D3.4a CUSTOMIZED INFORMATICS TOOLS FOR THE HYDROPOWER RESERVOIR MANAGEMENT OPTIMIZATION

WORK PACKAGE 3 – METHODOLOGIES AND TOOLS FOR BETTER WATER & HYDROPOWER PLANNING AND MANAGEMENT

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10.5. Upload initial alphanumeric data
10.5.1. Configuration data
10.5.2. Time series
10.6. Methodology for determining the hydro network and the schematic network
11. Conclusions
12. References

Figure index

Figure 1 – Lumped model scheme used to interpret the basin response
Figure 2 – Data input of bucket model
Figure 3 – Example of run of reservoir model
Figure 4 – Example of the schematic network of Adige River
Figure 5 – Form to create "HALTFLOOD.INI"
Figure 6 – Form to create a new project
Figure 7 – Example of project without valid data of events
Figure 8 – Example of project with valid data of events
Figure 9 – The data uploading in the project GeoDatabase is activated by pressing the dedicated button
Figure 10 – Mask to select the rainfall-runoff forecasting model data
1. Preface

The present work is an outcome of the project “SEE HYDROPOWER, targeted to improve water resource management for a growing renewable energy production”, in the frame of the South-East-Europe Transnational Cooperation Programme, co-funded by the European Regional Development Fund (www.seehydropower.eu).

The project is based on the European Directive on the promotion of Electricity from Renewable Energy Sources respect to the Kyoto protocol targets, that aims to establish an overall binding target of 20% share of renewable energy sources in energy consumption to be achieved by each Member State, as well as binding national targets by 2020 in line with the overall EU target of 20%. Objectives of the SEE HYDROPOWER deal with the promotion of hydro energy production in SEE countries, by the optimization of water resource exploitation, in a compatible way with other water users following environmental friendly approaches. Therefore, it gives a strong contribution to the integration between the Water Frame and the RES-e Directives.

Main activities of the project concerns the definition of policies, methodologies and tools for a better water & hydropower planning and management; the establishment of common criteria for preserving water bodies; to assess strategies to improve hydropower implementation, such as small hydropower; testing studies in pilot catchments of partner countries; promotion and dissemination of project outcomes among target groups all over the SEE Region countries.

In particular, here is presented the report “D3.4a Customized informatics tools for the hydropower reservoir management optimization, concerning downstream river flood prevention”, which is part of the Work Package 3 - Methodologies and tools for better water & hydropower planning and management.

2. Introduction

Actually in most cases, as in the past, it is common practice to base reservoir operating rules on current information about reservoir storage without direct use of inflow forecasts.

The justification has been that inflow forecasts are uncertain. However, there is a growing interest in taking account of forecast information, including forecast uncertainties, to improve levels of flood protection through more effective use of available reservoir capacity.

Hydropower reservoirs, in fact, under certain circumstances may be used to attenuate and delay floods in order to contribute to protect the downstream territory. The overall goal is to obtain as much flood control as can reasonably be achieved with the existing infrastructure.

To permit flood volume to be stored in the reservoir, water elevation has to be lowered in advance to partially empty the reservoir. In order to attenuate and delay efficiently floods while limiting the decrease of hydropower production and impounded water volume (useful for other uses e.g. irrigation, drinking, etc.) it would be necessary to change, during the flood event, water elevation by opening/closing dam outlets in accordance with flood forecast in order to obtain reservoir emptying. This “dynamic” way of dealing with the flood (whereas a “static” way would lower water elevation notwithstanding flood forecast) would imply the prediction of flood events in terms of peak and time evolution, telemetric data
acquisition and processing and to be aware of reservoir operation components.

In order to provide a support system for emergency plans for flood control and dams management, a software system, called HaltFlood, was developed in RSE research activity.

This report describes the software and the procedure that allows creating a dams management project.

3. HaltFlood: tool to support operation of hydropower reservoir for flood attenuation

The software tool HaltFlood is capable of estimating flood hydrograph entering the reservoir and propagating downstream dams, it implements mathematical modules relevant to most important processes and involved data e.g. meteorological data, runoff estimate at watershed scale, reservoir operation, the propagation of forecast floods over river downstream dams.

Forecast accuracy for the first hours, that is approximately the lag time of many small mountain watersheds where dams are, depends on the accuracy of rainfall-runoff model and on the availability of real time rainfall measures.

Using a well calibrated rainfall-runoff model and real time rainfall measures it is possible to make a very reliable runoff forecast for the next few hours, which is useful for dam safety.

However, to obtain a 3-days-forecast it’s needful to make use of weather forecast and in this case the accuracy of the meteorological model’s output becomes crucial.

Limited area models (LAMs) were developed in order to downscale the global circulation model (GCM) outputs, using a better representation of the mesoscale processes (Mesinger et al. 1988). Nesting a LAM into the GCM deterministic boundary conditions, however, did not—and still does not—improve the forecasts as required by hydrologists. In order to make rainfall fields coherent with hydrologic scales, hydrologists try to disaggregate the large-scale meteorological predictions to bridge the scale gap between numerical weather prediction model output and hydrologic modelling input.

There are alternative downscaling methodologies in research literature review: some based on probabilistic tools, other on the physics characteristics of the phenomena such as orographic effects. Nevertheless, the transferability of these methodologies to all cases is difficult because it depends on the statistical characteristics of seasonal storms and on the role of regional orography by determining the spatial distribution of precipitation.

The software tool HaltFlood, therefore, uses weather forecasting without particular downscaling methodology, but for every forecast three runs are carried out: one making use of the output of LAM model and two arranged by the users selecting respectively values lower and higher as the LAM model output. The purpose of making more than a single run is to provide a range of possible solutions taking the forecast uncertainties into account.

The main modules included in the HaltFlood software are:

- physically based hydrological rainfall-runoff model, lumped over many sub-basins;
• reservoir flood operation model;
• flood routing model based on Muskingum method.

3.1. The rainfall-runoff model

In the HaltFlood current version, the hydrological rainfall-runoff model is based on equations governing various physical processes, calibrated at storm event scale and applied to each single sub-basin. The contributions of each sub-basin are summed up, comparing the study area to a network composed by nodes and connection.

The rainfall-runoff model was performed using a “bucket” approach (Fiorentino and Manfreda, 2004), transforming excess precipitation into surface runoff. Outflow from a sub-basin is computed from rainfall data by subtracting losses, transforming excess precipitation and adding base flow.

An automatic pattern search optimisation method is implemented to calibrate the model based on the Genetic Algorithm (GA) method: it doesn’t have the typical optimization problem of n-parameters rainfall-runoff model, as it follows the Global Search approach (Franchini, 1996).

The basic structure of the rainfall - runoff model and the equations representing the various hydrologic processes are shown in the Figure 1.

Figure 1 – Lumped model scheme used to interpret the basin response.

To transform the excess precipitation into surface runoff, the storm event model needs as input data the watershed initial condition, represented by the following 4 parameters:

• baseflow at the beginning of the event (Qb)
• initial soil moisture store capacity (S_{ini})
• initial control volume of the generated runoff (W_{s_{ini}})
• initial control volume of the generated subsurface runoff (W_{sub_{ini}})
These parameters are evaluated by the model using the rainfall data of the previous 10-20 days and the observed discharges in significant stations within the basin.

