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HYDROLOGIC FORECASTING IN BISTRITA CATCHMENT AREA WITH THE HELP OF RFS PROGRAM (RIVER FORECAST SYSTEM) (ROMANIA)

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Abstract

The Bistriţa River springs from the Rodna Mountains, runs through the Eastern Carpathians, passing through six towns (Vatra Dornei, Bicaz, Piatra Neamt, Roznov, Buhusi and Bacau) and flows into the Siret River downstream Bacau. It is the largest tributary of the Siret River and it holds an important hydro-technical power in the same time. It has a length of 157 km, an area of 7039 km² and 193 tributaries (Dorna, Neagra, Putna, Bistricioara etc). The hydrometrical monitoring of the watercourses represents a main stage in knowledge of the hydrologic regime. Lately there have been introduced new monitoring programs that are much more co-operative and offer the possibility of real-time processing of the data, thus forecasts can rapidly be obtained and therefore effective decisions in critical moments can be made. In the River Forecast Center Bacau, within Siret Water Basin Administration, a very useful hydrologic forecast program is developed, namely the RFS program (River Forecast System), which was aquired through the DESWAT (Destructive Waters) project. This paper examines the theory, capabilities, and potential applications of the RFS program on Bistrita catchment area (for the main course). The RFS program uses conceptual hydrologic/hydraulic models to forecast future stream flow using the current snow, soil moisture (Sacramento Catchment Model), river, and reservoir conditions, also taking into account the meteorological data from the previous days, weeks, from radars. The RFS program assumes that the meteorological events that occurred in the past are representative for the events that may occur in the future. In Bistrita River catchment, there are 13 automatic hydrological monitoring points: 5 on Bistrita River (Carlibaba automatic hydrometrical station, Dorna Giumalau automatic hydrometrical station, Dorna Arini automatic hydrometrical station, Brosteni automatic hydrometrical station and Frumosu automatic hydrometrical station), 2 on Dorna River (Poiana Stampei automatic hydrometrical station and Dorna Candreni automatic hydrometrical station), 2 on Neagra River (Gura Negrii automatic hydrometrical station and Brosteni automatic hydrometrical station), 2 on Bistricioara River (Tulghes automatic hydrometrical station and Bistricioara automatic hydrometrical station), 1 on Tesna River (Cosna automatic hydrometrical station) and 1 on Putna River (Tulghes automatic hydrometrical station). The sensors register the information needed for the RFS program to work properly and deliver a detailed hydrologic forecast in order for the River Forecast Center to provide public warnings of flooding.The program can also forecast the water supply in snowmelt areas, the probability to produce spring and summer flash floods, the inflow hydrographs for reservoir operation, and any information needed for risk analysis in the periods of droughts. The hydrologic forecasting is displayed by the means of two applications: HBT (HydroNet Briefing Terminal) and HTN (HydroThreatNet). These applications show the results and analysis from the RFS program, and warn about possible overlaps of the defense quotas of the rivers.

Keywords: catchment area, floods, hydrologic parameters, hydrologic forecasting, RFS program

1 INTRODUCTION

From ancient times, water has played a very important role in the economic life of the territories. People use the water from the rivers as drinking water, industrial water, irrigation, recreation, production of electric power and transport fluvial. With the development of industry, agriculture, transport, energy, economy, the need for water has become essential so that it has imposed a thorough knowledge of the quantitative and qualitative evolution of rivers and water resources utilization.

Modern hydrology is based on two concepts, namely one deterministic and one probabilistic. The first reflects the mechanism for the formation of water flows due to the cause-effect process, the second concept produces random variables (observations and measurements, interpretations of hydrological phenomena) (Diaconu & Jude, 2009).

The observations and measurements represent the basic analysis of the evolution of the hydrological situation on rivers, so estimates of the river levels variation, liquid and solid flow rates, water and air temperature, winter phenomena, evapotranspiration, capacity curves of reservoirs, water quality parameters can be determined. The analysis of the hydrological regime of the rivers, considering that flash floods and flooding are a common threat to the territory of Romania, in general, and the Bistrita catchment area, in particular, has put an emphasis on the forecast of the maximum flows. Therefore, we analyzed the flash flood waves, the maximum volumes of spring and summer runoff, and tried making calculations based on different parameters, in order to obtain some short-term forecasts, which in time will become even more relevant.

