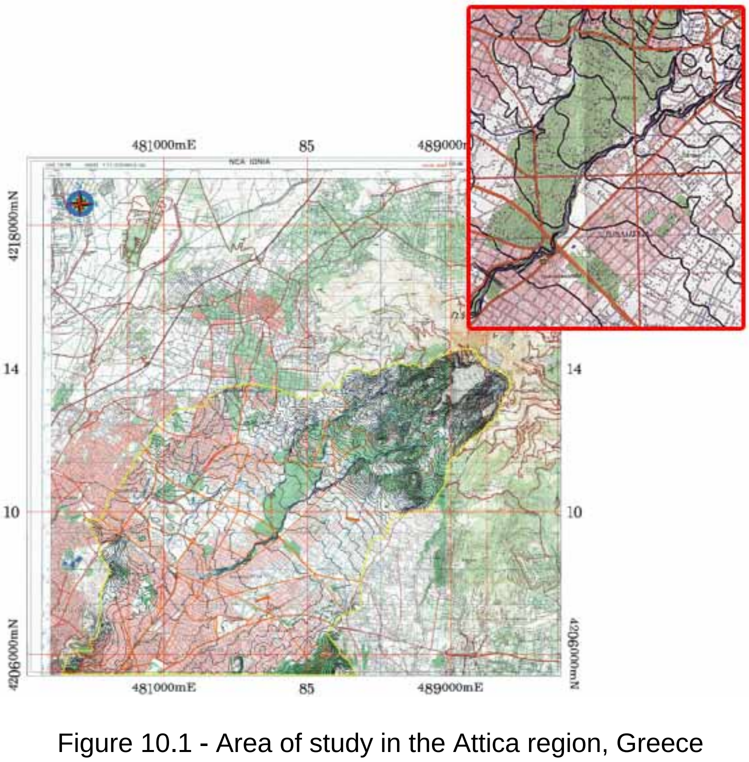


Figure 10.1 - Area of study in the Attica region, Greece

10.3 Definition of the analysis data

For the pre-processing of computation data and the graphical visualization of numerical results we used the GiD system developed by CIMNE.

10.3.1 Import of DTM and creation of the surfaces.

In order to import the Digital Terrain Model using information from Arc/Info ASCII Grid files, an additional code was developed including corresponding interface with GiD. The code reads the data file and uses it to create points, lines and finally the NURBS-surfaces.

An advantage of this code is that allows creating from original DTM files new files with the requested dimensions and import then with different accuracy. The result is a group of surfaces that represent the study area.

The following images show the interface and the result of the import task.

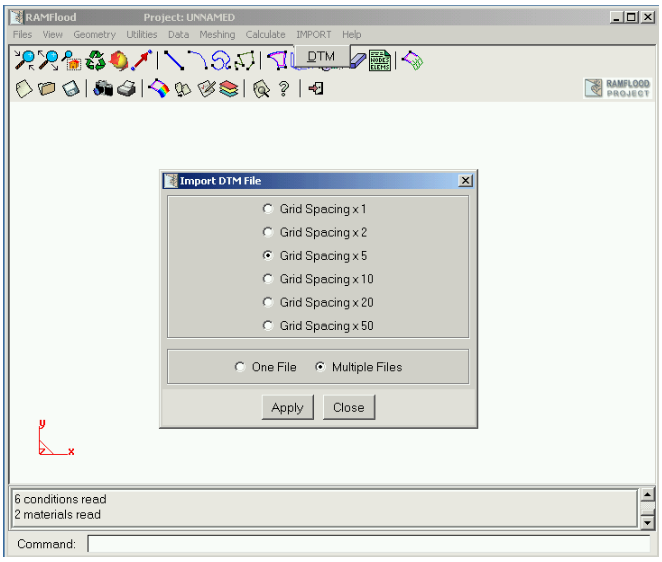


Figure 10.2 – Main window to import DTM information

The number of surfaces are related to the number of files imported.

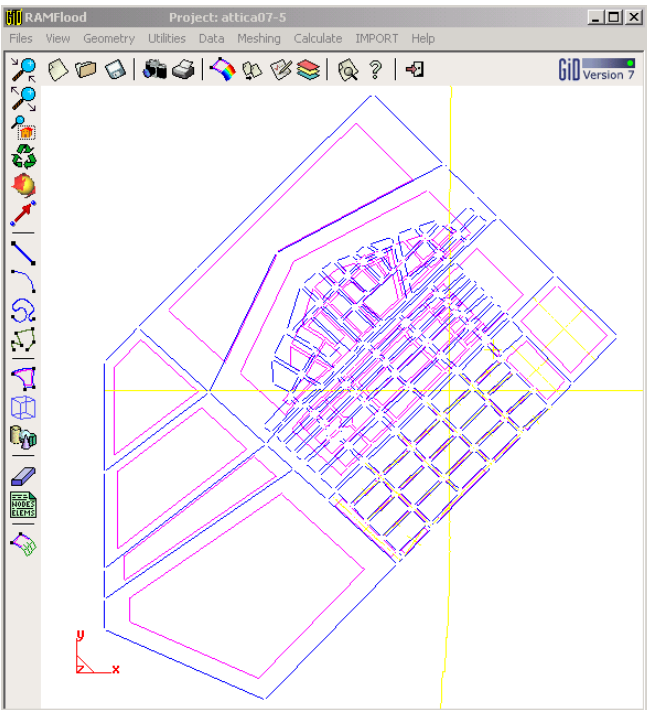


Figure 10.3 – Attica basin surfaces created using the GiD system

Figure 10.4 shows a rendered image of the study area. Using the GiD the details of area chosen can be visualized.

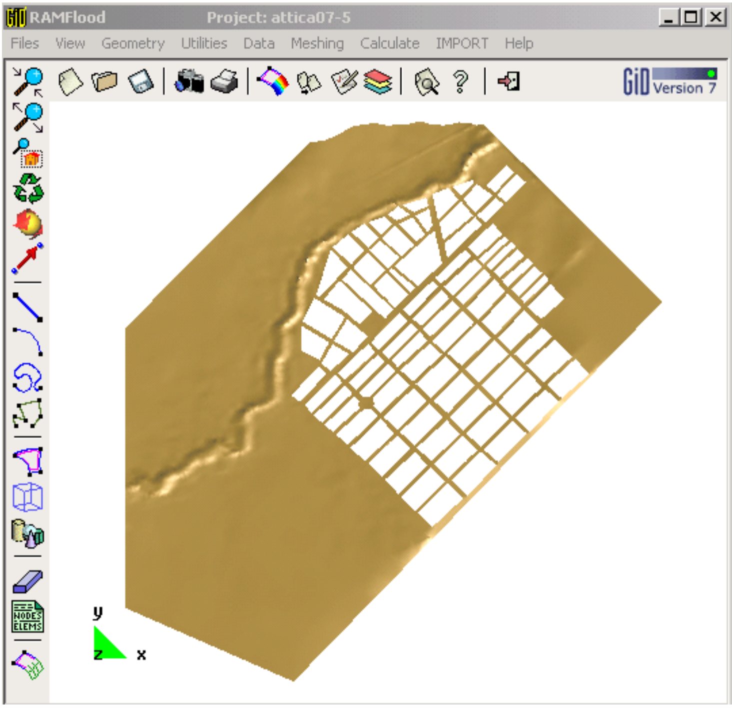


Figure 10.4 - Attica basin rendered image of the study area

10.3.2 *Creation of the finite volume mesh.*

The analysis mesh was generated using GiD. An unstructured mesh of 20187 quadrilateral elements was generated. Figure 10.5 shows the final mesh obtained

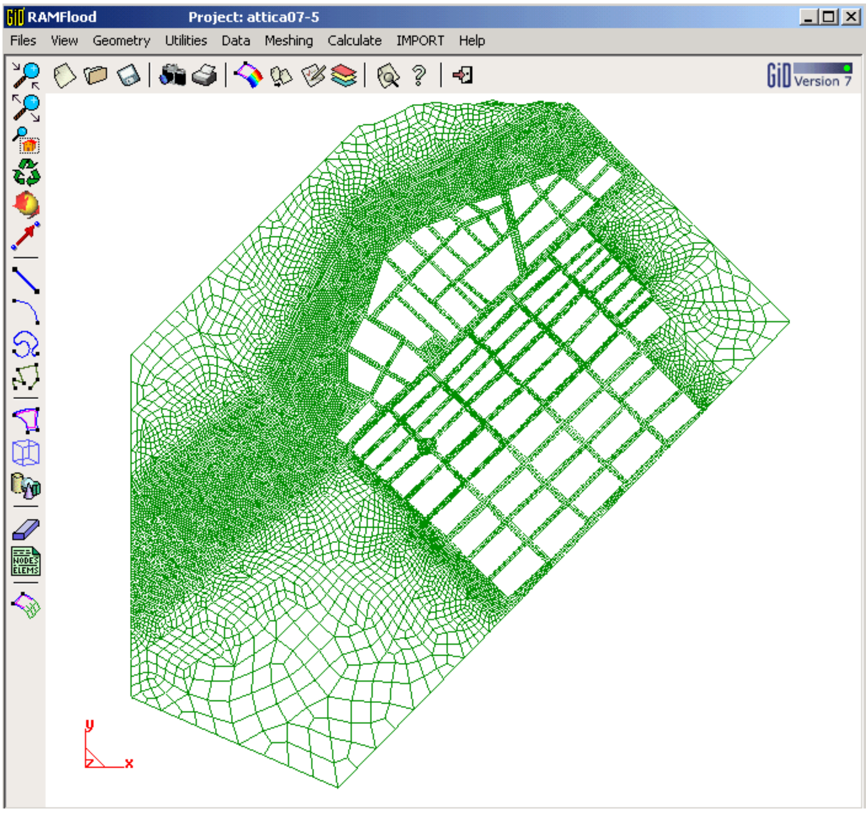


Figure 10.5 - Attica basin unstructured mesh of 20187 quadrilateral

10.3.3 Definition of the mesh properties

To assign the properties on the mesh we used the GiD tool "Properties" (roughness). This task was done automatically from the land uses map associated at the area of study (database files).

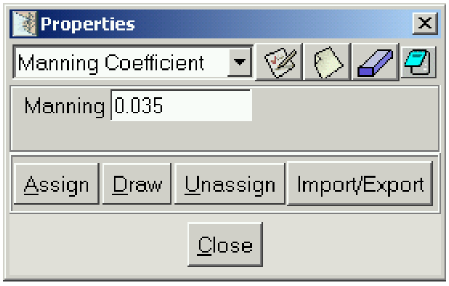


Figure 10.6 – Main window to assign the mesh properties

Figure 10.7 shows the properties assigned on the mesh.