The rainfall data can be obtained from a rain gauge network, or better from meteorological radar where it is available, while the discharge values can be furnished by stream flow gauge stations, or in case of dikes, from the water balance of the reservoir.

HaltFlood model makes use of the precipitation forecast for the following 3 days performed by a weather model applied to a limited area (for example COSMO ex Lokall Modell).

Precipitation data are transmitted to the model by means of internet, using the web-services technology.

3.2. The reservoir model

A differential mass balance model has been performed to simulate the transitional reservoir conditions. The module takes into account:

- initial reservoir water level, supplied by data acquisition system;
- water storage variations in the reservoir in function of the water level;
- discharge value from the reservoir outlet works in function of the gates opening degree, evaluated from geometric data and outflow coefficients;
- succession of the ordinary manoeuvres at the outlet works, as planned by the dam manager;
- outlet works management in case of alarm conditions;
rules for the water level lowering in order to attenuate and delay efficiently the floods.

In specific, the rules of management under emergency conditions are usually expressed by means of a table, indicating the necessary manoeuvres at spillways and outlet works to provide capability to release an adequate rate of water from the reservoir to satisfy dam safety and water control regulation, in function of the water level in the reservoir and its variation during the last observed interval (for example 15 or 30 minutes). Outlet works serve to regulate and release stored-water at such rates as may be dictated by technical legislation and norms to guarantee the dam safety (not exceeding the maximum reservoir level) and the flood routing to protect the areas downstream the dam.

The prescriptions for the reservoir emptying in advance are a succession of planned operations conducted at the outlet works, assigned in relation to the hydraulic condition in the downstream territory which has to be protected.

Figure 3 – Example of run of reservoir model.

3.3. The routing model downstream the reservoirs
The estimation of the flood routing discharged downstream the dam, in combination with the natural runoff, is essential to analyse the effects in the downstream areas.
For this reason an internal flow routing module is added to HaltFlood model. The natural river system is schematised and represented with a node-branch structure:

- the input nodes represent each sub-catchment with characteristic flood hydrographs;
- the branches correspond to the water network in which the flood waves are propagated.

There are some nodes of confluence of two or more branches acting as summation devices for the incoming hydrographs and nodes where a reservoir can be placed.

The Muskingum method is applied for the flood wave propagation along the main branches of the net. This method is commonly used in hydraulic studies to evaluate the propagation based on the relationship between discharge and volume storage.

Natural flood hydrographs are calculated by the model for each sub-basin and assigned to their respective nodes, therefore propagated along the network from upstream to downstream: in the case of a node representing a reservoir, the right model (explained in the previous paragraph) is applied to calculate the water storage volume and the outlet discharge.

In the following figure, as example, the schematic network adopted to simulate the Adige river is shown.

Figure 4 – Example of the schematic network of Adige river.
3.4. Required data to implement models

Conceptual models are considered to be the best choice for describing the rainfall-runoff process in a watershed. However, enormous requirements for topographic, hydrologic and meteorological data are often prohibitive factors in their practical applications. For this reason, a particular attention is given to the choice of the system components and to their availability to implement the model.

A useful digital terrain model database, required to implement the hydrologic model and to define the drainage network, is the publication from the Consortium for Spatial Information (CGIAR-CSI) of the digital world model with a spatial resolution of 90 meters produced by Nasa Shuttle Radar Topographic Mission (SRTM), available on the website http://srtm.csi.cgiar.org/Index.asp.

Finally, using special GIS functions, sub-catchments for each branch of the river network are automatically delineated from digital terrain model; furthermore it’s possible to evaluate other morphological parameters such as catchment area, river channel length, elevation of the upstream section and the basin average elevation that are necessary to apply empiric equations to estimate the concentration time.

The river network in vector-format could be a useful integration to the digital terrain model (DTM) to increase the accuracy of the elaborations. In addition, if the river network shapefile is available (for example in Italy it is downloadable from the website http://www.sinanet.apat.it and is accessible for the whole country), it is useful for the GIS processing tool in the catchment delineation.

Regarding reservoir and dam data, it’s necessary to achieve them from the National Register of Dams (for example in Italy www.registroitalianodighe.it).

In the end, as the software is based on an automatic update of weather forecasts with data exchange between Web service clients, it’s essential to identify, in the case area of study, location and accessibility of hydro-meteorological data: in particular, it is important to verify the availability of real time rainfall measures from meteorological radar or gauges network. Real time streamflow measures provide an essential input for the model such as the instantaneous reservoir water level furnished by dam’s owners.

4. Software and hardware requirements and installation guide

The HALTFLOOD tool is written in VisualBasic 6.0 language, the following programs/OS are needed to be installed:

- Microsoft Windows XP or 2000 (HaltFlood is not tested with “Vista”);
- Microsoft Excel.exe and MSAccess.exe (Microsoft Office Package);
- ESRI ArcGis 9.2 with the Spatial Analyst extension (*)
- International decimal separation must be set to the “dot” “.”
- PC pentium 4 with almost 1 GB ram
- Free Memory Disk almost 2 GB
It is recommended to have ESRI ArcGis 9.2 with the 3D Analyst and Spatial Analyst extensions.

The GIS is useful in managing data for new project and in editing GeoDataBase in which are stored the data for HaltFlood.

In order to run the installer program you must have Administrator privileges on your computer.

You only need the privileges during installation; once installation is complete the program can run successfully without Administrator privileges.

After you have obtained the Setup Package and Administrator privileges, use the following steps to install the program:

1. Run the Setup.exe;
2. Run the HaltFlood.exe program;
3. Create the HaltFlood.ini file (only during the first HaltFlood use), choosing “yes” (Si):

4. Choosing “Yes” it appears the following form;
5. Verify the screen and international properties and setup the “EXCEL” and “ARCGIS” directory paths in your disk;
6. Then click “Ok”;

It is also possible to update the data from the Project menu, choosing the option HaltFlood.ini

5. The menu system
The menu system contains four menus to help you use the program. Each menu contains a list of related commands.

The four menus are: Project, Events, Update Data, Real time forecasts.

- the Project menu contains a list of commands for opening and managing projects, to update or edit the GeoDataBase, which is the container for all the different objects that form the complete representation of the study area such: watersheds, dams, stream etc.;
- the Events menu contains a list of commands to run HaltFlood to study historical events;
- the Update Data menu allows, if available, to download real time rainfall forecast from the internet;
- the Real time forecasts menu contains a list of commands to run HaltFlood for real time flood forecasting.
6. The project menu

As shown in the previous figure the project menu contains different menu commands.

6.1. Data Schemes

This command allows inputting the schema code, given by the Forecast Office, for the download of the rainfall forecasts from the internet.

In Haltflood the schema code is just a unique name that uniquely identifies a geographical area divided into several sub-areas. If this name has been agreed with an Office that provides weather forecasts, then the office can provide the average precipitation expected in the same sub-areas used by Haltflood.

In you don’t have the code you must insert a name that you prefer, but you cannot download the forecasts from internet and you must enter the forecasts data manually.

Manually data forecast can be written in a file xls ad then upload in HaltFlood.

