WORLD METEOROLOGICAL ORGANIZATION

Global Water Partnership

THE ASSOCIATED PROGRAMME ON FLOOD MANAGEMENT

INTEGRATED FLOOD MANAGEMENT

CASE STUDY

ITALY: PIEMONTE REGION METEO-HYDROLOGICAL

ALERT AND REAL-TIME FLOOD FORECASTING SYSTEM

December 2003

Edited by

TECHNICAL SUPPORT UNIT

ITALY: *PIEMONTE REGION METEO-HYDROLOGICAL ALERT AND REAL-TIME FLOOD FORECASTING SYSTEM*

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1. LOCATION

The Piedmont Region in the northwest of Italy is a predominantly alpine region covering 25,000 km^2 ranging from 6° 40'E to 9° 15'E and to 44° N and 46° 30'N (Greenwich Coordinates). It is situated on the Padana plain and bounded on three sides by mountain chains covering 73% of its territory.

Hydrologically speaking, the Upper and Mid Po catchment is varied. The mountainous areas of the Alps, with the highest mountains in Europe, so near to the hot Mediterranean see provide a complex climatic and hydrological regime. The entire catchment drains to the Po River. The Upper Po River basin is characterized by a number of fast responding boulder-lined tributaries from the Alps (North and West) and Appenines (South). The mid Po River is moderately flat and contains wide floodplains and a meandering cobbled and sandy riverbed, it is predominantly alluvial with significant groundwater contributions and a much longer flood response time.

Rainfall patterns are extremely varied with the highest mean values in the northeastern mountains with more than 2000 mm per year while in the western mountain part and in the lowlands the mean annual rainfall falls below 900 mm. Moreover big storms can hit every part of the territory and intensities are frequently greater than 50 mm per hour.

More than 4 million inhabitants live in this complex physical and climatic environment. In the low land as well as in the major alpine valleys there are the most important infrastructures and communication networks. This means that many man made structures are present across and along either minor either main rivers: a huge number of bridges and weirs for water diversion. These interact with the flood waves propagation and often can produce local but heavy problems. In the same time many flood defense structures have been built. Levees are very common along the rivers in the valleys and in the low land. These are often very old structures as they are linked with the agricultural and industrial exploitation of over bank areas in low lands, which have begun in the early 20th century. Their maintenance cannot be always perfect and their failure, which occurred for example in the latest major flood events (November 1994, October 2000), is the cause of a great amount of damages.

The mountainous part of the territory is mainly natural and covered by forest and the pastures have been decreasing for the past decades. The low lands are mainly used for agriculture and the land use patterns haven't significantly changed. The border between mountain and lowlands as well as the major valleys are the areas more populated and industrially developed. In these zones the majority of structures and infrastructures developed in the last decades with a very important change in the land use patterns. The city of Turin (1 million inhabitants) lies alongside the Po River and the city of Alessandria (quarter million inhabitants) lies alongside the Tanaro River, a major tributary.

The water resources of the territory are rich and highly utilized for many human activities. In mountain catchments there are numerous high head hydropower plants. These are generally characterized by little volume reservoirs so their importance is low when considering flood mitigation. In the low land the main activity is agriculture and the main way for irrigation is river diversions into manmade channels. Often these channels are also used for drinking supply, low head hydropower plants and for industrial use. Even in this case the role that channels can have during floods is not very important because the derived water is very little compared even to ordinary flood peak discharge. On the other hand the management of the irrigation channel

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network has high impact on low flows and water quality standards. Water supply is generally obtained by groundwater resources but there are many cities that derive water from the main rivers. The last consideration concerns the big lakes in the northeast of the Country and in particular Lago Maggiore. This lake can store a significant volume of water and the outflow is controlled by gates in order to guarantee different purposes: water supply, irrigation, navigation and flood mitigation.

2. DESCRIPTION OF FLOODS

The complex hydrological regime has an obvious impact on the flood response of catchments. In the winter, the Alps are covered in snow and most of the precipitation is stored as snow and glacial depth. In the spring the snow melts, aided by rainfall, which can result in the spring floods. Summer rainfall can be stormy and the bare, rocky Alps give high runoff with a rapid response. Autumn rainfall can be heavy and prolonged mainly caused by the southwest wind coming from the see. The Appenine range has a lower altitude than the Alps, but suffers from warm Mediterranean currents that can carry a large volume of precipitation, particularly in the autumn and spring. Generally, the major floods occur during the autumn and spring.
On the basis of historical data, available since the year 1800, the Piedmont Region is hit by calamitous meteorological events, on average, once every two years. Where calamitous are those events, such as flooding of the lowlands as well as diffused flash floods of mountain rivers, that produced large damages, important from a regional scale point of view and not restricted to a village or to a part of a village, to structures and infrastructures and eventually in terms of human lives