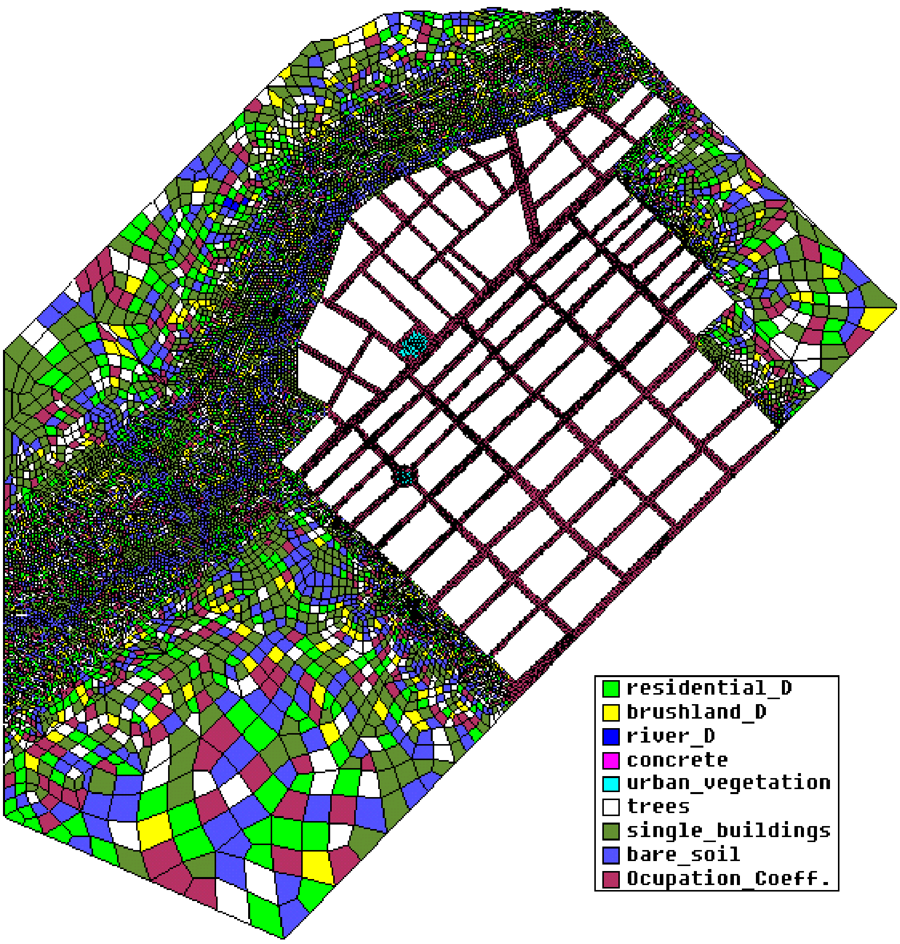


Figure 10.7 –Definition of mesh properties on the Attica region.

10.3.4 Definition of the type of analysis (2D) on the mesh.

The mesh properties on the mesh for 2D hydraulic analysis using CARPA were analysed.

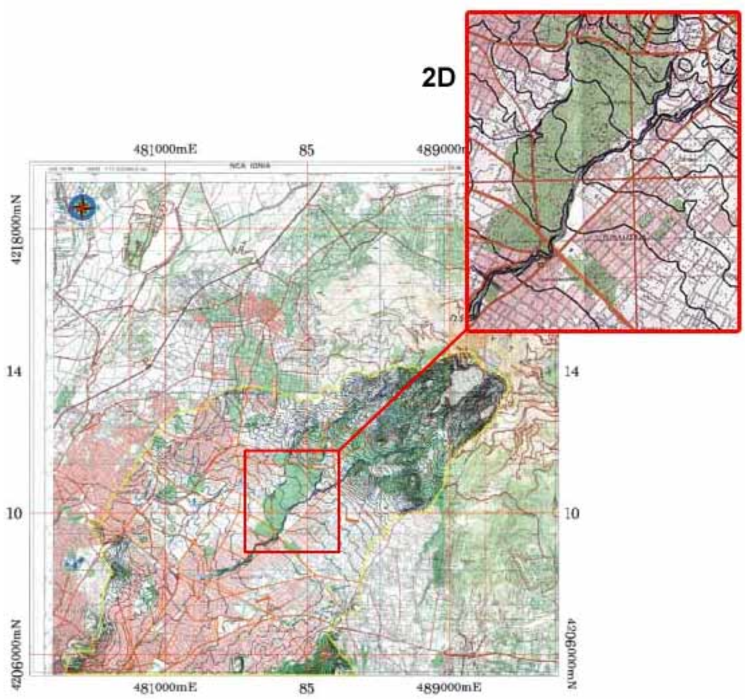


Figure 10.8 - Attica basin topographic map of the area of interest

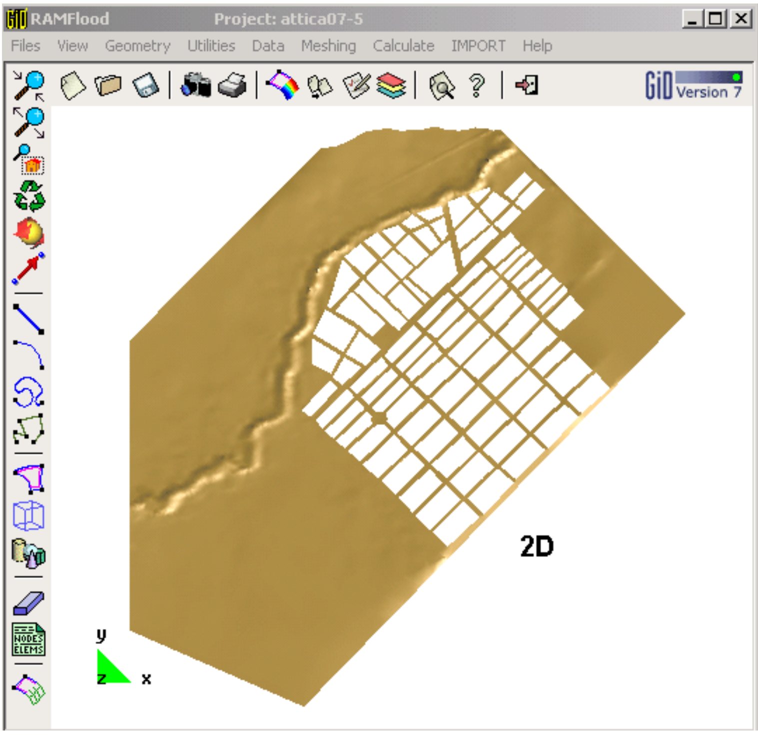


Figure 10.9 - Definition of the 2D areas in the Attica basin

10.3.5 Definition of the analysis conditions.

The next step was the definition of the hydraulic analysis conditions. The following GiD tools were used to define the initial conditions and the boundary conditions:

Initial condition: tool used to define the initial water depth on the mesh
Since the volume of base of the Halandri River is small in comparison with the water volumes that are transported after a rain, it was decided not to consider it and dry initial condition was assigned. That means initial condition = Wet depth (0.01 m)

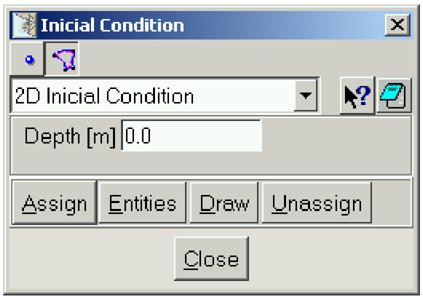


Figure 10.10 – Definition of the initial condition on the mesh

Boundary conditions: tool used to define the inlet condition and the outlet condition on the mesh

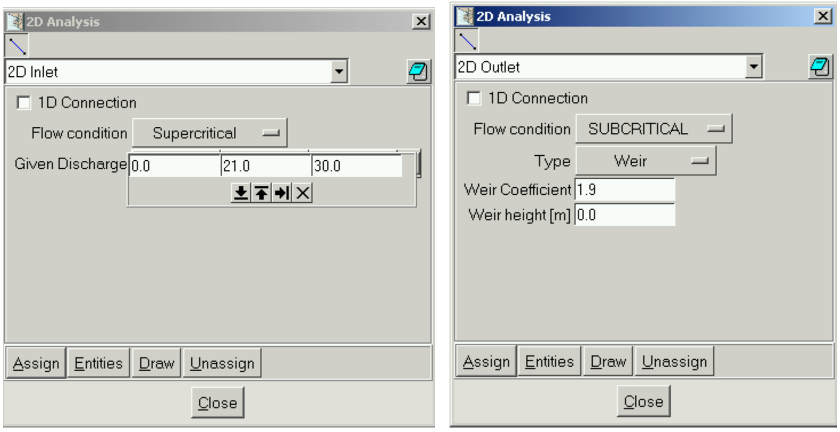


Figure 10.11 – Definition of the boundary condition on the mesh

In the following images we can see the conditions assigned to the hydraulic analysis model for the Attica basin.

2D inlet and outlet conditions

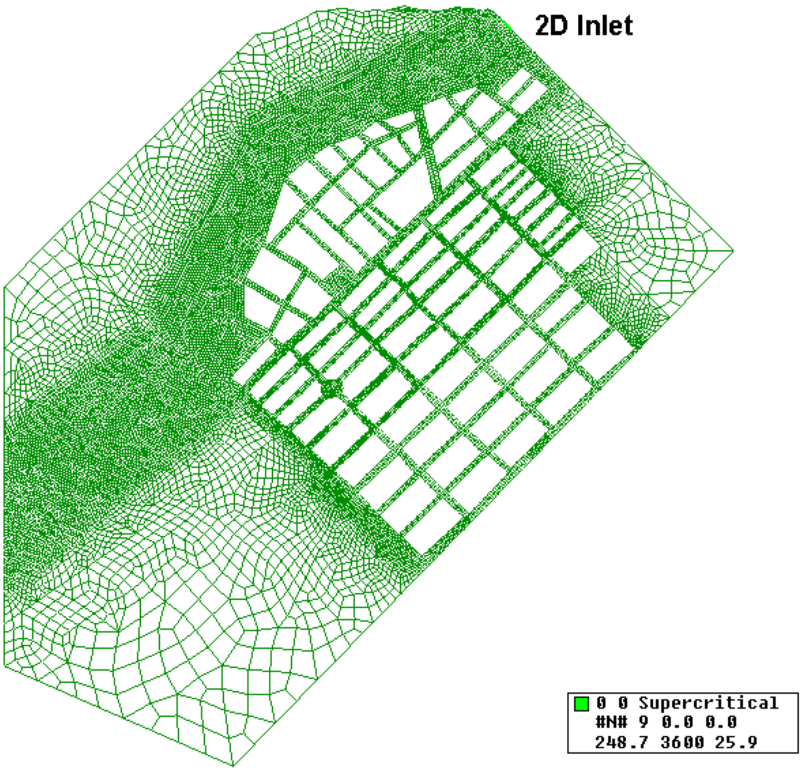


Figure 10.12 - 2D inlet conditions in the Attica basin

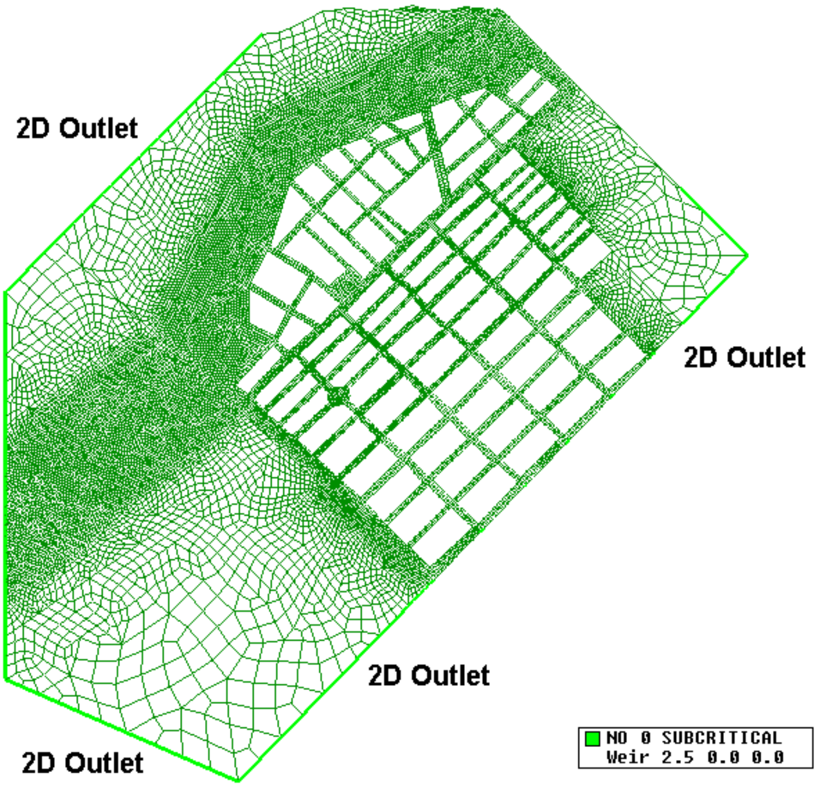


Figure 10.13 - 2D outlet conditions in the Attica basin

10.3.6 Proposal of the possible values range of the inlet conditions.

In order to generate the training data to build the ANN, UPC defined the possible values range of the inlet conditions for the Halandri River.