To create a new project using the next command menu, you need perform an existing scheme code to link to the project. If the scheme list is empty it is impossible to create a new project.

6.2. New

This command menu allows creating a new project. To create a new project you choose “New”. After this command is selected, the Create a New Project window will open were you can put in the name of new project.
Pressing the OK button it will open the Select scheme windows to select the scheme to link the project.

![Select scheme code from the following](image)

After the OK button is pressed the program makes a new project directory with the same name of the project in the default location on your computer to store the project. The default projects location is a folder named \Progetti in the installation location of the HaltFlood.exe program.

In the project directory an empty Personal GeoDataBase (ProjectName_GDB.mdb) will automatically be created, where you will store the date concerning the project.

This following message reminds you that you must enter additional data into the Geodatabase.

![Must enter data in the Tables Dam, Watershed and MonitoringPoint](image)

To enter data in the Tables it’s useful to use ArcGis. The different steps to do with ArcGIS are described in Appendix A.

If you don’t have ESRI ArcGis you can still load the data manually, but only alphanumeric data. The tool HaltFlood uses only alphanumeric data, so you can run simulations, but you can not control the congruence between geographical and alphanumeric data.

### 6.3. Open

This command menu allows opening a project. To open an existing project you must select the Open menu option.

![Select a project from the followings](image)
When a project is opened in the menu system the menus, for which valid data exist, are enabled.

![Figure 7 – Example of project without valid data of events](image)

![Figure 8 – Example of project with valid data of events](image)

After you have inserted valid data into the tables Dam, MonitoringPoint and Watershed of the project GeoDataBase the list of commands of Project menu will be enabled.

<table>
<thead>
<tr>
<th>Project</th>
<th>Events</th>
<th>Update Data</th>
<th>Real time forecasts</th>
<th>?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Schemes</td>
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<tr>
<td>New</td>
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<td>Open</td>
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<tr>
<td>Delete</td>
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<tr>
<td>Watershed's data</td>
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<td></td>
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<tr>
<td>Muskingum's parameters</td>
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</tr>
<tr>
<td>Load XY Curves for the Dams</td>
<td>MAJUSCH2</td>
<td></td>
<td></td>
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<tr>
<td>Create an Event</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Transfer Tab to Event</td>
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<tr>
<td>Load Historical series</td>
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<td>Historical series Graphic/Transfer</td>
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<td>Create a Forecasts' Database</td>
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<td>Visualize basin model map</td>
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<tr>
<td>Exit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 6.4. Delete

The command *Delete* allows the user to remove a project: this procedure requires attention as the elimination is irrevocable. Selecting the Delete option from the *Project* menu, a new window will be opened to choose the project to delete:
If the user answers OK, a confirmation of the choice will be required, as the deleted data can not be recovered:

If the user answers OK, a confirmation of the choice will be required, as the deleted data can not be recovered:

Answering “Yes” (Sì), the project selected is deleted not only from the general database, but also physically from the disk.

6.5. Watershed data
This option lets the user to assign the required parameters for each watershed previously defined, to implement the rainfall-runoff model.

A new window is opened presenting the parameter values already stored in the Geo Database and it allows, if necessary, to change them and save the new values.
6.6. Edit Muskingum’s parameters

This form shows the HydroCode, reading the data from the SchematicLink Tab of the project GeoDataBase, when the TypeRouting parameter is set to the value 3 (it means that the wave propagation is estimated by the Muskingum routing method). In the SchematicLink Tab the following parameters of the Muskingum-Cunge model are reported:
- K, factor that approximately corresponds to the propagation time of flood waves along the channel;
- X, weighting factor ranging between 0 and 0.5.

There is the possibility to change these values and store them in the geo-database.

6.7. Loading curve XY dams

This function allows the user to upload some data regarding the dams in the GeoDataBase. The following form will appear:

![Loading curves XY dams form]

The form allows the user to upload two different Excel files:

- reservoir capacity curves + any automatic opening rules of the outlet works depending on the water level in the reservoir;
- possible withdrawal standard curves from the reservoirs;

An example of the data structure of the two different excel sheets is shown below. The first line contains the headers and the data begin from the second row.
Where the meaning of each field is the following:

- **FeatureID**: HydroID code used in the Geodatabase for the dam or the outlet work. In the Geodatabase each feature has a unique identification code called HydroID, to load data for a certain feature you should indicate their HydroID. The HydroID is assigned at the time of creation of feature.

- **HydroCode**: alphanumeric code of the dam or of the outlet work;

- **TbTypeID**: data type code (1 = volume curve; 8 = rule of the opening percentage as function of the water level);

- **TbValX**: X abscissa value (height for data type = 1; water level for data type = 8);

- **TbValY**: Y ordinate value (volume in cubic meters for type = 1; percentage of the opening for type = 8);

- **Tipo Curva**: optional description.

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ReservoirsCurves / CurveInvasi

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<td>6</td>
<td>0</td>
<td>0</td>
<td>h=0mcs</td>
</tr>
</tbody>
</table>

Where the meaning of each field is the following:

- **FeatureID**: HydroID code used in the Geodatabase for the current withdrawal;
- **HydroCode**: alphanumeric code of the withdrawal;
- **TbTypeID**: data type code, which could assume the following values:
  - TbTypeID =210: WaterDemand cyclical daily (one day, hour by hour)
  - TbTypeID =220: WaterDemand cyclical weekly (one week, hour by hour)
  - TbTypeID =230: WaterDemand cyclical monthly (one month, day by day)
  - TbTypeID =240: WaterDemand cyclical yearly (one year, month by month)
  - TbTypeID =250: WaterDemand constant each year
- **TbValX**: X abscissa value (could be: time, day or year);
- **TbValY**: Y ordinate value (discharge in cubic meters per second);
- **Tipo Curva**: optional description.
6.8. Create Event
This function allows the user to create an “Event” associated to the Project. The following window is shown:

The list of the events already created appears at the top of the form, while in the bottom part it’s possible to create a new event, by means of an appropriate frame, assigning the desired identifier (ID is unique and therefore it’s not possible, for a given project, to create two events with the same ID). It is also possible to add a brief event description in the appropriate form. At the end, the user should click on “Create Event”.

Actually, with this function only the name of the new event is stored in an appropriate table of the project GeoDataBase. The creation of the event itself occurs with the following function (Transfer tables to Event), as explained below.

6.9. Transfer tables to Event’GDB
This feature allows the user to transfer prefixed tables from the Project GeoDatabases to the GeoDataBase of an event associated to the Project; these tables are necessary for the further processing of the discharge and rainfall data associated to the event. The following window appears:
The selection of the chosen event is made by means of the Combo Box. Clicking on the “Transfer” button, in the Project directory, a new folder will be created with the name of the Project and Event, in which the tool copy from the folder “Generali” a template Geodatabase and rename it with the name of the event.

In this GeoDatabase, the folders previously selected will be copy.

6.10. Load monitoring data
This option allows the user to upload in the project GeoDatabase the time series of precipitation, discharge, levels, etc.. The following form appears:
The first step is the selection of the data file, you can find the file by clicking the "Select data file" button.