3. FLOOD MANAGEMENT PRACTICES.

Flood Management practices in the Piemonte Region is highly influenced by the natural peculiarities of the Piemonte territory. Steep and impetuous streams fall down from the Alps into the Padana Plain, these are characterized by flash floods and high mass transport. In the low lands the main rivers, Po, Tanaro, Dora Baltea and Sesia, suffer from the rapid flood of their tributaries and, despite the high lead-time can produce rapid and unpredictable responses.
This natural landscape doesn't allow to cope with floods in a on-line way, that is during the flood event occurrence, and the actual practices are mainly addressed to structural mitigation of floods and to non structural safety measures subdivided into land use planning and emergency plan activation.

3.1 Structural measures

The most common flood mitigation structure used for the main river in the lowlands is building levees. These are generally efficient and allow mitigating the effects of the major floods. The big problem with these structures is the possible and unpredictable spot collapse that can produce high and localized damages, as it effectively occurred in the last big flood of October 2000. In the last years the design of lamination reservoirs has started for some rivers in the region but the construction hasn't still initiated.
The mountain streams are generally natural and human intervention is restricted to weirs designed for erosion and bed load transport mitigation. Reforestation and the standard structural bioengineering measures are widely used in little mountain catchments for mitigation of hilltop erosion and shallow landslide that are the main source of mass transport during flash floods often enhancing the damages produced. Bioengineering practices have been sponsored by regional and local authorities due to their light impact on landscape. There are Regional laws defining the types of intervention for the different purposes fixing also the types of plants to be used avoiding the use of exotic species.

3.2 Non-structural measures

Due to the peculiar environment, as already described in the previous paragraphs, and the characteristics of the floods that usually hit Piemonte territory, the Authority of the Region decided to set up a specific organization for flood forecasting and damage mitigation from natural hazards based on a Alert System issuing Mete-hydrological forecast aimed at the early warning of Civil Protection structures. This is a non-structural real-time measure for flood mitigation while there is no example of on-line operating structures. Generally structures are designed off-line for passive defense from floods.

An organization was created in 1978 under the name of Servizio Geologico Regionale (Regional Geological Service) and later became known as the Direzione Regionale dei Servizi Tecnici di Prevenzione (Regional Directorate of Technical Services for Prevention). The SSRN (Room for the Situation of Natural Risks) is the operational center of the Regional Directorate of Technical Services for Prevention and is dedicated to the mitigation of the impact of hydro-meteorological phenomena on the regional basis. Every day throughout the year, experts from various sectors organized in specific operational teams (geology, meteorology, hydrology, snow) analyze the events and decide which actions, if any, are required.

Every day the SSRN produces an evaluation of the expected and observed meteorological situation, forecasting the occurrence and following the evolution of important rainfall events that could have a critical impact on the territory. These evaluations are then issued to the functions of Civil Protection and the territorial organizations that deal with the management of the agency.

Local communities are strongly involved in the flood mitigation with three different activities. The first is the design of the emergency plan at local scale which is imposed by the national law for civil protection. The second is linked to the former, in fact, to elaborate such plans, local authorities are strongly encouraged to promote studies and analysis about floods and hillslope dynamics. These local scale insights into hydrogeological hazard allow defining and scheduling the best procedures to face the critical events. The different local emergency plans are then evaluated and organized at regional and national levels. The third activity is linked to flood management: local group of civil protection volunteers are involved in emergency actions during critical events as defined in the emergency plans. In particular local authorities must inform the central authorities about the evolution of the phenomena and have to activate the local operational center to receive information from regional and National Civil Protection Operational centers about forecasting and now casting of the events.

Other non-structural measures concern the general management of the territory. The Po River Authority, which has the task to define the guidelines for planning the land use and its development, produced the ‘Plan for the hydrogeological order’. Herewith a complete hazard map has been realized highlighting the interaction between human activities, river and hillslope dynamics.

The main objective of the plan is to identify the areas in the catchment exposed to hydrogeological risk. Three levels of hydrological hazard are defined along all the main rivers. The largest flooding area (so called ‘C’) is defined by the 500 years discharge or by the worst event ever occurred. Within this ‘C’ area, the ‘B’ area is designed by the 200 years flood taking in account the mitigation structures such as levees and lamination reservoirs. In the end the ‘A’ area is the part of the ‘B’ taken by the main stream flux. In the ‘A’ area the main objective of the plan is to ensure safe condition for the reference discharge, ensure the natural dynamics of the river morphology either during flood and during dries; no building is permitted. The ‘B’ area defines the flooding extensions and has the objective to guarantee the natural lamination of flood waves in respect to the natural environment; human activities are permitted only in accordance with the objective of the area. The ‘C’ area is generally where human activities and settlement are present: the plan focuses on the need of enhance the safety level by means of non structural measures in accordance with civil protection authorities as define by the national law.