The input variables of the inlet conditions are: Base time, Peak flow, Peak time

See the following image:

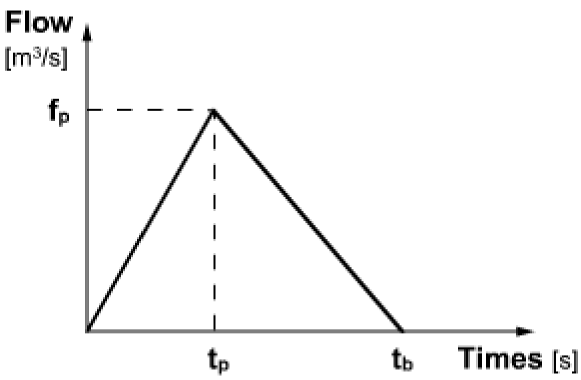


Figure 10.14 - Inlet conditions

The data range proposed by AUA were:

tb: 0 – 1020 s
fp: 19 m^3/s – 380 m^3/s
tp: ¼ - ½ of tb

10.3.7 *Generation of the output preprocess files to be used to develop the ANN training data.*

The next step was to define the pre-process data to run the hydraulic simulation model and to visualize the simulation results. Figure 10.15 shows one of the options to generate the preprocess files using the GiD system.

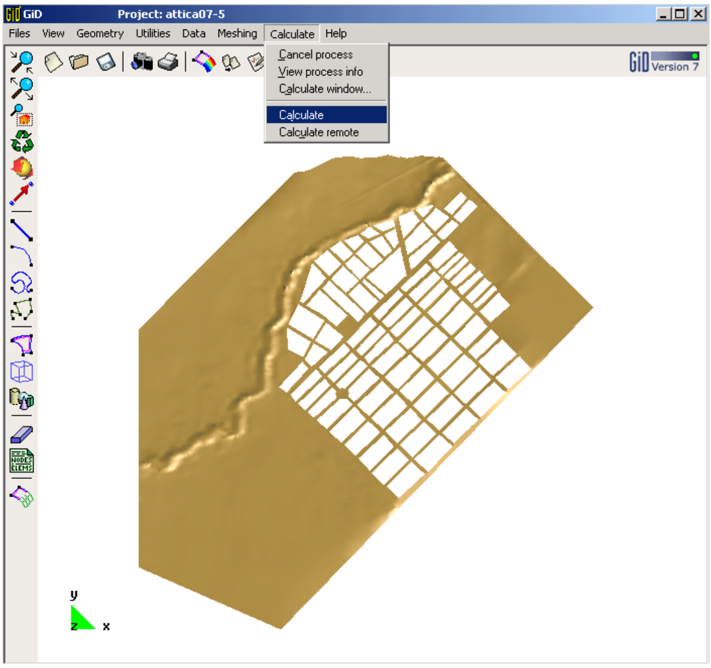


Figure 10.15 – Attica basin GiD tool to create the preprocessing files

10.4 Flood analysis of the Attica river basin.

Different hydraulic simulations were carried out a the Attica basin using information available in the AUA and UPC about floods of the Attica region (flow data, depths, velocities, floodplain, etc).

The numerical results are visualized using the post-processing tools in GiD.

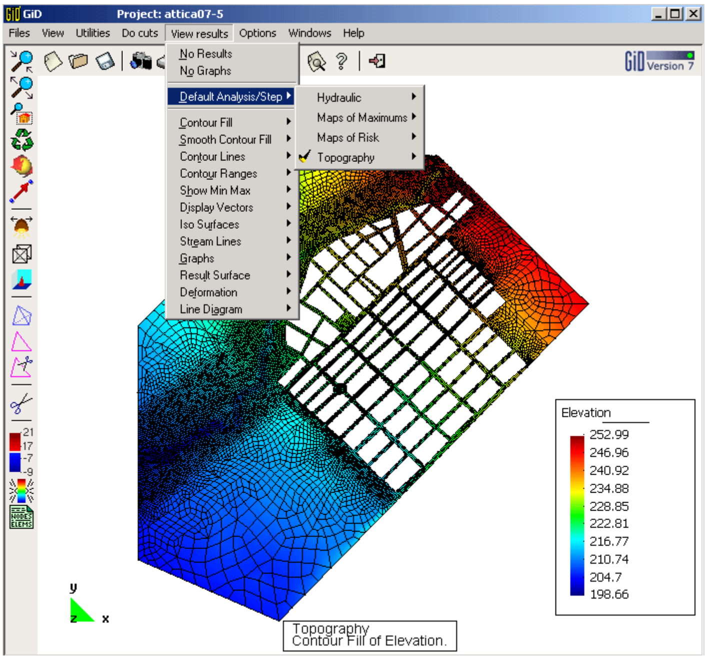
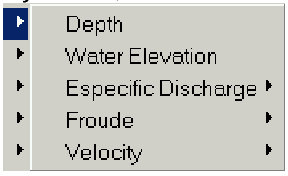


Figure 10.16 – Attica basin results visualized using the post-processing tools of the GiD system

Some of the results options are listed below.

Hydraulic,



Maps of Maximums,

Topography,

Figure 10.17 shows some numerical results for different times.

Velocity

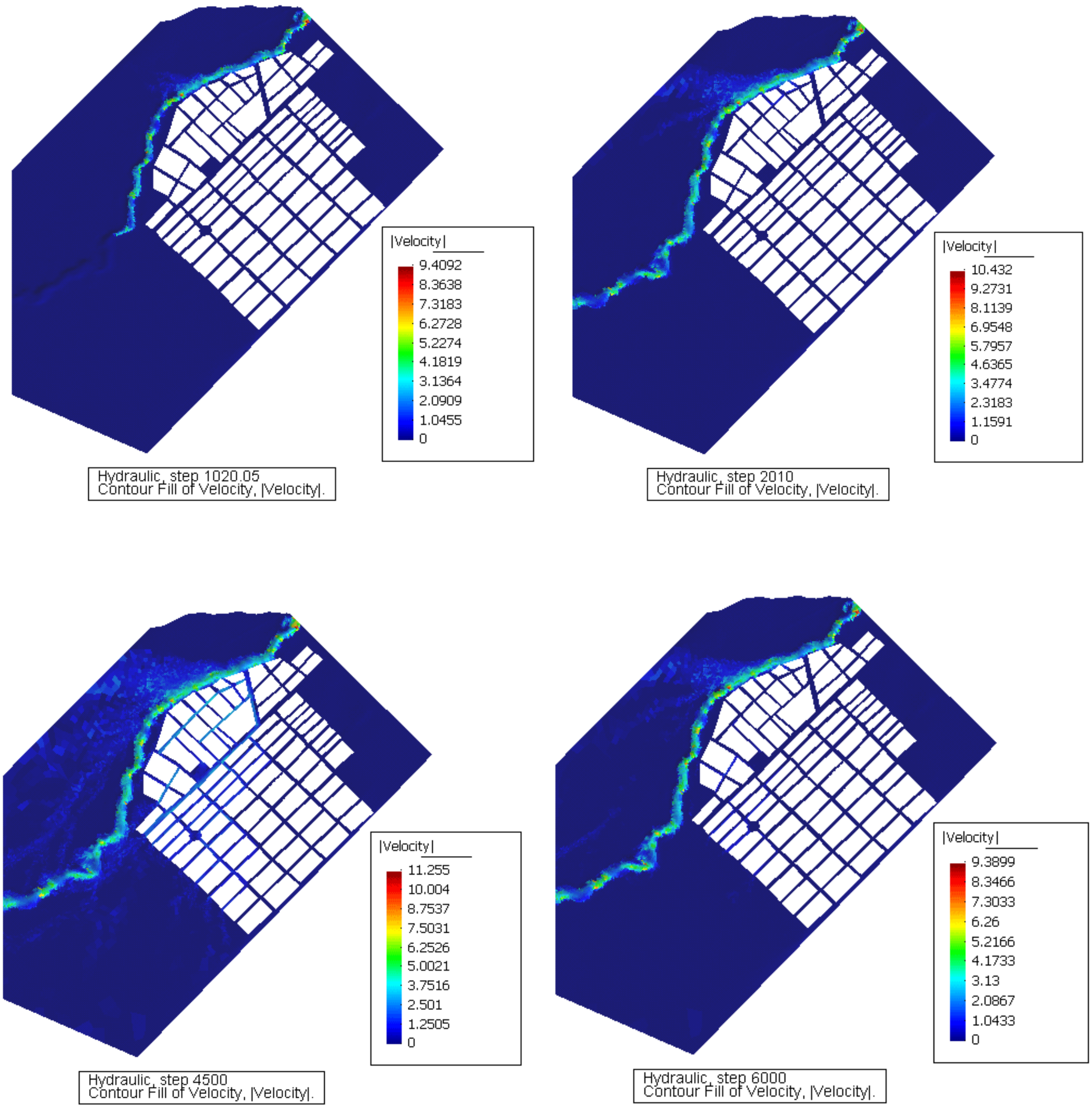


Figure 10.18 – Attica basin results of the water velocity at different times for a specific simulation