The data file must be in excel format and have a fixed format, as shown in the figure below. The first five rows are fulfilled with the identification data of each sub-basin and / or monitoring stations and the type of data to be loaded: the codes must match with those reported in the GeoDataBase.

In the subsequent rows (from line 6) following data are reported: in the first column, the date and hour, and in the following columns the hourly data corresponding to the sizes of its respective header lines. After choosing the datasheet (the combo will be automatically filled), if the data is in the requested format, the program determines the different types of data and active options (in our case: Precipitation, Water Levels, Outlet Discharge).

It is possible to see the file including the data by clicking on “See data file”.
6.11. Plot/transfer historical time series

This tool allows you to draw graphs of time series stored in the project Geodatabase. From the graph you can select all or part of the data to copy them to another database (the event Geodatabase) in order to use them for the analysis.

The tool opens a form like that in the figure, in which there are two listview and a picturebox.

The listview on the top, lists the types of data stored in the database.

In this listview, you can select the type of data (maximum two) to display in the listview below.

The listview below lists the stations that have data types as those selected in the top listview. You choose up to a maximum of six stations: the graph of their data appears in the space below. When you draw together the graph of rainfall and flow, the precipitation is
represented by the y-axis pointing downwards.

Pressing the “Transfer to the Events’ GDB” button, it’s possible to transfer data to GeoDatabases event, led by the following mask, which allows, if desired, to restrict the time range of data to transfer.
6.12. Create a Forecasts’DataBase

It allows to create a database event dedicated to real-time forecasts.

Under the project folder is created a folder called NomeProgetto_Evento_Previsioni, within which the tool copy from the folder "Generali" a template Geodatabase to store real time data. In this GeoDatabase all the needed data are copied from the GeoDatabase project.

6.13. Visualize basin model map

It allows viewing the site map. There are different opportunities for displaying, as shown by the menu items.

<table>
<thead>
<tr>
<th>Visualize basin model map</th>
<th>with ArcGIS</th>
<th>with ArcExplorer</th>
<th>with Quantum GIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haltflood.Ini</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

So it’s possible to open an ArcGIS project on the current project or display it by ArcExplorer or Quantum GIS. Please note that only with ArcGIS it’s possible to display data contained in GeoDatabase and actually used by the program HaltFlood. ArcExplorer and Quantum GIS can display a copy of the data of GeoDatabase previously exported as shapefiles through ArcGIS.

Should be aware that, HaltFlood uses the data in the Geodatabase. If you change the geographic data in the Geodatabase, shape files are no longer update on: this may necessitate the re-export to shape files the features of the Geodatabase to see the update with ArcExplorer and Quantum GIS.

Below there is an example of displaying the map with ArcGIS.
In the absence of the program ArcGIS (in which case the corresponding menu item is disabled) it's possible to view the map through ArcExplorer.

ArcExplorer, to store map informations, uses a project file called *myname.axl*.

To open directly from HaltFlood the name’s map *myname.axl* of ArcExplorer must be: "*Name of Project + "_mappa.axl"* (in our case: *Adige_mappa.axl*) and must be located in the same folder where is the current project GeoDatabase.
Similarly, if there is a Quantum GIS installation, create the relative project file on standard name: "**Name of Project + "_mappa.qgs"**.

It must be remembered that, Quantum GIS unlike ArcExplorer, allows also to modify the data of ShapeFiles, but this has no effect on the data of GeoDatabase used by HaltFlood. The geographic data of GeoDatabase has to be changed only by ArcGIS, while the
alphanumeric by Access.

7. The events menu
The processing is performed on the data contained in GeoDatabase event. The function “Events” of the main menu has several items:

It is only after the selection of the event (option “Select an Event”) that the following options are enabled.

7.1. Select an Event
The event is chosen by selecting the corresponding record in the presented window and confirming the choice.

The name of the event is printed on the top of the screen:
7.2. Clean Event’s GDB
This option “cleans” the GeoDataBase event, eliminating any double data.

7.3. WaterShed Data
For each of WaterShed event, this mask allows to see or possibly change (saving changes) data of WaterShed to use in the rainfall-runoff model applied to one event (in this way you can keep save the original copy stored in the project Geodatabase):

![Image of WaterShed Data interface]

7.4. Dam options
It allows to change, for each dam included in the project, the display mode of the calculation form of the model tank, and to select the calculation step:
Note that the rainfall-runoff model is set to run the calculation with time step of one hour and this step provides the inlet discharges to the reservoir. If the rate of change in the level of the reservoir is small during one hour, it is recommended to choose for the reservoir model the hourly time step.

However, if the reservoir volume is small compared to its discharge capacity (e.g., in case of Barrage) it is necessary to use a smaller time step calculation. In this way the model can apply, with adequate time step, the rules of operation of discharges included in the geodatabase and update the degree of opening of floodgates to adapt them to rapid changes in the level.

### 7.5. Withdrawal options

This function allows selecting options concerning the withdrawal from the intake works of the dam. Selected it activates the mask below.

The mask shows the list of the intake works presented in the GeoDataBase and gives the possibility to select a curve sampling for each of them. With the yellow button at the bottom right it is possible to activate the graph of standard curves loaded into GeoDataBase.
7.6. Muskingum’s parameters

For the meaning of the tool see section 6.6. In this case, however, the change of parameters is only valid for the event. In this way you can keep save the original copy stored in the project Geodatabase.

7.7. Load monitoring and forecast

This function allows to load in the event GeoDatabase, observed or forecast data, in addition to any historical data already transferred from GeoDataBase project, as seen.
As shown, there are different types of transfer. For each of them an appropriate mask is presented, which allows to choose the desired file, to open it to check it and then upload the data. For the Excel files containing time series, the format must be identical to that already seen for the series.
The function “Load monitoring data from a XLS file” is designed for loading, instead of xml file, data of rainfall forecasts. It can load data for:

- Watershed
- Monitoring Point
- Water Withdrawal

the following data types:

- TSTypeID=70 : hourly observed rainfall
- TSTypeID=80 : hourly observed temperatures
- TSTypeID=90 : hourly observed freezing level
- TSTypeID=100 : hourly observed runoff
- TSTypeID=110 : hourly observed height snow
- TSTypeID=120 : hourly observed discharges
- TSTypeID=130 : hourly observed levels
- TSTypeID=200 : observed water demand

The function “Load rain forecast from a XLS file” is designed for loading, instead of xml file, data of rainfall forecasts. It can load data for:

- Watershed
- Monitoring Point

The following data types are expected:

- TSTypeID=71, 72, 73 : hourly rainfall forecast
- TSTypeID=81, 82, 83 : hourly temperatures forecast
- TSTypeID=91, 92, 93 : hourly freezing level forecast
- TSTypeID=101, 102, 103 : hourly calculated runoff
- TSTypeID=111, 112, 113 : hourly height snow forecast
- TSTypeID=121, 122, 123: hourly calculated discharges
- TSTypeID=131, 132, 133: hourly calculated levels

The function “Load Dams time series from a XLS file” is designed for observed data of dams.