The Plan also concerns hydrogeological hazard on hillslopes due to shallow landslides and debris flows and a careful identification of areas prone to this risk has been accomplished. The behavior in these areas is similar to that for ‘C’ areas. Insurance against floods or hydrogeological hazard have not been used till now but some discussion at political level is going on in these days.

3.2.1 Alert System

The National Law 225/92 defines emergency planning in Italy; it organizes the emergency plan in phases (Survey, Warning, Alarm and Emergency) activated successively on the basis of the forecasted events and their observed evolution.
The main phenomena taken in account are flood of the main rivers, flash floods and shallow landslides for little mountain or hill catchments (see 3.2.2)
Moreover the risk level is coded into three levels: 1, 2 and 3; respectively indicating: normal situation, low and high danger. Discrimination between level 2 and 3 is made on the expected number of critical phenomena and on the extension of the homogeneous areas involved.
This is very simple scheme that allows avoiding as much as possible subjective interpretations.
In this framework, Survey is the continuous activity of the central and Regional structure for hydro-meteorological forecasts. Warning implies the activation of local operating rooms when some criticity is forecasted. If the meteorological event starts and direct observations of the phenomena suggest high level of danger the Alarm phase is activated and population is alerted while visual recognition of phenomena starts. Emergency safety measures are ultimately taken if required. In this way the first step of the emergency plan implies the only activation of local authorities without involving people so limiting the impact of false alarms on population.

3.2.2 Risk scenario identification

At present the Piemonte alert system can account for the following typologies of risk:
(a) - Flood risk is due to long and diffused rainfall on big river catchments (Catchment Area >400-500 km^2). Major rivers flooding involving villages and infrastructures in the valleys and in the lowlands are the main expected effects. (b) - Hydro-Geological Localized risk due to short and Intense storms on little areas (Catchment Area <300-400 km^2), critical phenomena are restricted on small catchments rivers, as flash floods; on hillslopes, as shallow landslides; and on urban areas, as failure of the drainage system. (c) - Heavy Snow risk caused by heavy snow in lowlands producing interruptions of the mobility network: streets, railways, and airports. An extension to other meteorological adverse conditions, such as ice, fog and strong wind, is now under consideration.

3.2.3 Definition of homogeneous areas for vulnerability assessment

The key point of the regional alert system is the subdivision of the territory into homogeneous areas in terms of meteorological aspects and hydrological response during the occurrence of extreme events. This subdivision needs to be the best compromise between meteorological models synoptic scales, hydrological phenomena small spatial scales and practical needs for management of the defined risks by local authorities. So the alert areas have a physical and conventional meaning. The main criteria for detection is the climatic and meteorological characterization and in particular the homogeneous rainfall patterns. Criteria for perimeterization are mainly hydrologic, watersheds boundaries, and political, local authorities involved in flood management.