A hydrologic forecast consists in conducting a preliminary estimation of a hydrological feature on a watercourse at a certain moment in time (Diaconu & Jude, 2009).

For a good efficiency, both in terms of theory and practice, the forecast system was perfected with the development and modernization of measurements and observations on rivers, reservoirs, groundwater, etc; meteorological measurements; and with the determination of the correct morphometrical data and physical-geographical characteristics of the catchment area.

The first hydrometric observations on Bistrita catchment area established at Dorna Giumalau, in 1885 (Ujvari, 1972). In the beginning, the hydrometrical workers measured only the water level. Later the hydrologists decided to move to a more complex monitoring and switched to a program including measurements of liquid and solid flow, rainfall, temperature of water and air, the winter phenomena, etc.

All such information, to which is added and other data (longitudinal and transverse profiles, and the proportion of land-use, hydro-technical works status, etc.), have been and are used today in making hydrologic forecasts, both short term and long term (Diaconu & Diaconu, 2002). The short-term forecasts (for liquids flow, melting of the snow, the pluvial flash floods and of ice melting) use the evolution of meteorological variables as background. A wrong weather forecast will generate a wrong hydrological forecast. Generally, the wind and air temperature forecasts are more accurate compared to forecasts relating to the quantities of precipitation. As the weather forecast is developing on a shorter period so its viability is higher. Water propagation models increase the need of data and the physical characteristics of watercourses. However, not always by increasing the number of parameters taken into consideration can we get an accurate forecast (Diaconu & Serban, 1994). Lately there have been introduced new monitoring programs that are much more co-operative, offer the possibility of real-time processing of the data, thus forecasts are rapidly obtained, and therefore effective decisions in critical moments are made. In the River Forecast Center Bacau, within Siret Water Basin Administration, a very useful hydrologic forecast program is developed, namely the RFS (River Forecast System) program.

The Basin Forecast Center collects and processes the recorded data from the field. In order to collect, manage and analyze the hydrolometrical data the hydrologists use HIDRAS3. HIDRAS3 is an application used for collection and transmission of the measured data of hydrometrical and pluvial stations sensors, as well as for their processing and interpretation in the operative system, does the data storage. .

The advantage of this monitoring system and forecasting system is that data interpretation can be done in real time (primary data processing; analyzing the updated critical events; analyzing the lack of data monitoring and replacing it with calculated real data; running programs for developing/updating the hydrological forecasts; updating the forecast parameters, modified as a result of some major events in the basin or because of some analysis errors; analyzing the development of new structures of mathematical models). This paper examines the theory, capabilities, and potential applications of the RFS program on Bistrita Catchment area.

2 THE STUDY AREA

Bistriţa River springs from Rodnei Mountains. It crosses the Eastern Carpathians Mountains passing through the towns: Vatra Dornei, Bicaz, Piatra Neamt, Roznov, Buhusi and Bacau County. The Bistrita River confluences with the Siret River downstream Bacau. It is the largest and the most important tributary of the Siret River. The Bistriţa River basin has an area of 7039 km² and a length of 276 km. The main tributaries of the Bistrita River are: Dorna River, Neagra Sarului River, Neagra Brosteni River, Borca River, Sabasa River, Bistricioara River, Putna River, Bicaz River, Damuc River, Tarcau River, Cracau River, Romani River and Trebes River (Siret Water Basin Administration, 2012).

The Bistrita River basin has an elongated shape and falls between the Meridians: 24°47'55 " and 27°00'49" East longitude and Parallels: 46°29'33" and 47°44'42" North latitude (Figure 1).