It can load data for:
- Water Withdrawls Dams
- Monitoring Point
- Outlet Works Dams

the following data types:
- TSTypeID=70: hourly observed rainfall
- TSTypeID=80: hourly observed temperatures
- TSTypeID=90: hourly observed freezing level
- TSTypeID=100: hourly observed runoff
- TSTypeID=110: hourly observed height snow
- TSTypeID=120: hourly observed discharges
- TSTypeID=130: hourly observed levels
- TSTypeID=200: observed water demand
- TSTypeID=300: hourly level demand
- TSTypeID=400: hourly opening percentage discharges demand

The function “Load reservoir flood routing plan from a XLS file” is designed for loading the data of reservoir flood routing plan prescribed by control authority for the:

- Dam

the following types of routing plans:

<table>
<thead>
<tr>
<th>PrTypeID</th>
<th>PrCode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EMPTYING</td>
<td>Emptying the reservoir up to a given level in a given time and with a flow rate limit</td>
</tr>
<tr>
<td>2</td>
<td>CLOSING</td>
<td>Closing outlets</td>
</tr>
<tr>
<td>3</td>
<td>FILLTOLEVEL</td>
<td>Fill the reservoir up to a given level</td>
</tr>
<tr>
<td>4</td>
<td>RELEASEFROMLEVEL</td>
<td>Release a given discharge when it reaches a given level</td>
</tr>
<tr>
<td>5</td>
<td>RELEASETOLEVEL</td>
<td>Release a given discharge</td>
</tr>
</tbody>
</table>
The function “Load rain measures and forecasts by WEB (from a XML file)” allows loading, in GeoDataBase, the observations of rainfall and forecasts of various sub-basins acquired from Internet in the form of XML files.

7.8. Execute rainfall-runoff forecasting model
The tool allows you to run the rainfall-runoff model.

If the study area was divided into several sub-watersheds the model runs for each sub-watershed.

At the end the tool store the results in the GeoDatabase of the current event.

Is first presented with the following mask:

![Figure 10 – Mask to select the rainfall-runoff forecasting model data.](image)

Then it's important to operate as followed:

- Choose the starting date of one of the forecasts loaded.
- Specify data from previous hours of rainfall and discharge that are used to assess the initial condition of soil moisture (Figure 10 shows the default values).
- Press the button “Check previous data”. The following Table will appear:
It shows if there are the necessary data for calculating the model.

If at some point the present monitoring has less data than needed (in the Table are marked in red those Monitoring Point for which data must exist), it’s possible to enter them manually:

- select desired record;
- press button “Entering values manually”;
- enter desired value in dedicated mask;
- confirm the operation.

- Press the button “Determines the initial conditions”. The following Table appears:
This operation also enables the lower current mask, with the frame "Model", initially disabled:

- Choose the option "Show results", then press "Run Model"

It is presented the following mask, which gives the performance graph of the forecasts of rainfall and discharge in different sub-basins (Watershed). The black vertical line indicates, in this as in other similar graphics, the "actual" start of the forecasts.

- If calculated data are incorrect, it’s possible to store them in GeoDataBase. Select the option “Store results to the GDB”, and then press “Run Model”.
7.9. Compute flow routing

First it’s asked to choose the date of the forecasts for which the network calculation is made:

Pressing the button “Execute”, the program reads data of the network scheme from the database and the inflow hydrograph to the network itself, and then calculates their propagation and sums the inflows at different nodes. In case a node of this network is a reservoir, it enables the calculation module for calculating the transition in it and the resulting flow downstream.

If in the options of the dams, the user has chosen to display the calculation, when the calculation of a reservoir is enabled, the following mask will be opened for each dam:

Pressing the button “Perform Calculation”, the program reads data from the database of the dam and performs the calculation of transition in the reservoir and the resulting flow downstream. All the results are stored in the database.
7.10. Forecast graph at Monitoring points

It allows obtaining the graph of the inflows and outflows to the measuring stations of type "hydrometer" and "reservoir".
For the current measurement station, the frame “Thresholds”, at the bottom right of the mask, appears, if there are certain threshold values of flows, which can be indicated on the graph. You can add or remove a line on the graph that shows the threshold by selecting or un-selecting the relative name on the list. These threshold values are stored in the table CurveXY GeoDatabases Project.

If the frame “Contributions to the flow” is enabled, as in the case stated above, it’s also possible to see the contribution of flow on the graph (with dotted line) at the current station, due to individual discharges of dams upstream. It’s necessary to activate the function by selecting the appropriate check, and then selecting the wanted contribution from dedicated Combo Box.

7.11. Graphs of forecasts at reservoirs

This option opens a mask with two graphs, both related to measured and forecasted data about reservoirs. The top graph shows the rainfall and flow (both in and out), while in the bottom graph the levels of reservoirs appear, in conjunction with the maximum level of regulation and the maximum level of reservoir.
7.12. Forecasts and historical data comparison

The choice of this option opens the following mask, where, for each Monitoring Point, it’s possible to have a comparison between historical data (black line) and those forecasted by the models (coloured lines) for each date of the forecast start.

In this graph you can also show threshold values and contribution flows due to upstream reservoirs. (see “Graph of forecasts at stations”).

If the Monitoring Point is of the type "Reservoir", the frame “Graphs of reservoir” is enabled, in which case it’s possible to graph both the inflows and the outflows, or only the inflows, and finally the levels:
8. The update Data menu

This function is developed to allow users to download from the Internet data of monitoring networks external to their own organization.

Assuming, in current version, that the program is installed by a reservoir owner which uses their own measurements of inflow and reservoir level and upload them into the Geodatabase through the Project menu (for historical events) and Events (in case of an event in real time) organized as Excel files, the function “Update Data” is designed to update the other data types, so:

- Data of hydrometric network of stations located upstream and especially downstream of the dam;
- Data of rainfall measures and average forecast on the sub-basins of geographic area where the dam is located.

The “Update Data” function is therefore divided into two menus:

- Check for updates of hydrometric monitoring
- Control measure and forecast updates by web

The first of the two menus is not yet active, and it’s possible to activate it only after an agreement with the operators of the monitoring network of the area where the dam is located.

The second menu is activated in the event of sample basins, for which, on an experimental basis, the Laboratory of Meteorology RSE, provides measurements of rainfall by radar and forecasts of precipitation from meteorological model.

The menu allows to activate the program HaltFlood-WS client, that connects to the web service of the RSE server and to download the update of the measures and forecasts available of the calculation scheme, which is associated with the current project.
The files are in XML format and are downloaded in a special subfolder.

This subfolder has the name of the code scheme (eg *adige*) and it is in a subfolder named *wsdati*.

For example, if the program HaltFlood.exe is installed on:

d:\HaltFlood

The data of “adige” scheme are downloaded in:

d:\Haltflood\wsdati\adige

If the folder doesn’t exist, it’s necessary to create it before running the HaltFlood –WS Client. To calculate the forecasts, the first task is downloading forecast data to your computer the second task is loading them into the GeoDataBase using the menu:

*Events \ Load monitoring and forecast \ Load rain measures and forecasts by WEB (from a XML file)*
In the figure below, it's possible to choose if past measures should be updated: this option is recommended in real-time analysis to always have the latest update, however, if an analysis of historical events, whose measurement data are already in the GeoDataBase, it's possible to omit loading them to speed up the processing.