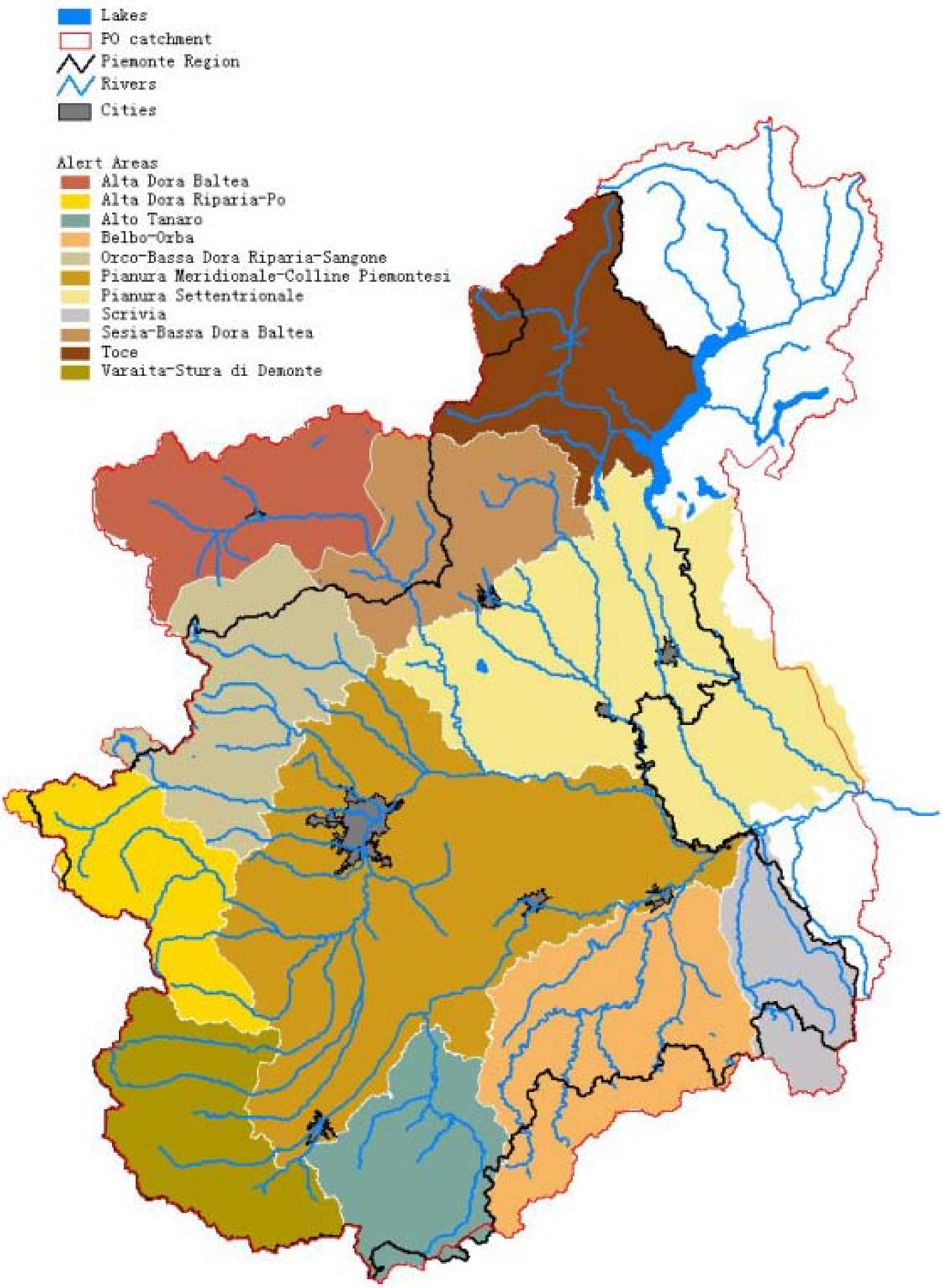

Figure 1. The Piemonte region alert system: the homogeneous areas for hydrogeological hazard level forecast.

3.2.4 The operational structure

The SSRN is a H24 operating room for survey and warning. It is a technical structure achieving two main tasks. (1) – Hydro-meteorological survey: a group of technicians ensures that all the informative systems always run properly and all the data from the network are received. (2) – Hydro-meteorological forecast: groups of experts composed by Meteorologists, Hydrologist, Geologists and Snow scientist issue forecast and warning bulletins and develop studies and project to verify and improve the forecast and alert system.
The information systems in use at SSRN are the following:

Automatic network for meteorological and hydrometric monitoring
Meteorological radar
Automatic "radio-sounding" of the atmosphere
Numerical modeling for meteorological forecasting on global and local scales
Numerical modeling for flood forecasting on the main river network.

Every day the meteorologist group in the SSRN produces the quantitative rainfall and temperature forecasts with a 48 hors horizon for each of the 11 regional alert areas. This allows the hydrologists and the geologist to produce an evaluation of the expected effects induced by the meteorological situation, forecasting the occurrence of important rainfall events that could have a critical impact on the environment and following their evolution. Actually there are two different ways for danger level assessment. The former is by comparing the quantitative precipitation forecasts (QPF) with predefined rainfall thresholds, resulting from off-line studies of past events as well as from numerical model simulation. The latter is real time numerical simulations of the phenomena. In this context an Informative system for operational flood forecasting (see 3.2.5) as been developed to produce an objective evaluation of expected flood dynamics on the river network offering a sound help to decision makers.
At the end the pool of experts issue a forecast bulletin pointing out for each alert zone: the expected risk typology (coded in a, b or c) and the corresponding danger level (coded in 1, 2 or 3).
Finally, survey of the effect on the environment is an important feedback activity useful for improving the system. A database is updated every time that damages induced by floods, river dynamics and rainfall triggered shallow landslides are reported. In this way it is possible both to check if rainfall and water level thresholds used in the Alert system are representative or need recalibrating, and to verify the flood-forecasting model.