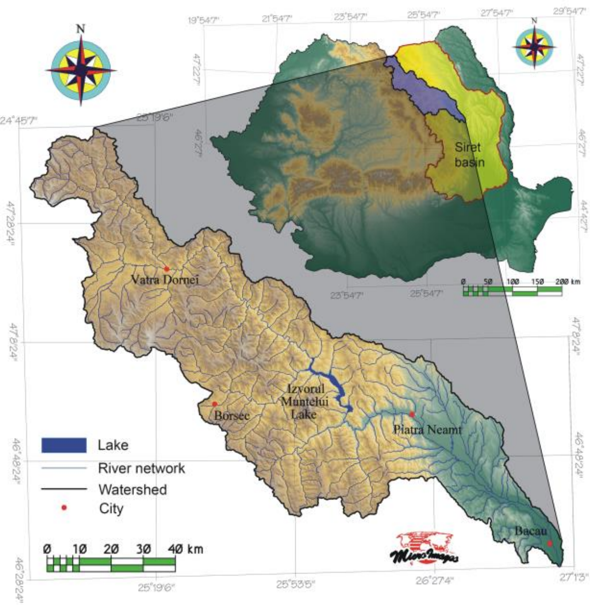

Figure 1. Location of the basin of the River Bistrita

The physical-geographic characteristics of the Bistrita river basin are different from West to East. The basin successively develops on mountain (82%) and sub-mountain (18%) level units. The Bistrita River has a NNW-SSE orientation and on its way, it drains all three major geological units of the Eastern Carpathians, therefore it has a very varied lithological substrate. After 1960, the middle and lower course of the Bistrita River was hydro-energetically developed through a number of 10 reservoirs, 13 hydroelectric plants, several canals, dams, flow transfers, banks and slopes protection, relocation of human settlements, mining gravel, digging galleries, viaducts location, and communication channels. The largest reservoir is Izvoru Muntelui, with a volume of 1.12 billion m³ (Romanescu G, 2003; Romanescu G, 2005).

3 METHODOLOGIES

The research is based on data gathered from old and new literature sources, water cadastres material during 1970 - 2013, observations at the manual and automated hydrometrical stations. To assess temporal and spatial distribution of rainfall data, there were used simulated maximum rainfall observations recorded in 24 hours at the hydrometrical stations from the main course of Bistrita River Basin. This paper is based on rich hydro-meteorological data background obtained from the monitoring network and specialized information on hydro-climatic trends present in the area.The database includes measurements of levels, the corresponding flows, water and air temperature data, monthly average flow rates of the period under consideration, which contributed to the liquid flow, mophometric data on Bistrita basin.

In Bistrita River catchment, there are 13 automatic hydrological monitoring points: 5 on Bistrita River (Carlibaba automatic hydrometrical station, Dorna Giumalau automatic hydrometrical station, Dorna Arini automatic hydrometrical station, Brosteni automatic hydrometrical station and Frumosu automatic hydrometrical station), 2 on Dorna River (Poiana Stampei automatic hydrometrical station and Dorna Candreni automatic hydrometrical station), 2 on Neagra River (Gura Negrii automatic hydrometrical station and Brosteni automatic hydrometrical station), 2 on Bistricioara River (Tulghes automatic hydrometrical station and Bistricioara automatic hydrometrical station), 1 on Tesna River (Cosna automatic hydrometrical station) and 1 on Putna River (Tulghes automatic hydrometrical station). There are also five automatic precipitation stations in isolated areas, which constantly provide information: Ciocanesti automatic precipitation station, Chiril automatic precipitation station, Vatra Dornei automatic precipitation station, Panaci automatic precipitation station, Borsec automatic precipitation station. The sensors register the information needed for the RFS program to work properly and deliver a detailed hydrologic forecast in order for the River Forecast Center to provide public warnings of flooding if needed (Siret Water Basin Administration, 2012).

This paper examines capabilities and potential applications of the RFS program on Bistrita Catchment area. The RFS program uses conceptual hydrologic/hydraulic models to forecast future stream flow using the current snow, soil moisture (Sacramento Catchment Model), river, and reservoir conditions, also taking into account the meteorological data from the previous days, weeks, from radars. The RFS program assumes that the meteorological events that occurred in the past are representative for the events that may occur in the future. The paper also exemplifies a flash flood simulation on the main course of the basin. The images from the paper represent screenshots from the RFS program. The map was created in ArcGIS and the tables and graphs were created using Microsoft Excel.