When you make a new loading data, it's recommended to overwrite any old data in the GeoDataBase.
In the picture above, for example, a forecast in “adige” scheme is loaded, on November 23, 2002. The name of the xml file, estimates forecast date.

9. The real time forecast menu

This function is planned to use HaltFlood in real time. It is a function similar to that of the events menu, with the only difference that it uses the forecast event contained in GeoDataBase Event Name Progetto_Evento_Previsioni.

Compared to the function event, in this case when is chosen "Load rain measures and forecasts by WEB" the latest forecasts available is automatically loaded.

In this case, there isn’t commands menu for comparing the forecasts with historical data: this option is only available after the event has happened. If you want to study historical events, you should load the observed data into an event Geodatabase and use the Events menu.
10. APPENDIX A: Getting started on a new project

This appendix describes how to create, with ESRI ArcGIS, the geographic data for a new HaltFlood project and store them in a Personal GeoDataBase.

10.1. Creating an empty project GeoDataBase

To store a project on your computer, you need an empty Personal GeoDataBase in the project directory: this is done automatically with the command menu New, after you have inserted the name of new project.

The command makes a copy of the template Geodatabase, after that it renames the copy as the name of the project GeoDataBase. The project GeoDataBase data model is derived from the standard ArcGIS Hydro Data Model (http://www.crwr.utexas.edu/giswr/hydro/index.html) to which fields and tables have been added to take into account the special needs of the application HaltFlood.

10.2. Modify/Update coordinate system and Domain

In the empty GeoDataBase are three Feature Data Sets:

1. Drainage
2. Hydrography
3. Network

For these Feature Data Sets the following coordinate system (useful for Italy) are set as default:

Projected Coordinate System:
 Name: WGS_1984_UTM_Zone_32N
 Alias:
 Abbreviation:
 Remarks:
Projection: Transverse_Mercator
Parameters:
   False_Easting: 500000.000000
   False_Northing: 0.000000
   Central_Meridian: 9.000000
   Scale_Factor: 0.999600
   Latitude_Of_Origin: 0.000000
   Linear Unit: Meter (1.000000)

Geographic Coordinate System:
 Name: GCS_WGS_1984
 Alias:
 Abbreviation:
 Remarks:
 Angular Unit: Degree (0.017453292519943299)
 Prime Meridian: Greenwich (0.000000000000000000)
 Datum: D_WGS_1984
 Spheroid: WGS_1984
   Semimajor Axis: 6378137.0000000000000000
   Semiminor Axis: 6356752.3142451793000000
   Inverse Flattening: 298.2572235630000300

X/Y Domain:
If you need a different “XY Coordinate system”, you must change it for each Feature Dataset. In this case you also need to change the “Domain”. This can be done with ArcCatalog.

If you have a shape file or an existing GeoDataBase of your study area you can simply import the coordinate and the X/Y, Z domains from it.

10.3. Append new record, if necessary, in some dictionary tables

In the following tables of the GeoDataBase, there are some initial data needed for subsequent loading operations:

- TSType: table that lists the types of time series
- TSQuality: table that lists the types of data quality acquired
- CurveType: table that lists the types of curve XY

These tables, in the Progetto_GDB.mdb empty file, already contain records that relate to the most common types of data: if you want to load more data types into the GeoDataBase you must first enter the description of these new types and assign them to a univocal number of TSTypeID and/or TSQualityID and/or TbTypeID.

10.4. Upload initial geographical data
The starting geographic data consist of the following feature classes:

- In the Feature DataSet Hydrography: features that represent the river system
  1. HydroEdge: these features are typically represented in hydrography as a blue line and in general they represent such features as streams, rivers, canals and pipelines that can be represented by a single line on a map.
  2. HydroJunction: are the locations at which Hydro Edges intersect each other.
  3. SchematicNode: the SchematicNode Point feature class contains the points in a Schematic Network, which may represent any feature within an Arc Hydro geodatabase. Typical types of SchematicNodes are: drainage area centroids, drainage area outlets and stream confluences.
  4. SchematicLink: is Polyline feature class that provides a connection between the upstream and downstream node. Typically they represent a stream or a channel.

About the table SchematicNode, is listed below the meaning of some fields:

- **HydroID**: integer: A unique feature identifier within a geodatabase.
- **FeatureID**: it contains the number of HydroID of the HydroFeature from which the node was created. This enables the SchematicNode to connect to the attribute information of the feature it describes. Typical feature connected to the SchematicNode are Watersheds and HydroJunctions.
- **SrcType**: it contains the CodedValueDomain number of the type of node. CodedValueDomains are the followed:
  1. Sorgente (Source)
  2. Confluenza (Confluence)
  3. Foce (Outfall)
  4. Derivazione (Water withdrawal)
  5. Centrale idroelettrica (Hydroelectric power plant)
  6. Utenza Irrigua (Irrigation user)
  7. Utenza Industriale (Industrial user)
  8. Utenza Idropotabile (Drinking water user)
• **Subroutine**: it contains the CodedDomain number of the type of subroutine call at the node. CodedValueDomain are the follow:

1. sorgente (Source: input runoff hydrographs from the connected watershed)
2. SommaIdrogrammi (Sum hydrographs: sums the discharge from upstream schematic links)
3. Diga (Dam: calls the dam tool performing flow routing at the connected dam)
4. Diversion (Diversion: calls the subroutine Diversion that calculates the outflow into the downstream schematic links)
5. Utenza (Users: sub. not yet implemented)

About the table **SchematicLink**, is listed below the meaning of some fields:

- **HydroID** – integer: A unique feature identifier within a GeoDataBase
- **FromNodeID** – integer: Indicates the HydroID of the SchematicNode at the upstream end of the Link
- **ToNodeID** – integer: Indicates the HydroID of the Schematic Node at the downstream end of the Link.
- **LinkType**: it contains the CodedValueDomain number of the type of node. CodedValueDomains are the followed:
  1. affluente (tributary)
  2. principale (main river)
  3. canale (channel)
- **Subroutine**: it contains the CodedValueDomain number of the type of subroutine call at the link. CodedValueDomain are the follow:
  1. traslazione (transfer: transfers the inflow hydrograph to the downstream node unchanged)
  2. Muskingum (Muskingum: calls the Muskingum subroutine to routing the inflow hydrograph to the downstream node using the Muskingum method)
  3. IdrogrammaUnitario (Unit hydrograph: not yet implemented)
  4. InvasoLineare (Linear reservoir: not yet implemented)

The section 10.6 describes the proposed methodology for the creation of this set of data and watershed mentioned below.