Depth

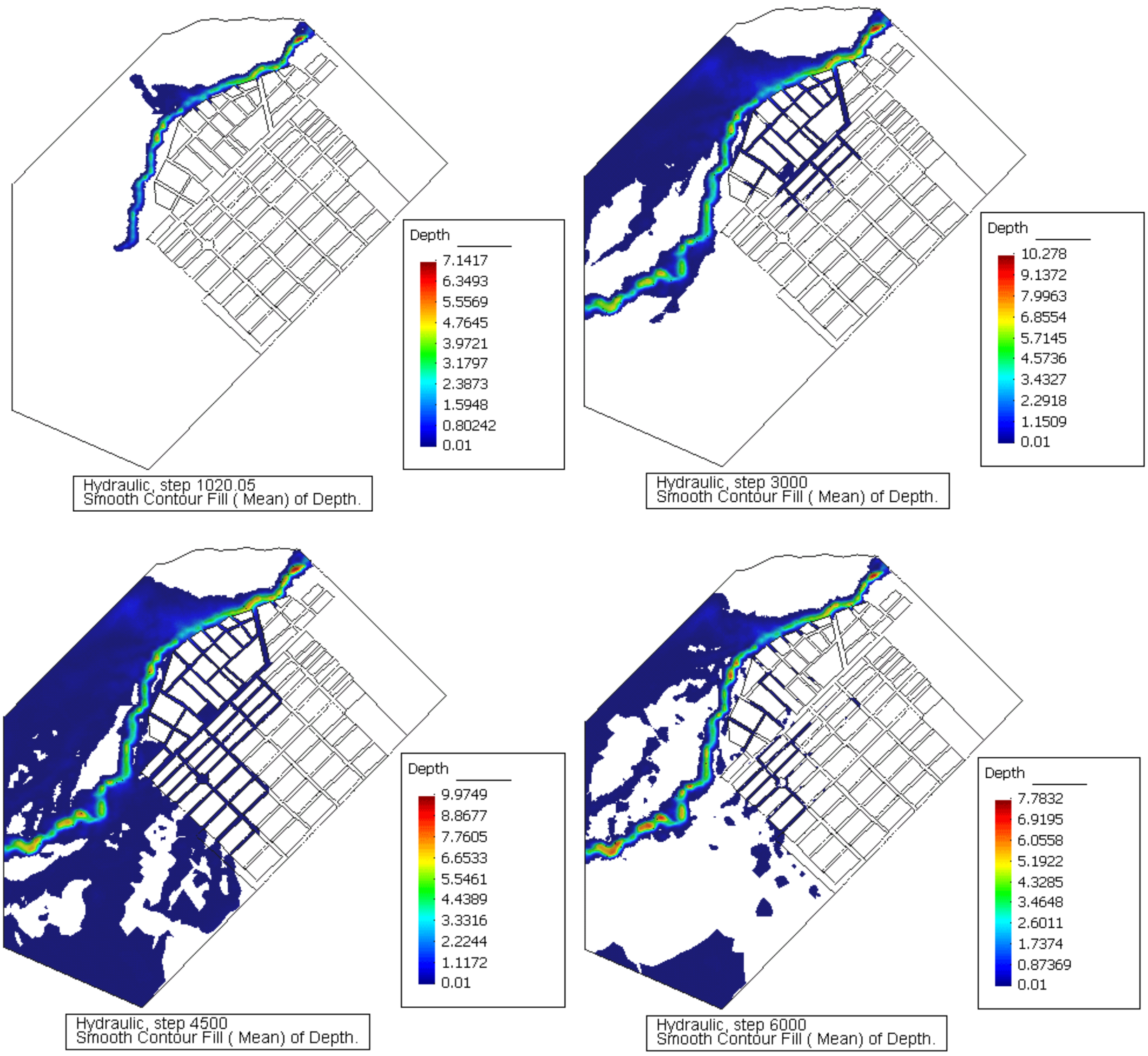


Figure 10.19 – Attica basin results of the water depth at different times for a specific simulation

Figure 10.19 -10.21 show results of the: velocity, water elevation and water permanence.

Velocity

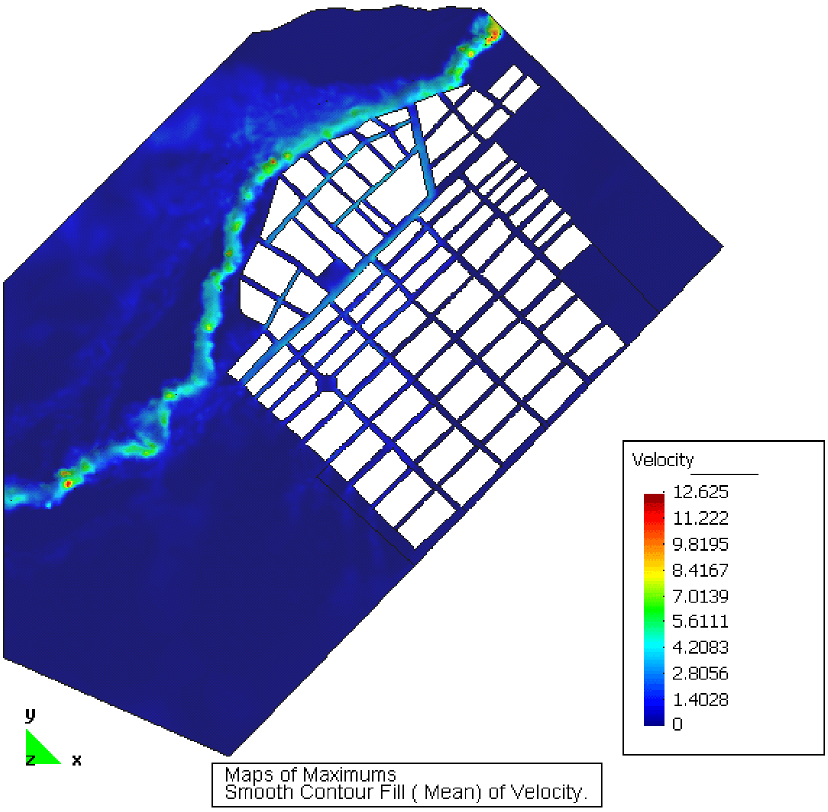


Figure 10.19 – Attica basin results of the water velocity for a specific simulation

Water Elevation

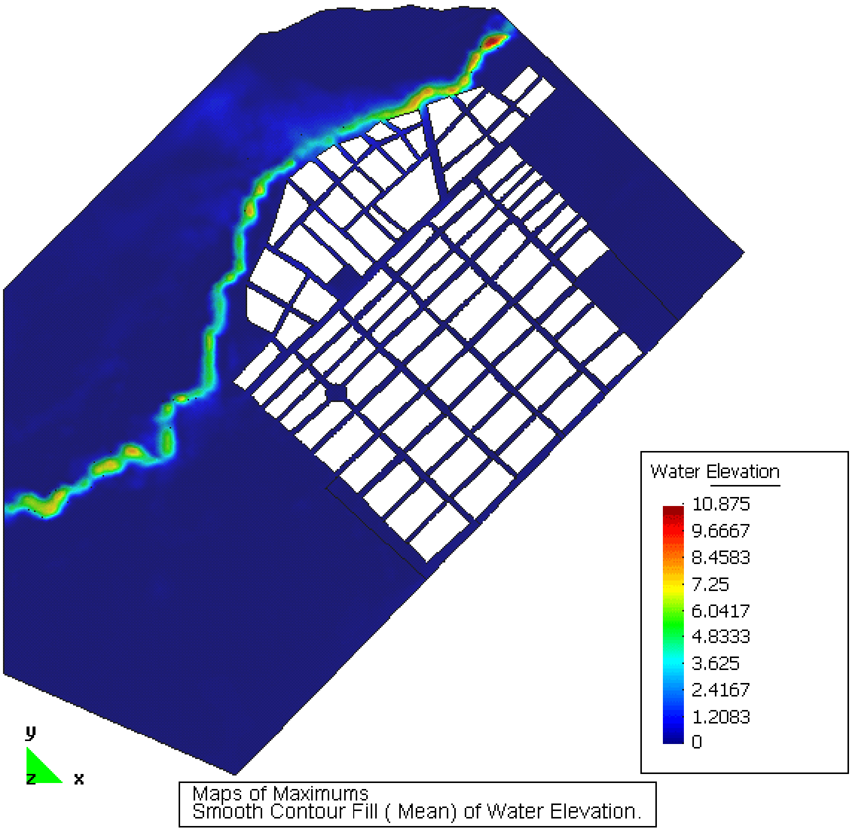


Figure 10.20 – Attica basin results of the water elevation for a specific simulation

Water Permanence

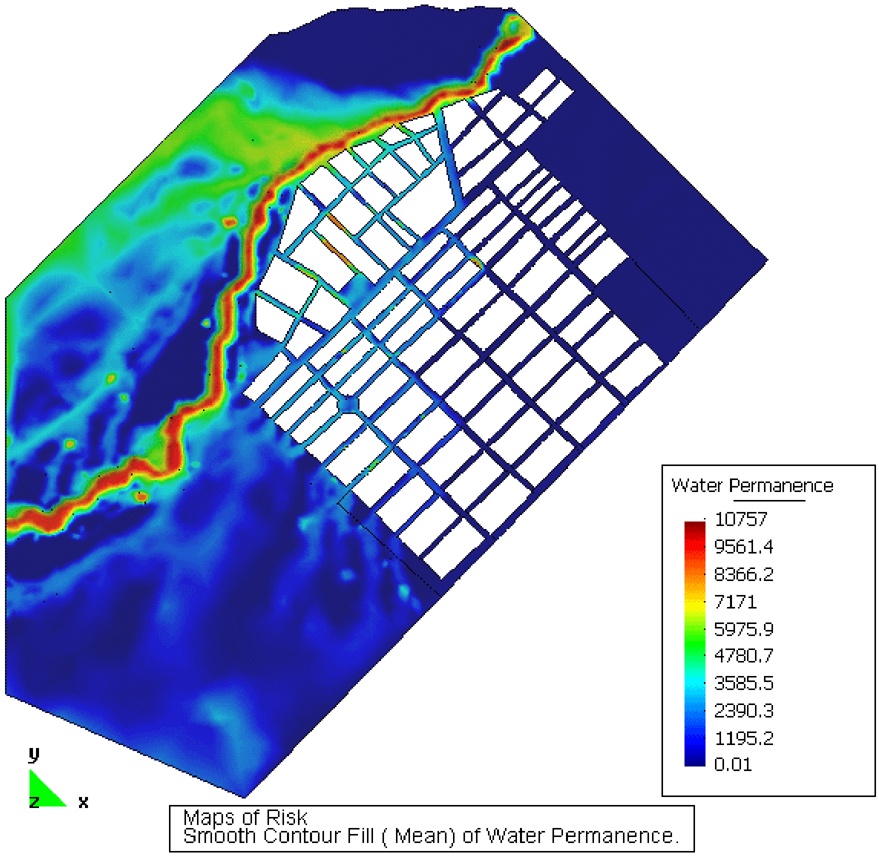


Figure 10.21 – Attica basin results of the water permanence for a specific simulation

10.5 Development of the ANN training data.

To train the ANN is necessary generating a great number of results obtained from the hydraulic analysis on the Attica basin.

Using the range of the possible values of inlet conditions defined by AUA and the Montecarlo method we generated different combinations to obtain the hydraulic results on each finite volume.

CIMNE developed a wizard tool to generate the training data. The user must simply fill in the necessary information for each step.

The next figure shows the first step, where the user must define the project name, and the preprocessing files, as well as the CARPA code.

Figure 10.22 shows the main steps necessary to create the AI. Module:

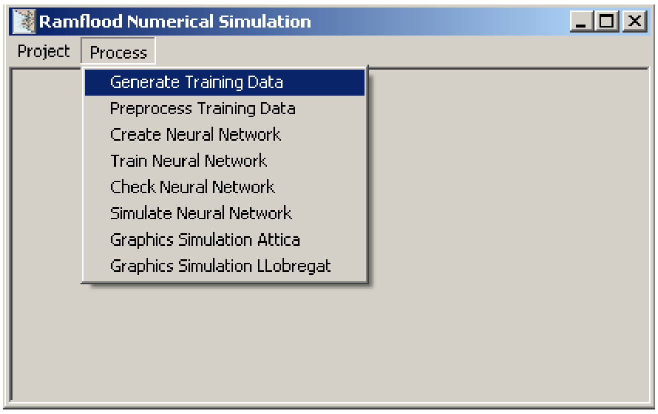


Figure 10.22 – Main steps necessary to train the ANN

10.5.1 *Generate the Training Data*

The next figures show the first step of the training process, where the project name and the pre-processing files, as well as the CARPA code are defined.