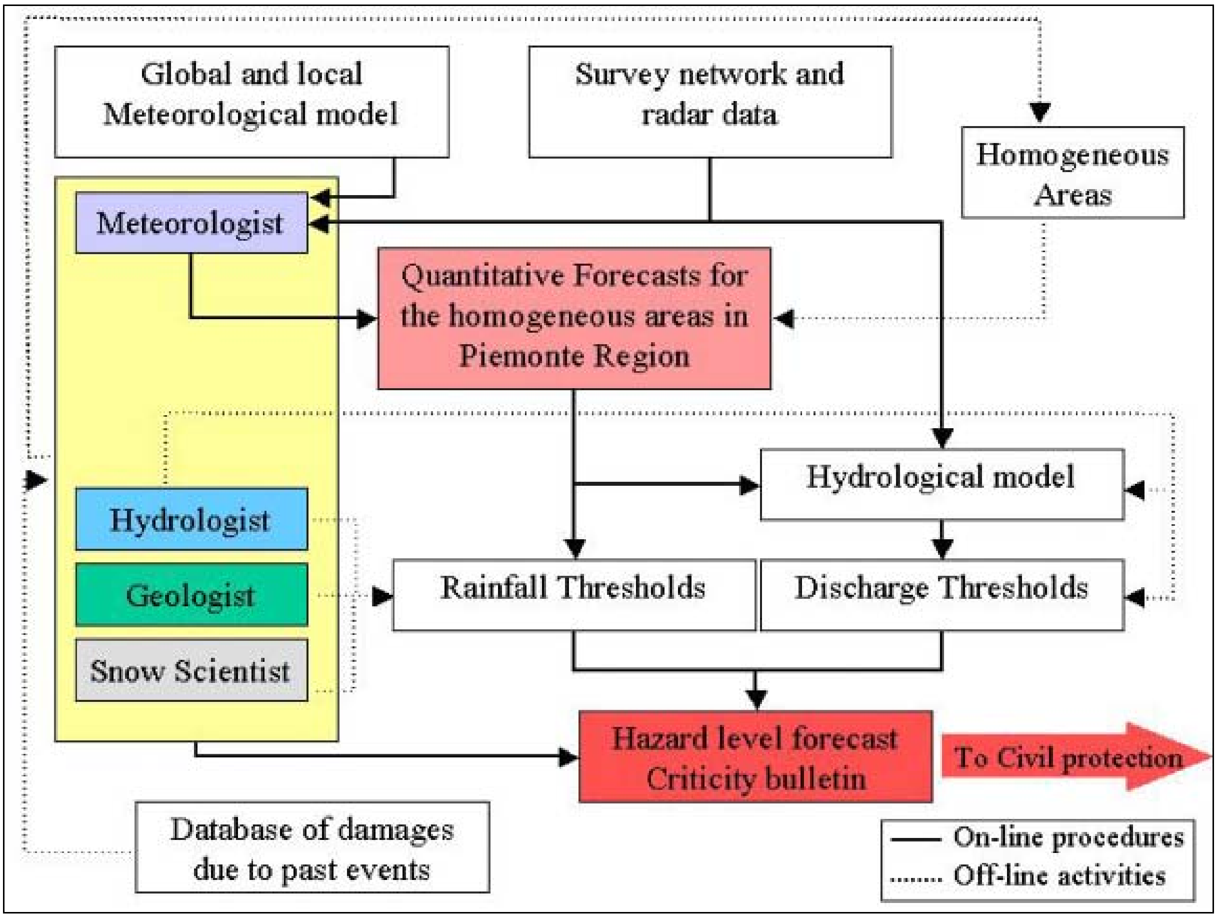

Figure 2. Structure of the group for Hydro-meteorological forecast.

3.2.5 Informative system for Operational flood forecasting

FloodWatch is a decision support system for real-time flow forecasting combining an advanced database with MIKE 11 hydrological and hydrodynamic modeling and real-time forecasting system all wrapped together with the ArcView GIS environment. The integration of a flood forecasting system in a GIS environment provides a very powerful tool for real-time flow forecasting and flood warning. Once the database is established and the graphical display of stations configured, FloodWatch allows for the fast and easy handling of the procedures involved in the management of a real-time flow forecasting and flood warning system. FloodWatch can run in a fully automatic mode by means of a built-in task scheduler, or in manual mode, where the operator controls the system. Figure 3 shows a schematic outline of the FloodWatch system, where the flow of data is from real-time data input to flow forecast output.