- **Feature DataSet Hydrography**
  1. **Dam**: it contains the data of dams (NOTE: In the table Dam, only those dams are considered in the simulation which are assigned to a value of the field JunctionID
that defines the HydroJunction of the hydrographic network in which the work is located);

2. **MonitoringPoint**: it contains data from the monitoring stations in the concerned area. The stations must correspond to points where instruments are or where you plan to save the results of calculation. (NOTE. For each reservoir, for which you make the simulation, it is necessary to include at least two monitoring points: one reservoir and one type Dam Outlet)

About the table **MonitoringPoint** you must note the meaning of some fields:

- **HydroID** – integer: A unique feature identifier within a geodatabase
- **JunctionID**: it contains the number of HydroID of the **HydroJunction** of the HydroNetwork to which it’s related. This enables the MonitoringPoint to connect to the attribute information of the **SchematicNode** that have the same value in the **FeatureID** field.
- **FtypeID** – it contains the CodedValueDomain number of the type of Monitoring Station. CodedValueDomain are the follow:
  1. Streamgage
  2. Reservoir
  3. Dam Outlet
  4. Rain Gauge
  5. Snow gauge
  6. Weather station
  7. Avalanche safety
  8. Other

- Feature DataSet Drainage
  1. **Watershed**: feature class which contains a landscape subdivision into selected drainage areas, which drain to a point of the river network. It also contains the calibrated parameters of rainfall-runoff Bucket model.

About the table **Watershed** you must note the meaning of some fields:

- **HydroID** – integer: A unique feature identifier within a GeoDataBase
- **JunctionID**: it contains the number of HydroID of the **HydroJunction** of the HydroNetwork to which it’s related. This enables the **Watershed** to connect to the attribute information of the **SchematicNode** that have the same value in the **FeatureID** field.
10.5. Upload initial alphanumeric data
Alphanumeric data can be divided into:

- Configuration data
- Time series

10.5.1. Configuration data
- The Fields of Watershed feature class contain the calibration parameters of Bucket model: these fields must be filled in. (There is an automatic calibration tool that allows to evaluate parameters from historical data. The tool for automatic calibration uses the GeoDataBase of historical events.)
- Dam’s data
  1. Fields of Dam table: as an example, the field values of QuotaMaxRegolaz; QuotaMaxInvaso are used to show reference levels in the graphs
  2. Table DerivazDighe: contains, for all dams, the data of the intake works.
  3. Table ScarichiDighe: contains, for all dams, the data of the outlet works.
  4. Table CurveXY: contains, for all dams, the data of the elevation-storage relationship, the curve of automatic outlet opening, the curve of standard withdrawal from intake works.
  5. Table TabSorveglianza: contains, for all dams, the data about how much open the outlet works during the flood events;
  6. Table TabRientro: contains, for all dams, the data of outlet works closure when the flood decreases;

10.5.2. Time series
The geospatial feature of the Arc Hydro data model describes the water environment, that is the physical environment through which water flows. Also important are the water properties at any geographic location: precipitation, discharge and water surface elevation. These properties are contained in the TimeSeries component of the data model.

The project GeoDataBase contains observed time series. To perform the analysis we use a second type of GeoDataBase: the event Geodatabase. We create an event Geodatabae for each event, where an event is a time period within much precipitation falls, it causes runoff, which discharging along successive streams can rapidly swell the flows of the main river. Then, in the main river flows propagate downstream.

The Event GeoDataBase stores the rainfall forecast and the calculated and observed runoff.

The data model of both GeoDataBase is expected to contain all time series in the table TimeSeries, which is related to other tables used to define the data type.

A list of time series in the GeoDataBase is as followed:

1. Observed data during various events of rainfall on each watershed;
2. Observed values of flow in the closing sections of the river with streamgauge;
3. Observed values of inflow in the reservoirs;
4. Observed values of water elevation in reservoirs;
5. Observed values of outflow from reservoirs.

The historical time series are listed by event according to a list contained in a schedule of events (table TSEvent) and are related to a monitoring point (streamgauge, reservoir) or area (watershed).

The TimeSeries table has two key fields:

- **FeatureID**: field that contains the value of HydroID of the Watershed or MonitoringPoint, to which it is related.
- **TSEventID**: field that contains the value of TSEventID referred to the list in TSEvent table.

It is possible to upload time series data from an excel sheet having the following format. The tool takes care of assigning the proper TSEventID.

In the first five rows, there are the identification data of sub-basins and / or of monitoring stations and the data type you want to upload: codes must match those in GeoDataBase.

In particular are important:

- **HydroID**: identification code of station or of sub-basin that must correspond to that presented in GeoDataBase respectively in:
  - column HydroID of the table MonitoringPoint;
column HydroID of the table Watershed.

- **TSType**: identification code of the data type that must match to the field TSTyeID of the table TSType.

In the subsequent lines (ie from the sixth row) following data are shown: in the first column the date and hour and in the following columns relative hourly data corresponding to the variables of the respective header line.

### 10.6. Methodology for determining the hydro network and the schematic network

The Arc Hydro data model provides a basic database design for water resources, which describes geospatial and temporal data on surface water resource features of the landscape.

The standard ArcGIS Hydro data model describes only natural water systems, and does not support constructed water infrastructure: therefore the data model has been integrated by adding additional tables and fields to meet the needs of HaltFlood.

One of the most important components of the Hydro Data model is the Network. This component contains a water resource network of streams, rivers and the centrelines of water bodies. Its main purpose is to describe the connectivity of water movement through the landscape.

The Network is contained in the Network feature dataset of GeoDataBase. In this Feature Data Set are included:

- **HydroNetwork**: It’s the principal feature class of this dataset: It’s an ArcGIS geometric network, whose components are HydroEdges and HydroJunctions. Water flows along HydroEdges, and HydroEdges are connected by HydroJunctions. The Hydro Network describes the flow through rivers and streams, and the centerlines of waterbodies.

- **SchematicNetwork**, which consists of the SchematicLink and SchematicNode feature classes. These features are used to symbolise the connection of drainage areas to HydroJunctions, and to provide a simplified view of water flow through the landscape.

About **HydroNetwork** should be noted that there are two types of junctions:

1. **HydroJunction**: Junctions that may have particular behaviours and attributes and are related to other features in the GeoDataBase (hydro features).

2. **HydroNetwork_Junction**: Locations that are anonymous points on the network with no attributes or user interests. These junctions are required only for the network connectivity.

In the Hydro Data Model the geographical points of reference are **HydroJunctions**, which in GeoDataBase have a unique number named **HydroID**, which is the key field for relating them to other objects (the connection of any objects to the HydroJunction is obtained by inserting in the key field **JunctionID of the object** the HydroID value of the related
HydroJunction).

In particular following features are related to the HydroJunction:

- Watershed
- MonitoringPoint
- Dam

Creating a new project, you must choose a list of points of interest. For each point you need to create a HydroJunction.

At the HydroJunction there may be works such as dams or points of interest where the runoff is calculated. (in this case it is a drainage point of watershed).