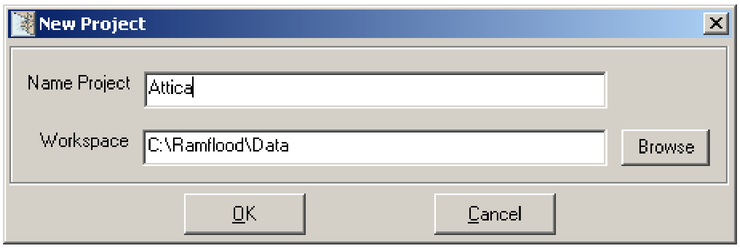


Figure 10.23 - Create a new project window.

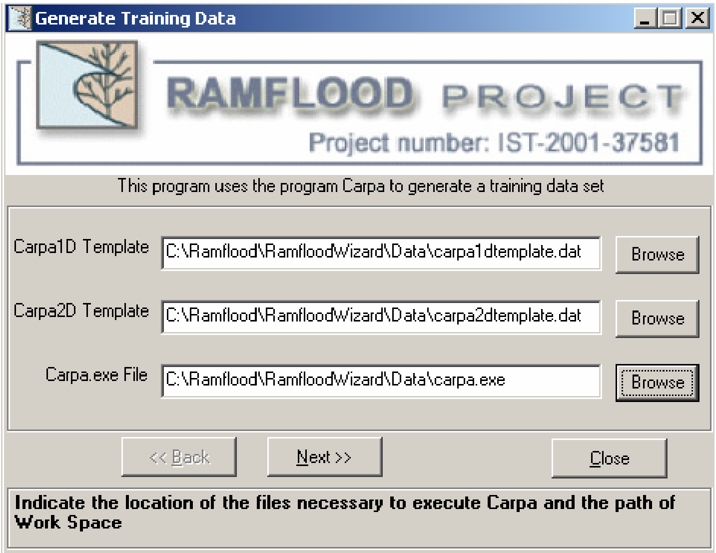


Figure 10.24 - Generate training data

In the second step we completed the information about the value range of the inlet conditions. See the following example, (time [s], flow [m^3/s], Level [m]):

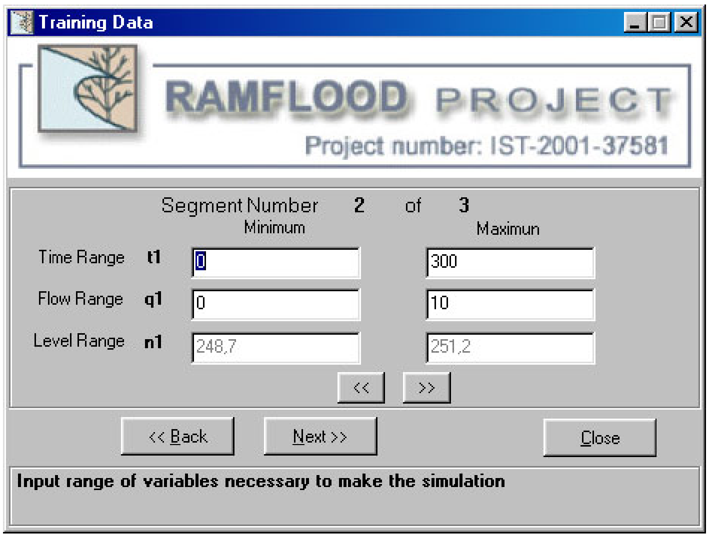


Figure 10.25 – Definition of the value range for the inlet conditions

For the Attica region 395 simulations were computed. From the total training data, 300 simulations were used to train the ANN, and the remaining 95 simulations were used to validate the ANN.

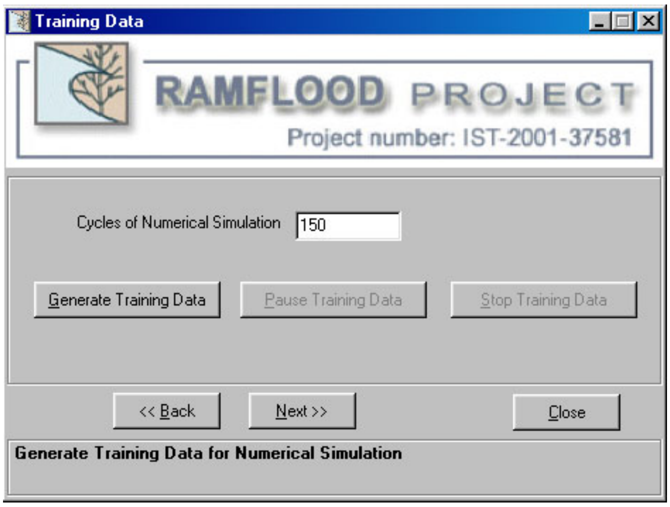


Figure 10.26 - Choose the number of cycles of numerical simulation in the training data set

Next, the training data is defined directly by a click on the button *Order Data*.

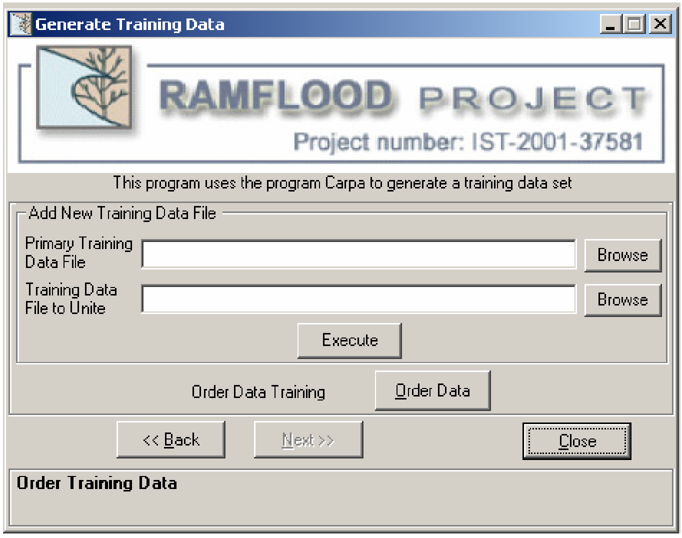


Figure 10.27 - Order Training Data Window.

10.5.2 Preprocess the ANN

In order to preprocess the training data we specified:

- The location of the raw training data file.
- The location of the preprocessed training data file to be created.
- The location of the mean and standard deviation of the input and target variables data file to be created.

The following figure shows how this process appears in the main window of the Ramflood wizard tool.

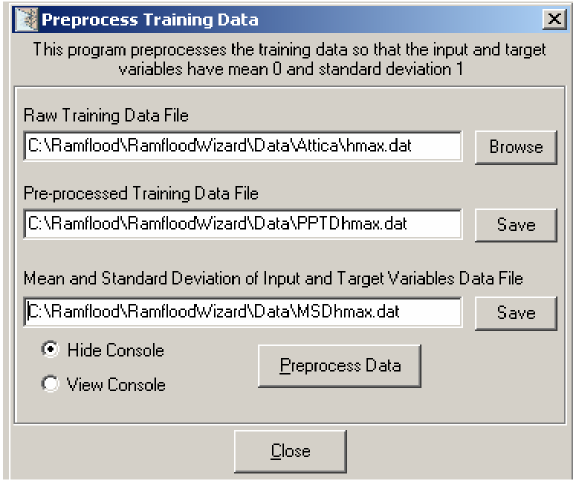


Figure 10.28 - Preprocess Training Data.

10.5.3 Create the ANN

Once the training data file has been created and pre-processed, we are ready to create the ANN structure. This consists of a data file containing the size, architecture and free parameters of the ANN.

To create the ANN structure with the Ramflood wizard tool, the following parameters are specified:

- The location of the raw training data file. This file contains the variables name, the size of the neural network and the number of input and output variables.
- The number of neurons in the hidden layer.
- The location of the neural network data file to be created.

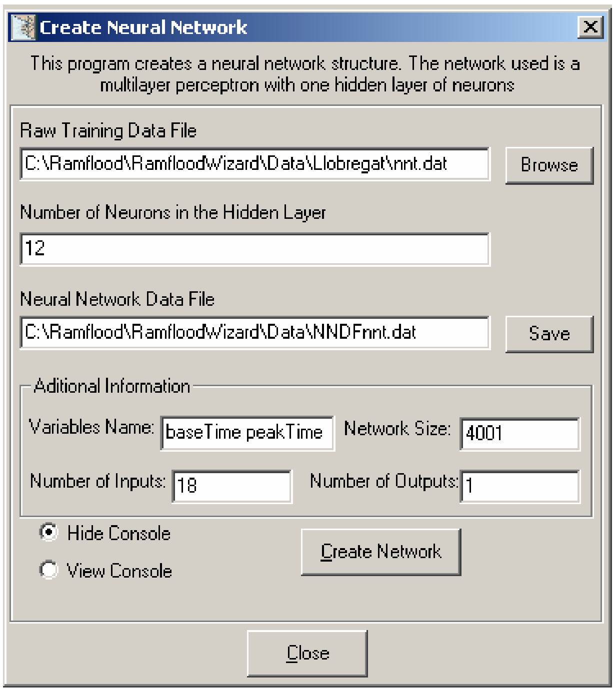


Figure 10.29 - Create the ANN.

10.5.4 Train the ANN

From the total training data file, we only used 300 hydraulic simulations in this step.
The ANN are trained with the Ramflood wizard tool by specifying the following parameters:

- The location of the pre-processed training data file with which the ANN is to be trained.
- The location of the neural network data file.

- The stopping criteria: Performance goal, goal for the norm of the performance function gradient, maximum number of epochs to train and maximum training time.
- The number of epochs between the showing progress training parameter.
- The number of cycles this training process is to be performed.

The following figure shows how this process appears in the main window of the Ramflood wizard tool.

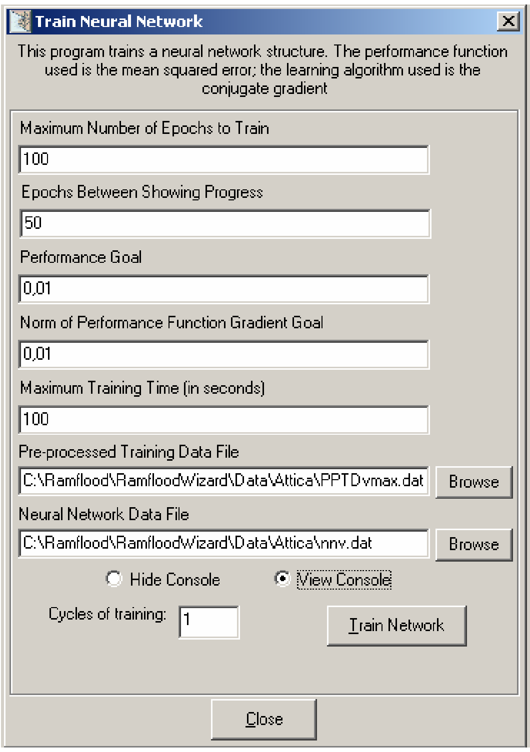


Figure 10.30 - Train the ANN.

10.5.5 Check the ANN

From the total training data file, we used the remaining 95 hydraulic simulations in this step.
To validate a single ANN structure we need to specifying the following parameters:

- The variable for which we want to validate the ANN: maximum height, maximum velocity, maximum velocity-height or wet time.
- The location of the ANN data file for that variable.
- The location of the mean and standard deviation data file for that variable.
- The output file to be created. This file contains the results of the simulation for a single output variable.
- The input values for simulation.