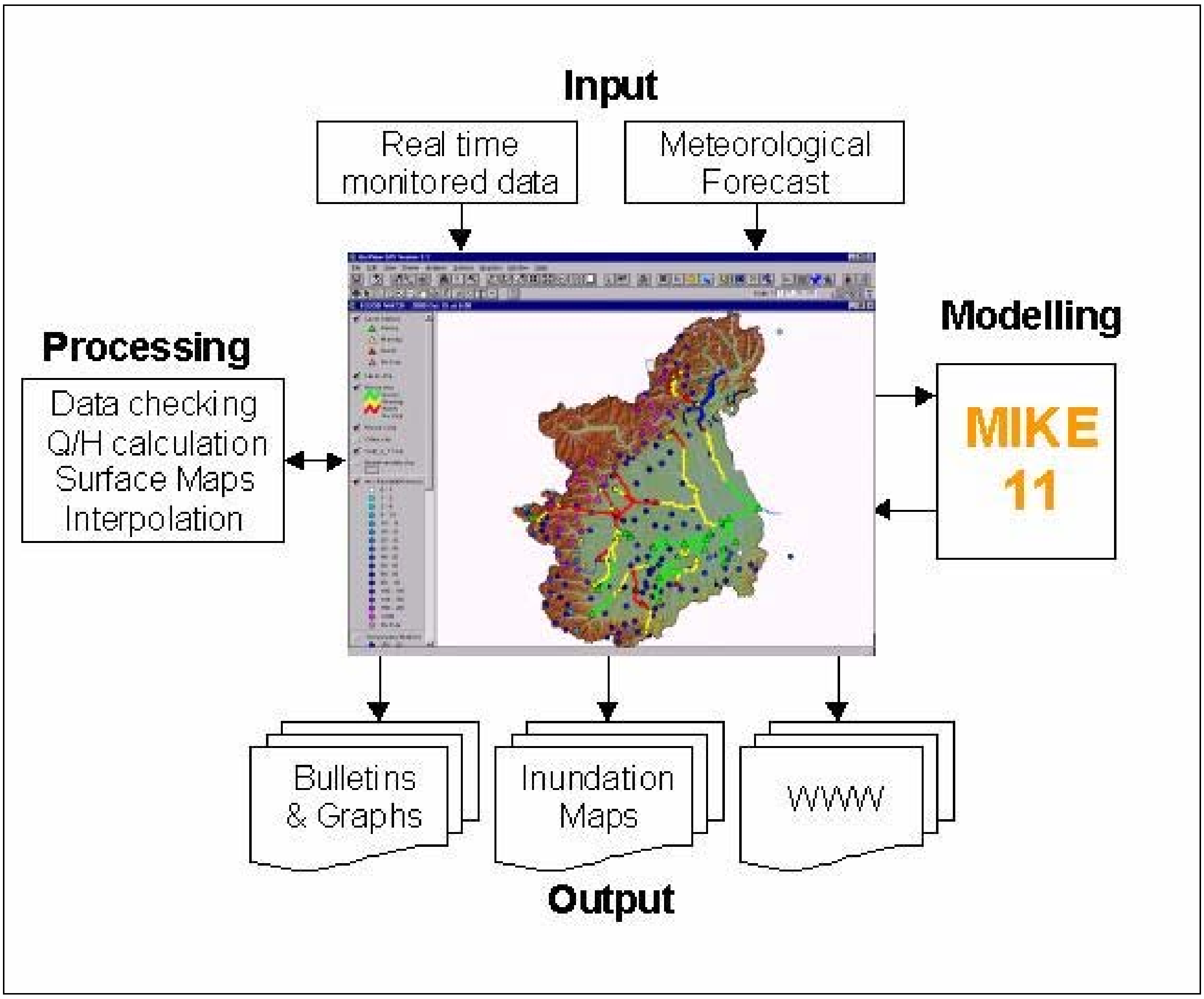

Figure 3. A Schematic of the FloodWatch System.

Real-Time Data Input:
Telemetry data is imported to FloodWatch from the hydro-meteorological network through the data import and conversion module, which can be run automatically or manually. Quantitative forecasts of precipitation and temperature during the forecasting period can also be imported automatically or manually.
Processing:
The first step before a forecast simulation is to process the input data. Processing serves several functions that are guided by tools to augment this process:

- Interpretation and gap-filling of data
- Quality assurance check of data (maximum, minimum, maximum rate of change, etc)
- Q/H calculation (for estimation of flow from recorded water-depth)

Modeling:
Once a request for a forecast is made (either manually or automatically) the system will automatically extract the required data from the FloodWatch database and convert to MIKE 11 format. The model simulation, based on coupling rainfall-run off with flood wave propagation, is then automatically executed and the MIKE 11 simulated forecasts (water-levels and flows) are transferred back to the FloodWatch database for output (display and dissemination).
Flow Forecast Output:
A variety of output types are available. ArcView graphical displays are automatically updated with the most recent information (real-time status and forecasted states). In addition, forecasts are produced as graphs (observed and forecast water-levels and flows).
For operational purpose within the operational structure the system provides levels and discharge

forecast for the whole river network. The forecast are validate by expert hydrologists for 40 cross sections located in the main rivers and then are all saved in HTML format for immediate display on the Intranet site hosted by RUPAR (Unique netwoRk for Regional Public Authorities) where access is reserved so that the information can't reach citizens directly.