4 RESULTS
4.1 DESWAT Project. Objectives and accomplishments in Bistrita catchment area.

In 2006, the Ministry of Environment and Climate Change had in mind the achievement of a hydrological information system integrated at the country level for reducing the effects of floods and their effect. In order to achieve this purpose the project DESWAT (Destructive Waters) was implemented.

At the level of the Bistrita catchment area, as a result of the DESWAT project, there have been installed 21 automatic hydrometrical stations with sensors for measuring the levels/flows, water-air temperature and precipitation; five pluvial automatic stations and one automatic station for water quality (pH, conductivity, salinity, dissolved oxygen, ammonium).

The DESWAT project objectives are: a better speed and capacity of the forecasting; a better accuracy; to use the products from SIMIN project (National Integrated Meteorological System); and evaluate the potential damage (if the flooding occurs). The SIMIN project supplies the data necessary for the hydrological models to work properly and provides an accurate forecast for saving the human lives and their properties, if the case. While the ultimate goal of this project is to modernize the existing hydrologic monitoring network in Romania, in our case we refer to the Bistrita catchment area, using the latest technology and creating appropriate products for awareness/alarming the public in case of floods (Siret Water Basin Administration, 2010).

Due to the implementation of this project, the work of hydrology and water management has entered both a new modern stage of development and monitoring of rivers and a modern hydrological forecast in the same time.

In order to make realistic forecasts, at the Basin Forecast Center from Siret Water Basin Administration, is used the DESWAT RFS program, which has been customized for use in Romania and is a part of the larger DESWAT Hydrological Forecast Modeling System (HFMS). The RFS consists of interrelated software and data components for performing a wide variety of hydrologic and hydraulic functions. The RFS is run under the Linux operating system on a workstation platform and it is connected to the DESWAT Database Management System (DBMS) the National Institute of Hydrology and Water Management from Bucharest. The RFS user interacts with the databases to generate a forecast by using a series of programs that run through scripts. The models used in the RFS are conceptual deterministic models, which require mean areal precipitation (MAP) and mean areal temperature (MAT) as inputs for simulation of snow accumulation and ablation, soil moisture and runoff, and downstream routing of stream flow. Reservoir operations models in RFS also are available for simulating single reservoirs or network systems of reservoirs and channel control.

When preparing to make a forecast it is important for the forecaster to understand the previous performance of the hydrologic model and the meteorological and hydrologic conditions, which influence the forecast period. To assure the best forecast possible, several items must be reviewed at the beginning of the forecast process. The forecasters should receive daily briefings from the ANM (National Meteorological Administration) meteorologists to review the meteorological conditions expected for the forecast period. This should also include a review of the forecasted meteorological conditions for the next five days. In addition to obtaining a forecast, the forecasters should review meteorological information on Hydro ThreatNet (HTN) or HydroNet Briefing Terminal (HBT), applications which show meteorological and hydrological information, to understand the weather conditions for the region that the forecast covers. The forecaster should review hydrologic conditions, including rivers in high flow, reservoir level, etc., from both the previous and present day. The forecaster should review the previous day’s forecasts to see what forecasts were previously given for the river. This should prepare the forecaster with the appropriate level of situational awareness for the present day’s operations.

When you open the program and the **IFP_Map** run starts, two windows appear: one is a geographic display of the area; and the other shows all of the Forecast Groups that are in Carryover Groups. To produce a graphical plot of the model outputs and observed data, a user must select **begin** in the IFP_Map File menu. This will run the Forecast Component using default setting for a number of options and will produce a plot of the resulting hydrographs.

A forecast run is started by selecting **begin** in the File menu. The Operation Table for the appropriate segments are run until a Tulsa plot Operation is found, at which time a graphical Tulsa plot and a Tultable are displayed (Figure 2).