Figure 10.31 shows how this process appears in the main window of the Ramflood wizard tool.

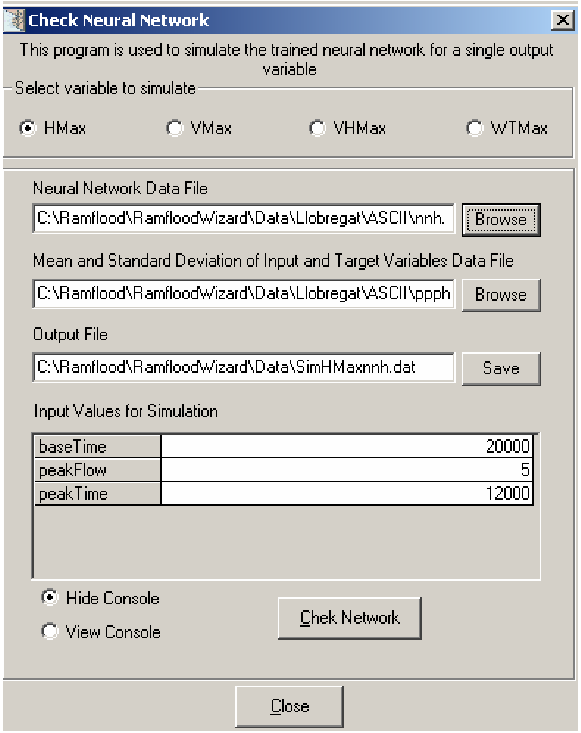


Figure 10.31 - Check neural network.

Once the ANN has been validated it is ready to be used. The results obtained by the ANN are post-processed for visualization. Risk or hydrological variables are plotted on a map of the region. To do this we create a results data file to be read by the GiD pre and post-processing system.

10.6 Integration of the ANN of the Attica basin into the Ramflood DSS.

Once the AI module of the Attica basin was developed, we created a new project in the Ramflood DSS and included the AI module.

If we enter into the Ramflood System as an end user, we find the following interfaces:

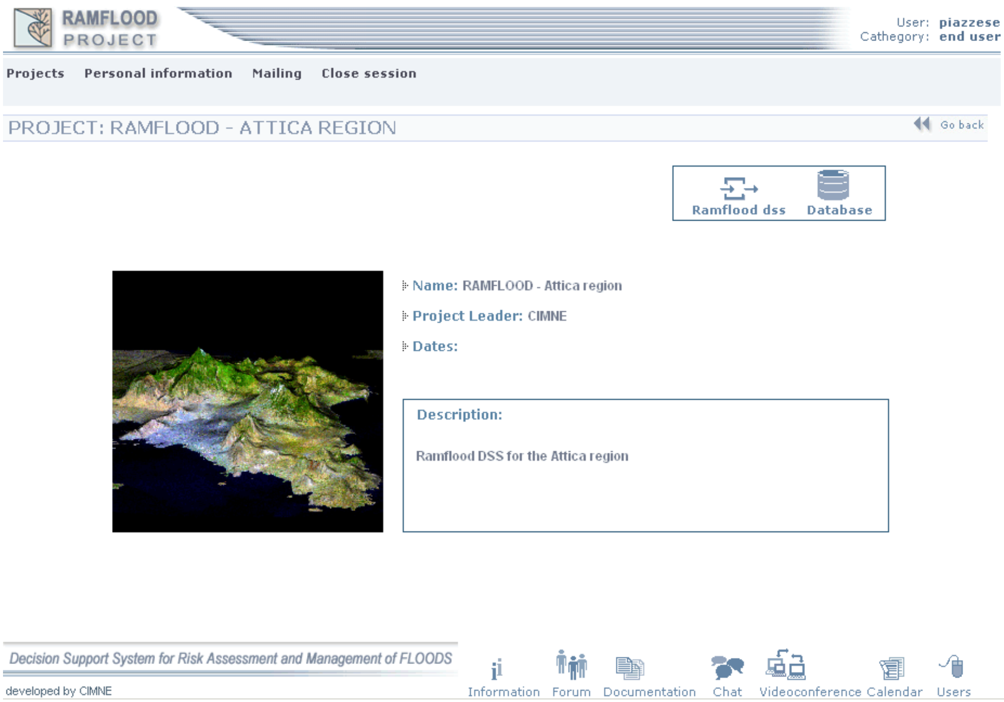


Figure 10.32 – Attica basin main work window for the end user level

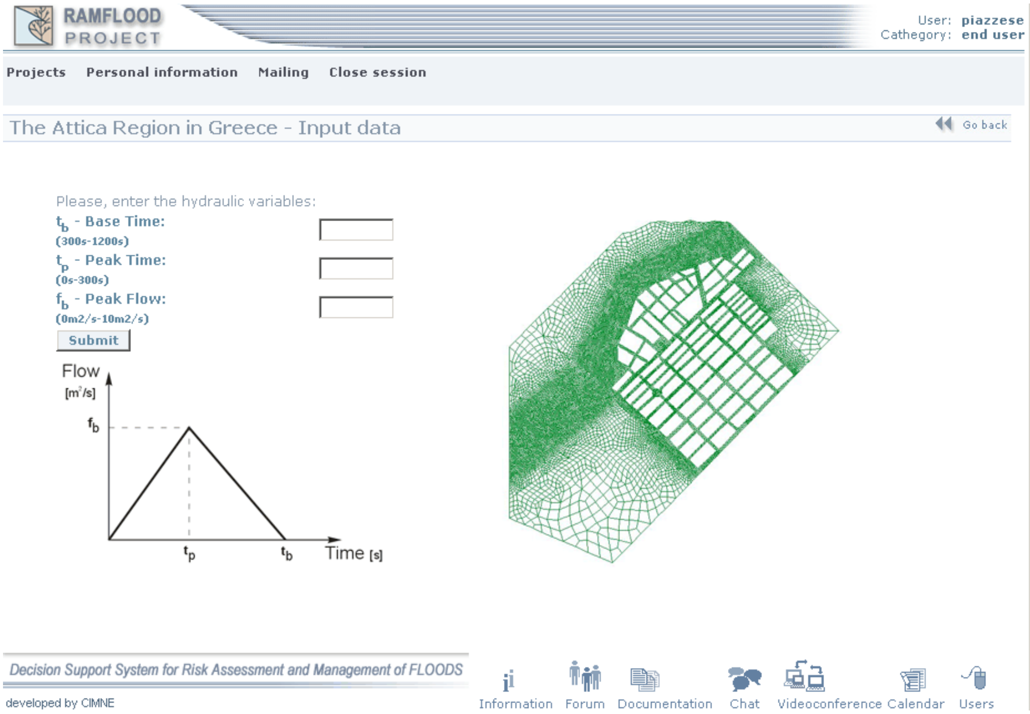


Figure 10.33 – Attica basin input data window

End users introduce the specific hydraulic parameters for which the map will be produced. We recall that these parameters are the flood base time, the peak flood time and the peak flood flow.
Figures 10.34-10.37 show maps provided by the Ramflood DSS in "quasi" real time (aprox. 20 seconds)