Once the HydroJunction of interest was selected in the network, the following steps need to be done to create the necessary calculation scheme:

1. defining the watershed, which has the closing section at these HydroJunctions;
2. should be fill in the field JunctionID, of the Dam table, with the HydroID value of the HydroJunction
3. Building the SchematicNetwork establishing the appropriate SchematicNode SchematicLink and in particular:
   - Creating a SchematicNode at each HydroJunction (The nodes will be of type confluence ScsType=2, except for the final network node that will be of type outfall ScsType=3) and filling the HydroID value of relative HydroJunction in the field FeatureID;
   - Creating a SchematicNode at the centroid area of the watershed (The nodes will be of type source ScsType=1.) and filling the HydroID value of relative watershed in the field FeatureID;
   - Link with a SchematicLink the SchematicNode of type ScsType=1 source to the SchematicNode of the relative drainage area outlet (the sequence of steps for finding the SchematicNode of confluence is 1) select the watershed related to the initial SchematicNode using the key field FeatureID 2) the field JunctionID of the watershed contains the HydroID value of the arrival HydroJunction and at this point you can select the arrival SchematicNode searching where FeatureID= HydroID of HydroJunction). This ShematicLink will be of type LinkType=1 tributary (affluente).
   - Link with a SchematicLink the SchematicNodes of type ScsType=2 confluence or ScsType=3 outfall: This ShematicLink will be of type LinkType=2 main river (principale)

For all these operations it’s very helpful to use the software for ArcGIS Arc Hydro Tools, downloadable from the internet site of ESRI (http://www.esri.com/) in the download area. To use all the functions of the software, it’s necessary to have, for the same geographical area, a digital terrain model, for example, it’s possible to use the IGM, or extract the part that
affects the data published by Consortium for Spatial Information (CGIAR-CSI) on the digital model of the world with 90 meter steps produced by NASA Shuttle Radar Topographic Mission (SRTM) and downloadable from the website http://srtm.csi.cgiar.org/Index.asp.

Having the terrain model, the hydrographic network and the software Arc Hydro Tools, it is possible to do automatically using ArcGIS:

- Automatic perimeter of **Watershed** closed on sections of selected HydroJunction;
- The automatic creation of **Schematic Node** and **Schematic Link**.

Below the toolbar and a description of the data input and output menus used to perform the two calculations above is shown.

To perform the data preprocessing for the automatic perimeter of Watershed, you must perform the calculations indicated in the submenus of the figure below:

Here the input/output data of the menu **Terrain Preprocessing** are represented.

Where:
- **Raw DEM** is the original elevation grid (DEM) of the area;
- **AGREE Stream**: are the vector hydrographic lines of the area;
- **AGREE DEM**: is the output of AGREE, a surface reconditioning system for Digital Elevation Models. The system adjusts the surface elevation of the DEM to be consistent with vector coverage. The system has been developed by Ferdi Hellweger at the University of Texas in Austin in 1997. For a full reference to the procedure refer to the weblink (http://www.ce.utexas.edu/prof/maidment/GISHYDRO/ferdi/research/agree/agree.html);
- **DEM**: is the input of Fill sink functions. If a cell is surrounded by cells with higher elevation, the water is trapped in that cell and cannot flow. The Fill Sink function modifies the elevation value to eliminate these problems. This input can be a copy of Raw DEM or, as in the example above, a copy of AGREE DEM;
- **Hydro DEM**: is the output of Fill sinks function;
- **Flow Direction Grid**: is the output of the Flow Direction function. The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell.
- **Flow Accumulation Grid**: is an output and represents the dimension in cells for upstream contributing basin for each point;
- **Stream Grid**: is an output and represents the difference between points considered river cells and basin cells, where river cells are those that have an upstream contributing area more extensive than a typical threshold defined by the user.

For automatic perimeter of Watershed, run the submenus shown in the following figure:

For automatic perimeter of Watershed, run the submenus shown in the following figure:

Input and output of menu **Watershed Processing** are represented below:
Where:

- **Raw DEM, Flow Direction Grid, Flow Accumulation Grid and Stream Grid** are the result of elaborations shown above;
- **Batch Point**: are input data and should be set in the Stream Grid immediately upstream of watershed Point using the tool *Batch Point Generation*.
- **Watershed Point**: are input data, for example the HydroJunctions chosen as closing sections of interest.
- **SubWatershed Point**: are outputs and are the closing points in the centre of Stream Grid cells nearest to the Batch Points.
- **SubWatershed**: are outputs and are sub-basins closed to Batch Points. They can be used as watershed of our project.
- **LongestFlowPath**: is an output of the function *Longest Flow Path* and represents the drainage path longer than each drainage area; it’s important for the time of concentration of watershed.

In the figures below the parameters to assign respectively to the functions *Batch Subwatershed Delineation* and *Longest Flow Path* are described.
Node/Link Schema generation

On each node and each branch a subroutine of calculation is expected to be activated: the possible subroutines of calculation are different depending on the type of node or branch. List of possibilities:

Type nodes:

- SchematicNode.ScrType=source
  - Subroutine=source: The calculation of rainfall runoff model is applied to the corresponding watershed.
- SchematicNode.ScrType=confluence and SchematicNode.ScrType=outlet
  - Default -Subroutine=SommaIdrogrammi: The instantaneous calculation of the sum of the outflows of branches, which converge at the node, is made.
Optional - Subroutine=dam: The sum of inflows at the node and the calculation of routing at the dam, which corresponds to the node.

Types of branches:

- **SchematicLink.LinkType=tributary**
  - Default - **TypeRouting=translation**: calculation of the outflows from the branch like that for the inflows, but translated in time for a number of hours identical to the value of translation associated to the respective field.
  - Optional - **TypeRouting=Muskingum**: calculation of outflows from the branch with Muskingum method using the parameters Musking\textsubscript{K}, Musking\textsubscript{X} and NumSubReach contained in the respective fields.

- Optional - **TypeRouting=Unit Hydrograph**: calculation of outflows from the branch with the Unit Hydrograph method using data represented in the table UnitHydro.

- **SchematicLink.LinkType=principal**
  - Optional - **TypeRouting=translation**: calculation of the outflows from the branch like that for the inflows, but translated in time for a number of hours identical to the value of translation time associated to the respective field.
  - Default - **TypeRouting=Muskingum**: calculation of the outflows from the branch with Muskingum method using the parameters Musking\textsubscript{K}, Musking\textsubscript{X} and NumSubReach contained in the respective fields.
  - Optional - **TypeRouting=Unit Hydrograph**: calculation of the outflows from the branch with the Unit Hydrograph method using the data represented in the table UnitHydro.

11. Conclusions

The purpose of this informatic tool, HaltFlood, is to simulate the performance of specified operating policies using inflow forecasts. These define the desired storage volumes, the water levels and the releases at any time as a function of the existing storage volumes and the possible expected inflows.

Actually during the flood events, it is common practice to base reservoir operating procedures on current information about reservoir storage without direct use of inflow forecasts. In some reservoirs, also the water level variation speed in the last 15-30 minutes, indicating the discharge inflow in that lag time, is considered to perform the operating procedures. This way of operating is based on hydrological parameters measured during the flood event, and manoeuvres at the outlet works follow the increase of the reservoir water level. If a prediction of flood events in terms of peaks and time evolution are available, it is possible to plan in advance the actions to control the flood and guarantee the safety of dams and territories downstream. Obviously the operating procedures should be planned taking into account forecast uncertainties and law prescriptions.
HaltFlood would be a friendly and valuable tool for all dam’s owner, able to estimate 3-days runoff forecasts and provide a range of possible solutions (manoeuvres at outlet works) in order to minimise the negative effects on the dam and the valley downstream.

Once flood event is passed, the tool allows a comparison between observed and calculated data in a simple way.

The main goal of HaltFlood software is to be a helpful tool to apply quantitative rainfall forecast at reservoirs management as nowadays only qualitative forecasts are used sometimes.

12. References