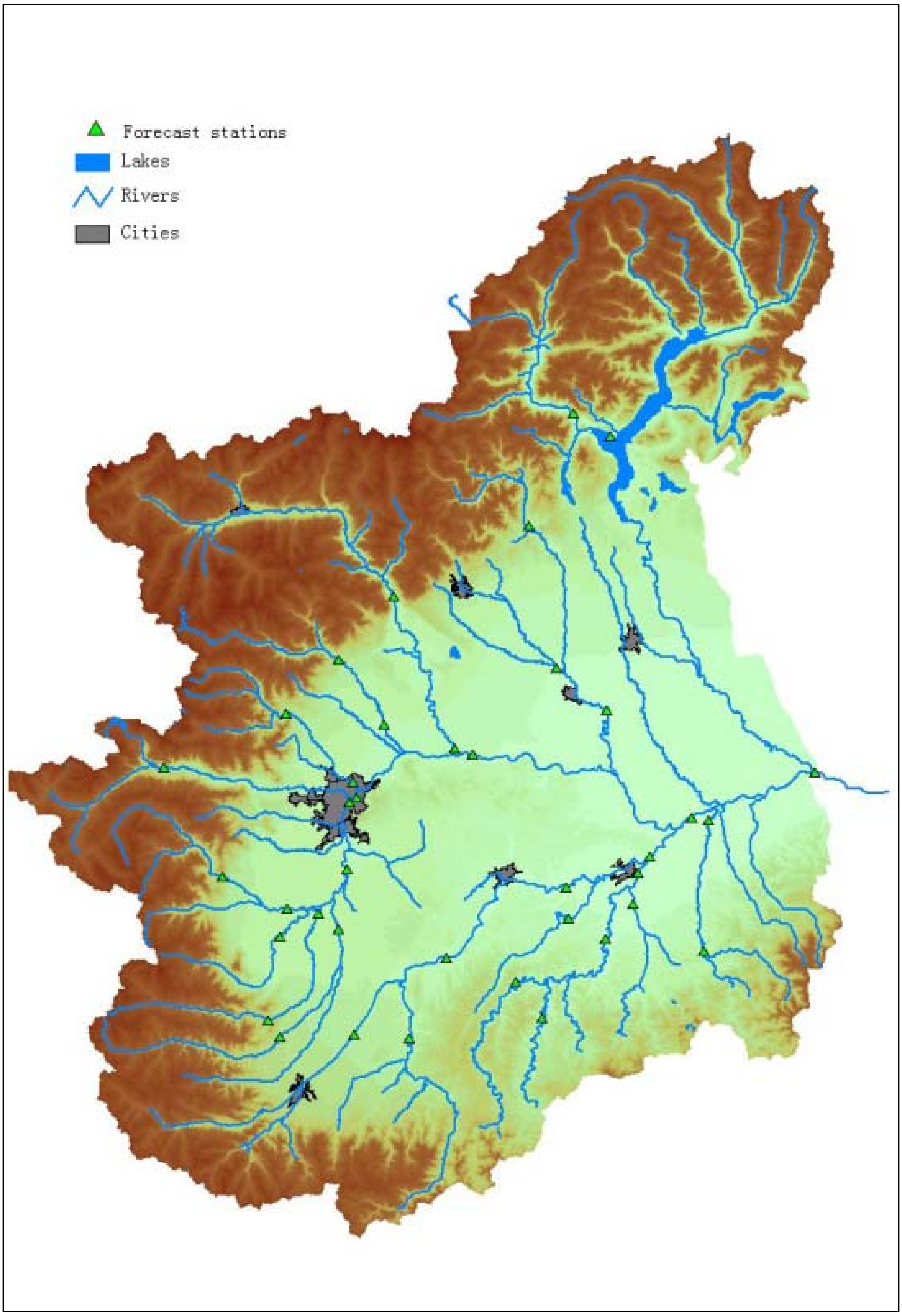

Figure 4. The Piemonte region flood forecasting system: the river cross-section analyzed.