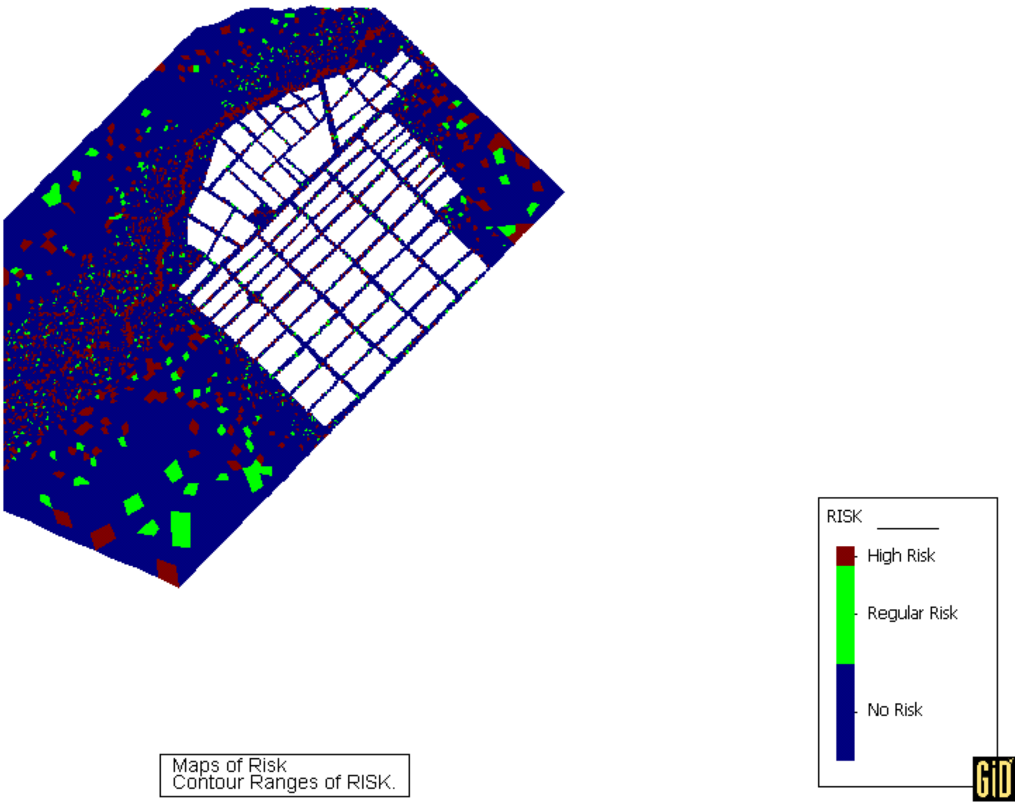


Figure 10.34 – Attica basin risk map provided by the ANN

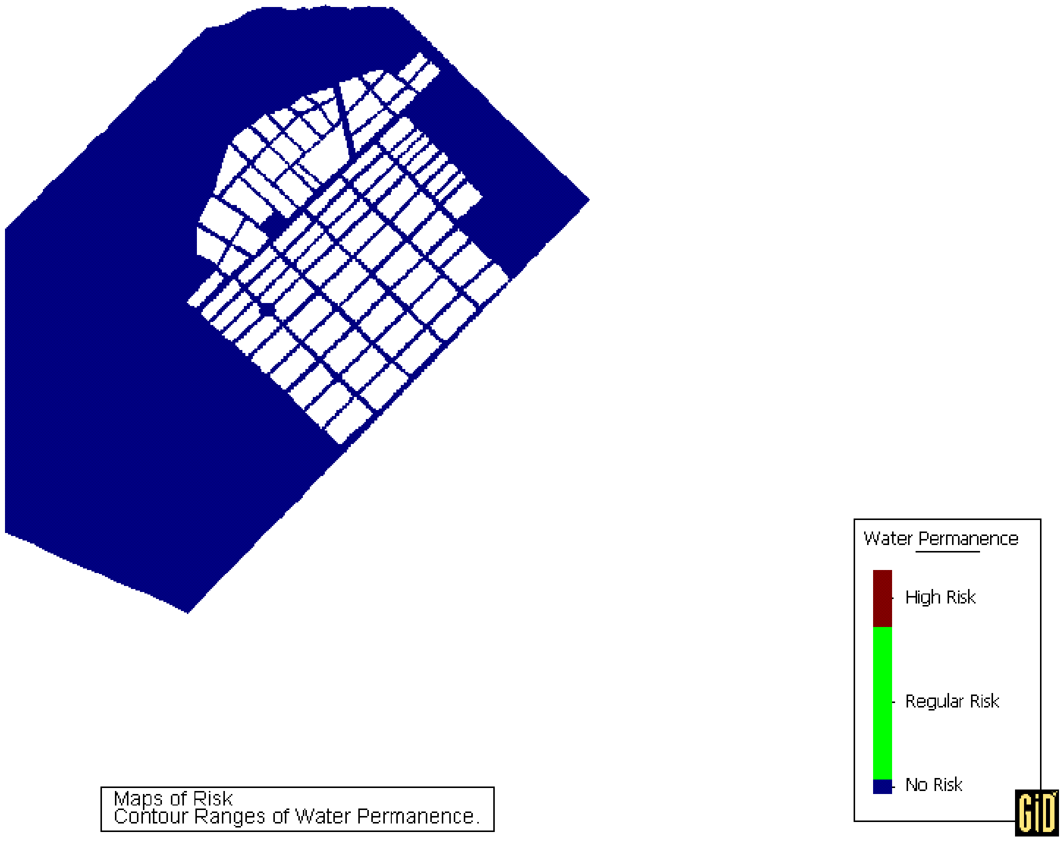


Figure 10.35 – Attica basin water permanence map provided by the ANN

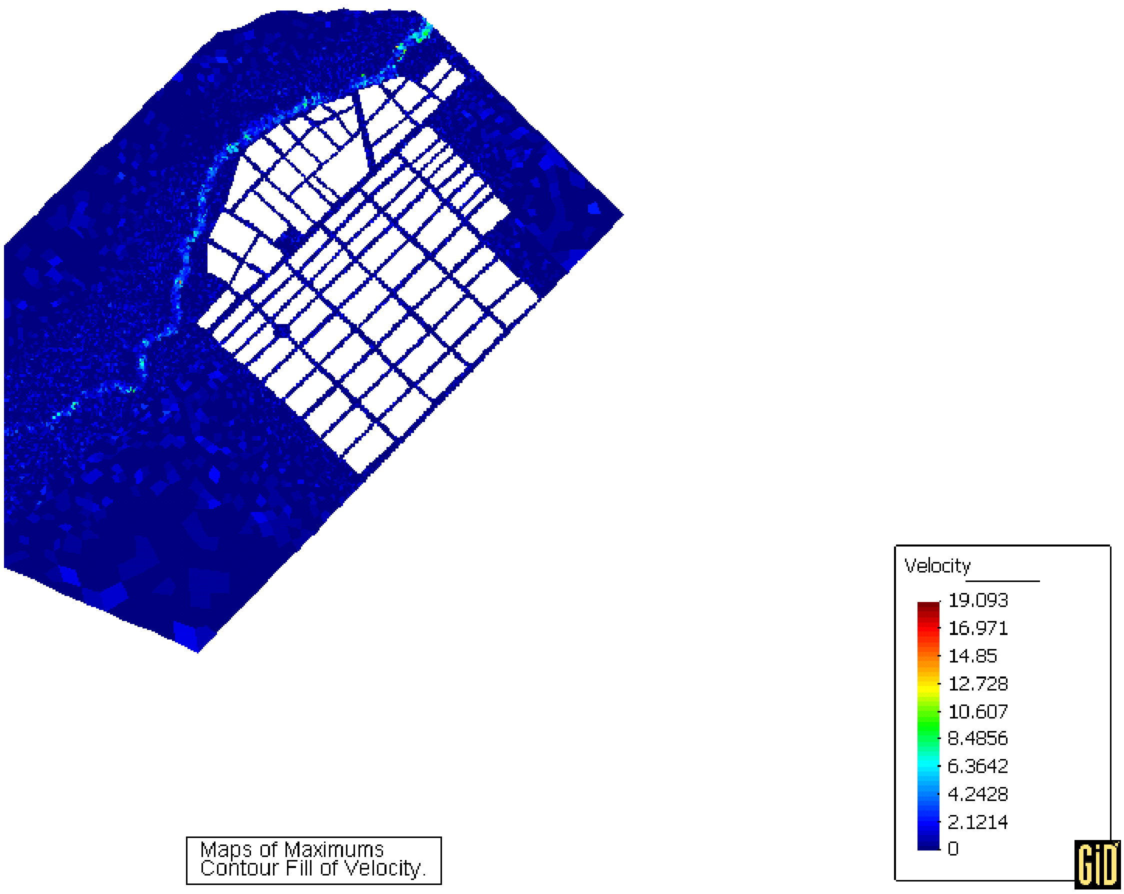


Figure 10.36 – Attica basin velocity map provided by the ANN

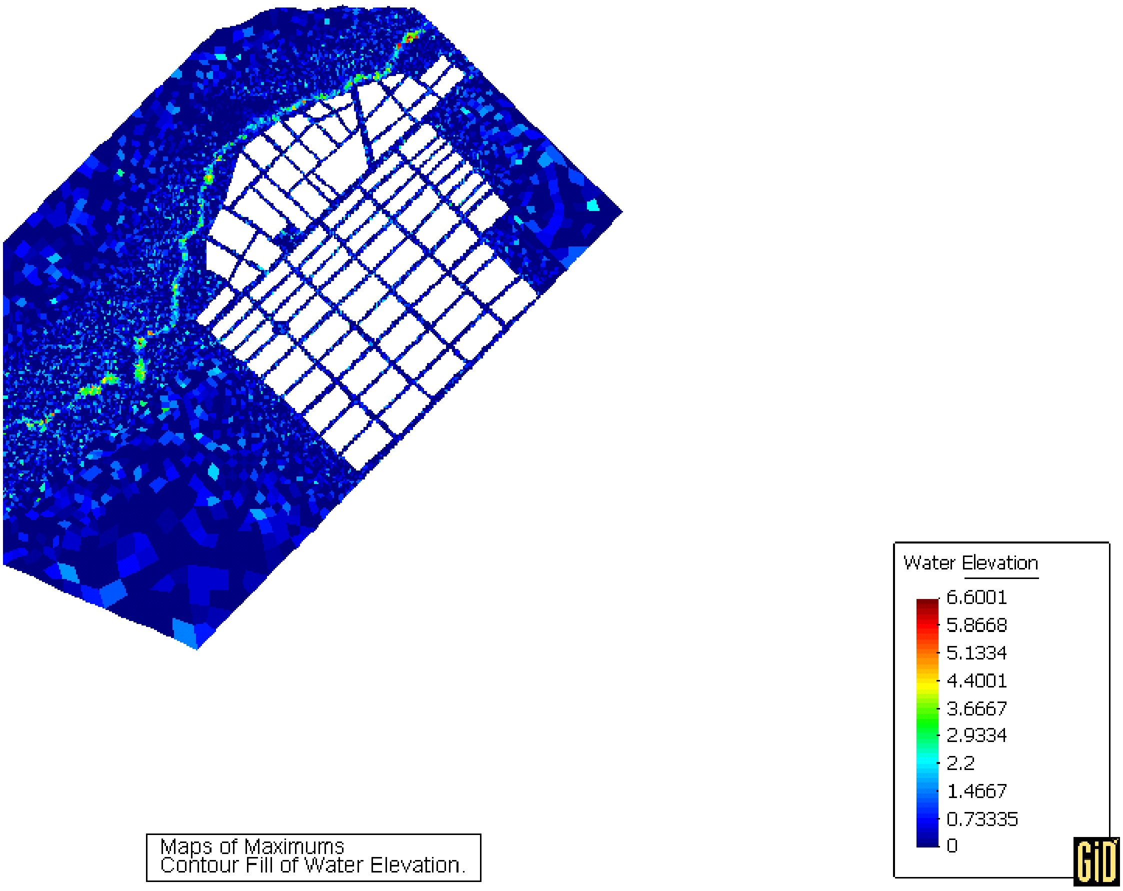


Figure 10.37 – Attica basin water elevation map provided by the ANN

11. DISSEMINATION OF THE RAMFLOOD DSS

11.1 Logo of Ramflood project.

The project image / logo was developed by CIMNE.
All partners have used the “corporative” image of the project for dissemination purposes:

Figure 10.1 - Corporative image

11.2 Brochure of Ramflood project.

The project brochure was developed by CIMNE. All the partners contributed to the development of the brochure. This brochure includes a brief description of the project objectives, workplan and outputs.

The list of project partners is also included with the corresponding contact persons.

Figure 10.2 – of the Ramflood DSS

11.3 Web page of Ramflood project.

The Web page of Ramflood project was developed by CIMNE. The direction of the web site of the Ramflood project is:

http://www.cimne.upc.es/Ramflood/

The site contains information relevant to the project which is of public nature. The site has also a space containing all the project documents and is accessible only by the partners.

The partners can publish selected project results and demonstrations of the RAMFLOOD DSS through the project Web site.

For the web environment implementation the following languages have been used:
Active Server Pages (ASP): The server side has been programmed in its totality in VisualBasic, by CIMNE. This technology needs a Microsoft Window server with the Internet Information Server.

HTML: Forms and web pages have been formatted using HTML, so they can be viewed in every web browser.
JavaScript: This language has been used to control that all the forms were correct before the data arrived to the server.

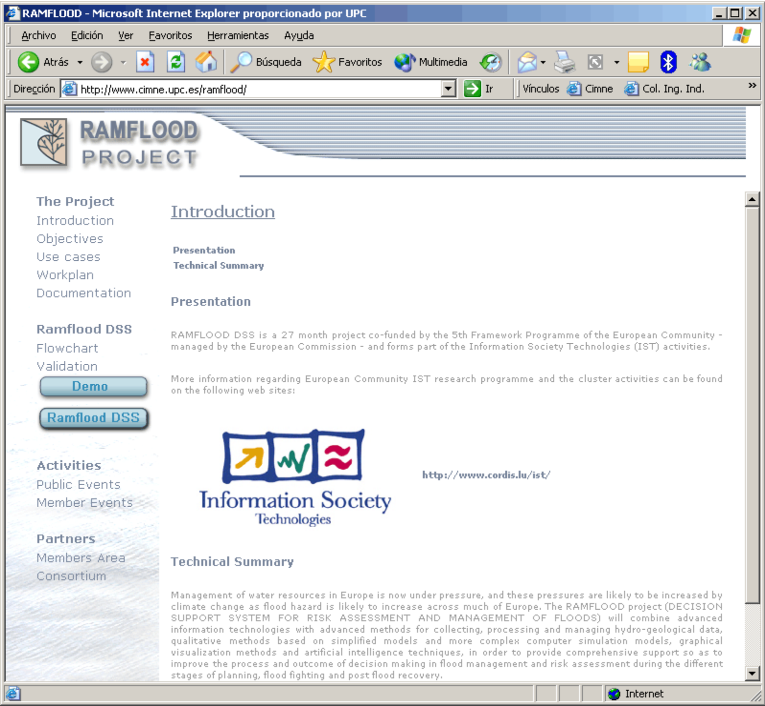


Figure 10.3 – Web page of the Ramflood DSS

11.4 Other dissemination activities.

11.4.1 Publications

"Sistemas de ayuda a la decisión en ingeniería civil. Posibilidades y perspectivas".
E. Oñate, J. Marcipar y J. Piazzese, Publication CIMNE Nº 238, Barcelona, 2003.

"El valor del cálculo en los sistemas de ayuda a la toma de decición en ingeniería"
E. Oñate, Publication CIMNE Nº 264, Barcelona, October 2004.