Operational guidelines:
In the first years of operational experience two different ways to use the system have been highlighted. The first (Forecast Mode) is mainly linked to the hydrological module and the quantitative precipitation forecasts as input. The system allows a very early warning but only a qualitative use of this long term forecast, 1-2 days, are heavily conditioned by uncertainties present in QPF. False alarms can be quite frequent but their undesirable effects are limited by the fact that in the great majority of these cases only local authorities are alerted while population is not warned until the event starts.
The second (Management Mode) derives from the hydrodynamic module and the use of real time hydro-meteorological observations as input. Short terms forecasts, 6-12 hours, are very precise in term of peak discharges and arrival times so that they can be used in a quantitative way. This kind of real-time information proved to be very useful for Civil protection emergency measures. It is important to underline that Civil Protection personnel can effectively use this information, characterized by a short advance, only if it is previously activated by an early warning enhancing the need of a preliminary long term forecasting activity.

4. INSTITUTION RESPONSIBLE FOR FLOOD MANAGEMENT.

In the environmental context described it is almost impossible to cope with floods during the evolution of the phenomena. The flash floods generating on the river network prevents the chance to manage the events. For this reason the most important activity in coping with floods is an early warning of the Civil Protection so that all the safety measures predefined in the emergency plan can be organized in time. The objective of the system is mainly focused on limiting human losses trying to limit hazardous activities during floods, while the active defense of structures, infrastructures, such as streets, bridges or railways, and villages is almost impossible to be achieved. The agencies involved in flood management so are the Regional Directorate of Technical Services for Prevention for survey and forecast and the Civil Protection for organization of safety plan and activation of alert procedures. These two institutions work in strict collaboration. There are also the agencies of power plants management or irrigation management that should be involved in the mitigation of floods that can be obtained with on-line management operations on reservoir or diversion regulations. However due to the rapid flood response of the mountain streams, this type of operations can be very difficult to be planned. On the other hand during the major events we sometimes have an informal exchange of information with those agencies but this collaboration is difficult to be formally scheduled because they are generally private agencies with different tasks and a different approach to water and flood management. Exchange of data seems to be the first important step to start any collaboration with those agencies and there are now some pilot projects to create a standard communication. Within Interreg III (European fund for interregional and transnational collaboration) we are studying which are the reservoirs that can contribute to flood mitigation with an off-line exchange of data in order to define the best policy in the dam regulation.
There is also an exchange of information and observed data with other Italian regions as well as with Switzerland. This is formally regulated and is often the basis for developing common project. During Interreg II Framework it has started a daily exchange of hydro-meteorological survey data between Switzerland and Piemonte Region. Since the Lake Maggiore watershed is subdivided in the territories of the two regions it is very important to share all the data available to enhance the two flood forecasting systems. In the near future, within the framework of Interreg III, en exchange of meteo-radar data is being designed.
An exchange of data is active with Liguria Region where all the stations in the Tanaro river watershed are connected to the Piemonte radio polling system. Within Interreg II framework two main activities where developed: first a common interface Storm® was designed to share survey data and meteorological and hydrological models forecast, second a meteo-radar had been installed in collaboration and now it can be used by the two region.
There is also an exchange of data with Val d'Aosta Region whose territory is located inside the

Dora Baltea catchment, one of the major tributaries of the river Po. Piemonte Region meteorological service provides forecasts for Aosta Region where survey stations are directly connected to Piemonte radio polling system.
As far as passive defense from floods is concerned many institutions have to be mentioned because of their overlapping responsibilities. The structural design, that is the construction of levees or reservoir for flood mitigation, is one of the tasks of central as well as local authorities depending on the importance of the river involved, while the non structural measures, that is developing policies for flood plain management and land use regulation, are normally taken by central or regional authorities. Cooperation between these agencies is limited to data exchange.

5. LESSONS LEARNED

The main lesson that can be derived from this is the great importance of a good a warning system linked to the Civil protection Structure. When one has to cope with flash floods often generated by heavy storms localized on mountain catchments there is not enough time during the events to operate for managing the flood waves with structural intervention. Moreover to obtain an efficient warning for Civil protection, that generally need enough time in advance for organization of men and means, it is also necessary to use quantitative precipitation forecasts, introducing a great amount of uncertainty. In this case it is very important to organize the plan into phases so that the first activation doesn't interest directly people. The False alarm rate in this phase can be very high due to uncertainties in meteorological forecasts and, as it is well known, a high false alarm rate normally result in a fall of reliance by people and this is to be avoided as much as possible.
The approach described has been developed and improved in the last 10 years. Comparing the big flood event of 1993 and 1994 with the last of October 2000 the result can be seen in a significant reduction of human losses.
The results of the informative system for flood forecasting was very useful during the big October 2000 flood event but this is the only big flood during which the system was operating so it is difficult to make a precise comparison with other cases. On the contrary as far as minor flood are concerned it surely allowed a significant improvement of the warning system helping decision makers to discriminate between hazardous and normal weather situation and in taking the right decision in the danger level forecasts.