"Posibilidades de los sistemas de ayuda a la decisión en ingeniería civil. Posibilidades y perspectivas". E. Oñate, Proceedings of the IV National Congress of Civil Engineering, Madrid, España, 26-28 de noviembre 2003.

"The value of computation in engineering decision support systems"

E. Oñate, Revista de Obras Públicas Nº 3449, Madrid, November 2004.
“Decision support system for risk assessment and management of floods”. Proceedings of the congress International Symposium on Environmental Software Systems 2003” (ISSES 2003) Semmering, Austria Environmental Software Systems, Volumen 5. Environmental Knowledge and Information Systems. May 27-29, 2003.

“Decision support system for risk assessment and management of floods”. Proceedings of the EU-LAT Workshop on e-Environment, San José, Costa Rica, November 30 – December 3 2004.
Research on computing science, Vol. 11.

“New GiD Interface for Ramflood-Dss Project Hydraulic Simulation Code”.Proceeding of the congress “2nd Conference on Advances and Applications of GiD”. CIMNE. Barcelona, February 2004 (UPC-CIMNE) G. Corestein, E. Bladé, M. Gómez, J. Dolz, E. Oñate, J. Piazzese.

11.4.2 Presentation in Conferences

“International Symposium on Environmental Software Systems 2003” (ISSES 2003) Semmering, Austria May 27-29, 2003

“NSCM XVI Seminar”, Norwegian University of Science and Tegnology, Trondheim – Norway, October 16 – 18, 2003.

“Enief 2003 – XIII Congress on Numerical Methods and Applications”, Bahía Blanca – Buenos Aires, Argentina, November 4 – 7, 2003.

“IV National Congress of Civil Engineering”, Madrid, Spain, November 26-28, 2003.

The project Ramflood was presented at the “Curso de Hidrología Urbana”, Barcelona – Spain, January 14 – 16, 2004.

Latin-American Congress of Hydraulics. Organized by the Latin-American Section of IAHR. Sao Paulo. October 2004

Workshop 2nd Call of IST Programme in 6th RTD Framework Programme Strategic Objective: “Improving Risk Management”, Brussels July 3, 2003.

Conference on Adaptive Modelling and Simulation, Göteborg, Sweden, September 29 – October 1st, 2003.

“Concertation Meeting, Improving Risk Management”, 22 April 2004, Brussels”.

“EU-LAT Workshop on e-Environment”, San José, Costa Rica, November 30 – December 3 2004.

Urban Hydrology. Continuous Education Course. Barcelona January 2004

Free surface flow modelling. Course for ENDESA (Hydroelectric Company) February 2005

Integral Water Management Master Course. Fundació Politècnica de Catalunya 2004

11.4.3 Use of the Ramflood DSS for training activities

The Ramflood DSS has been used as a training tool in the following courses:

- *Master in Hydro-informatics and Water Management “EuroAquae”* supported by the Erasmus Mundus Program. (www.euroaquae.org)

EUROAQUAE
Euro Hydro-Informatics and Water Management

The first EuroAquae Master course started on September 2004.

The European consortium is formed by the following universities:

University of Nice – Sophia Antipolis (France)

Brandenburg Technical University Cottbus (Germany)

Budapest University of Technology and Economics (Hungary)

Polytechnic University of Catalonia (Spain)

University of Newcastle upon Tyne (United Kingdom)

The main objective of the EuroAquae Master is to prepare and train executive engineers in charge of modelling and managing projects in hydro-technologies and environment. These professionals have vocation to assist local, regional, national and international collectives, public services and to be involved in private companies. Specifically, the training of these engineers is oriented towards:

- o Knowledge in major physical processes related to the water field
- o Capacity in process and information modelling
- o Operational and technical know-how in Hydro-Informatics environments
- o Development and coordination of ICT environment
- o Contributions to risk analysis and strategy building as well as
- o Advice and support decision makers

- *Master Course on "Numerical methods for structural design in engineering".* Organization:

"Technical Foundation of Catalonia" of the Polytechnic University of Catalonia (UPC)

International Center for Numerical Methods in Engineering (CIMNE)

- *Ph D Course on application of TIC in civil engineering*, Polytechnic University of Catalonia (UPC)

- *"Course of Urban Hydrology"*, UPC, Barcelona – Spain.

11.4.4 Presentations of the Ramflood DSS to potential user groups

Internationals organizations:

- International Olympic Committee.
- UNESCO, United Nations Educational, Scientific and Cultural Organization.
- Engineers Without Borders

Governments responsible for prevention and management of flood of urban zones:

- Government of Catalonia, Spain.
- Government of the Barcelona city, Spain.
- Government of the Castelldefels city, Spain.
- Government of the Santa Fe city, Argentina.
- Government of the Rosario city, Argentina.

Presentation of the Ramflood DSS at other possible End Users:

- Barcelona Airport "El Prat", Spain.

- Ministry of agriculture, fishes and feeding “MAPA” (Ministerio de Agricultura, Pesca y Alimentación), Spain.
- National technologic institute of agriculture “INTA” (Instituto Nacional de Tecnología Agropecuaria), Argentina.
- Civil Protection Agency, Athens.

Other dissemination activity was the publication of the project Ramflood in the CIMNE News bulletin (November 2003). CIMNE News is distributed by email to 5000 individuals.

12. EXPLOITATION PLANS FOR THE RAMFLOOD DSS

12.1 Exploitation models.

At the beginning of the project an initial marketing plan was produced and used as preliminary business plan of the project. This initial market plan included several actions items such as direct contact with potential users such as the Olympic committee, direct visits and selected information provision of the Ramflood developments via Internet.

Four different exploitation models will be implemented: License/Product, Service, ASP and Strategic Alliances.

The Ramflood License/Product

The Ramflood DSS exploited as a product, aims at the installation of the system in the intranet of water management organizations according to the specific needs of each organization. In this context, the end-users will be employees of the organization.

The target market are public and private organizations interested in flood prevention and management. The Ramflood DSS as a product will also be of interest to universities and research organization related to the water management sector.

The Ramflood Service

The Ramflood DSS will be exploited for services in the water management sector, using the Ramflood software as a product.

The target market is the same as for Ramflood as a product/license. A fee would be charged for every Ramflood-based marketing consultancy project.

The Ramflood Application System Provider (ASP) Model

The Ramflood DSS exploited as an ASP aims to rent the use of the system. A high acceptance rate is forecast, as the communication channels via Internet increase bandwidth. The reason for its probable success is the clear advantage in costs to access this type of services

The Strategic Alliance

The target markets for a Ramflood DSS are seen in the following areas:

- Local, regional and state wide governmental and public agencies concerned in river and flood monitoring
- Private and commercial operators of river infrastructures or technical infrastructures prone to flooding
- Private insurance and re-insurance companies trying to assess the potential risks and damages caused by floods

Plans for alliances and commercial entry in these markets need to be developed and adopted from case-to-case.

12.2 Internal exploitation

AGÈNCIA CATALANA DE L'AIGUA (ACA): will exploit the Ramflood DSS internally for risk assessment and management of flood emergency scenarios in the Llobregat river delta region as well as in other critical flooding areas of Catalunya.

SPAP: will exploit the Ramflood DSS as an effective tool for assessing the risk and management of flash floods in the Attica region.

EUROMAP: will exploit the Ramflood DSS to promote new market potentials for the application of satellite Earth observation data in planning monitoring processes in the environmental engineering field.

CIMNE: will utilise the Ramflood DSS for research and consultancy services into the risk analysis and management of flood emergency scenarios. CIMNE will support UPC in the use of the Ramflood DSS as a training tool in the Master in Hydro-informatics and Water Management "EuroAquae".

UNIVERSITAT POLITECNICA DE CATALUNYA (UPC): will utilise the Ramflood DSS for enhanced education and training of undergraduate and graduate engineers in the risk assessment and management of flood emergency situations. UPC will also exploit the Ramflood DSS to provide consultancy services. The Ramflood DSS will be used as a training tool in the Master EuroAquae.

AGRICULTURAL UNIVERSITY OF ATHENS (AUA): will use the Ramflood DSS for education of agricultural engineers in the risk assessment and management of floods. AUA will also exploit the Ramflood DSS to provide consultancy services in Greece.

12.3 External exploitation

The following companies and organizations have expressed their interest in the exploitation of the Ramflood DSS:

- Compass (http://www.compassis.com/)
- Quantech (http://www.quantech.es/)
- Structuralia (http://www.structuralia.com/)
- International Olympic Committee (http://www.olympic.org/)
- UNESCO, United Nations Educational, Scientific and Cultural Organization. (www.unesco.org/)
- Engineers Without Borders (www.ewb-international.org/)
- Barcelona Airport “El Prat”, Spain (www.barcelona-airport.com/)
- Government of Catalonia, Spain (www.gencat.net)
- Government of the Barcelona city, Spain. (www.bcn.es)
- Government of the Castelldefels city, Spain. (www.castelldefels.org/)
- Government of the Santa Fe city, Argentina. (www.santafeciudad.gov.ar/)
- Government of the Rosario city, Argentina. (www.rosario.gov.ar/)
- Ministry of agriculture, fishes and feeding “MAPA” (Ministerio de Agricultura, Pesca y Alimentación), Spain. (www.mapya.es/)
- National technologic institute of agriculture “INTA” (Instituto Nacional de Tecnología Agropecuaria), Argentina. (www.inta.gov.ar/)
- Civil Protection Agency, Athens. (www.greece-athens.com/)

13. ACKNOWLEDGEMENT

The support for the development of the RAMFLOOD DSS of the European Commission (EC) through the Information Society Technology Programme (project nº IST-2001-37581) is gratefully acknowledged.

14. REFERENCES

14.1 Project deliverables

Deliverables	Authors	Reference	Date
Brochure with project presentation	CIMNE	D1.1 Rev 0	March 2003
Specification of the RAMFLOOD DSS and users requirement.	CIMNE	D1.2 Rev 0	April 2003
Report on EO and Environmental Data.	EUROMAP and UPC	D2.1 Rev 1	March 2004
Multiscale analysis system and adaptable rules	CIMNE	D3.1 Rev 1	March 2004
System architecture and implementation document	CIMNE	D3.2 Rev 1	March 2004
Validation of classification results	CIMNE	D3.3 Rev 0	September 2004
Database of risk criteria	UPC	D4.1 Rev 0	January 2005
Report on the 1D and 2D computer codes and numerical simulation of floods	UPC	D4.2 Rev 0	January 2005
Integrated prototype Ramflood DSS for risk assessment and management of floods	CIMNE	D5.1 Rev 0	January 2005
Results from the validation of the Ramflood DSS in the chosen sites in Spain and Greece	UPC	D6.1 Rev 0	January 2005
Enhanced RAMFLOOD DSS	CIMNE	D6.2 Rev 0	January 2005
Pre-standarisation guidelines for risk assessment and management of floods using the Ramflood DSS.	ACA	D7.1 Rev 0	January 2005
Dissemination and use plan	CIMNE	D8.1 Rev 1	March 2004
Exploitation / Technology Implementation Plan (TIP).	CIMNE	D8.2 Rev 0	January 2005
Definition and validation tests	CIMNE	D10.1 Rev 1	March 2004

14.2 Publications

“Sistemas de ayuda a la decisión en ingeniería civil. Posibilidades y perspectivas”.
E. Oñate, J. Marcipar y J. Piazzese, Publication CIMNE Nº 238, Barcelona, 2003.

“El valor del cálculo en los sistemas de ayuda a la toma de decición en ingeniería”
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