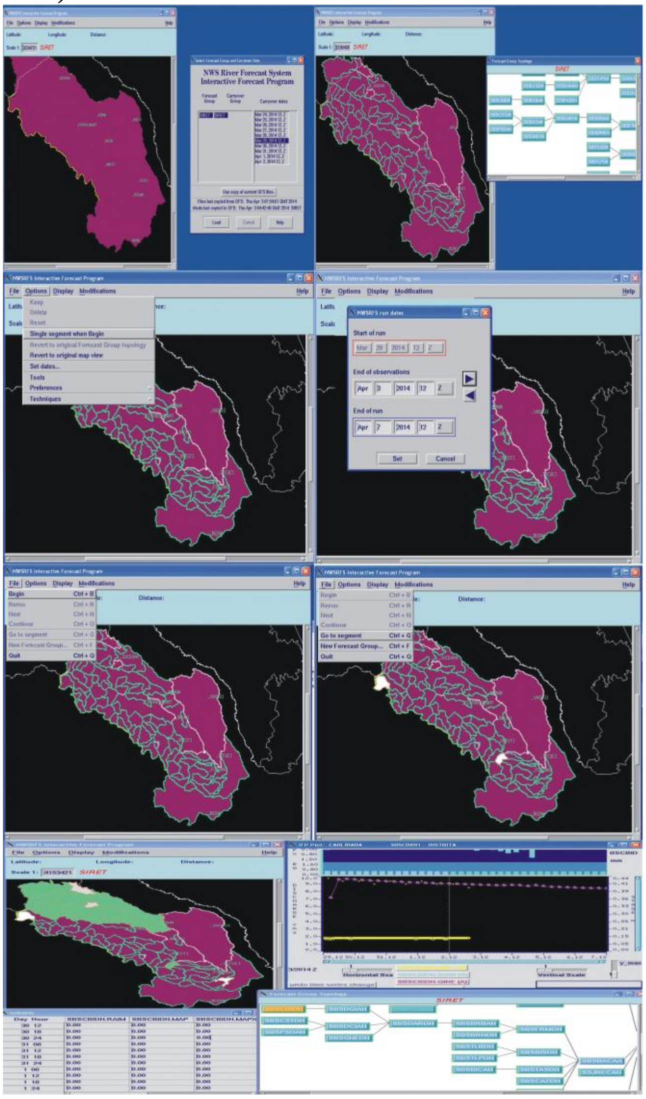

Figure 2. RFS interface. Steps in order to open the program.

The structure of the hydrometric points and the significance of the acronyms (Figure 2) in Bistrita catchment area are in the table below (Table 1):

Table 1. The hydrometric points corresponding to Bistrita catchment area

Hydrometrical station	River	COD RFS	Hydrometrical station	River	COD RFS
Carlibaba	Bistrita	S[1]BS[2]CBI[3]DH[4]	Frumosu	Bistrita	SBSFRMDH
Dorna Giumalau	Bistrita	SBSDGIAH	Tulghes	Bistricioara	SBSTLBDH
Cosna	Tesna	SBSCSTDH	Tulghes	Putna	SBSTLPDH
Poiana Stampei	Dorna	SBSPSDAH	Bistricioara	Bistricioara	SBSBISDH
Dorna Candreni	Dorna	SBSDCIAH	Bicaz Chei	Bistrita	SBSBICAH
Gura Negrii	Neagra	SBSGNEDH	Tasca	Bicaz	SBSTASDH
Dorna Arini	Bistrita	SBSDARDH	Cazaci	Tarcau	SBSCAZDH
Brosteni (Synthetic)	Bistrita	SBSBRBAH	Slobozia	Cracau	SBSSLODH
Brosteni	Bistrita	SBSBRNDH	Bacau II	Bistrita	SBSBACAA

[1]main collector name; [2]Bistrita catchment area; [3]acronyms for the hydrometrical stations from Bistrita catchment area;[4]DH-automatic hydrometrical station, AH-manual hydrometrical station, AA-manual station for reservoirs.

The Tulsa plot display contains three main plot areas (Figure 2 right corner down the figure):

- The top area is a plot of the precipitation time series. The information about the time and time series value may be obtained by selecting and holding the left mouse button while in the precipitation plot area.

- The middle plot is a plot of the runoff time series.
- The bottom plot is the plot of the hydrographs.

Besides the graphic form, the program also has a table form of the main input and output. The table has six columns as shown in the figure below (Figure 3):

Day Hour	SBSCBIDH.RAIM	SBSCBIDH.MAP	SBSCBIDH.MAPX	SBSCBIDH.SSTG	SBSCBIDH.MAT	SBSCBIDH.SWE	SBSCBIDH.QINE
31 12	0.00	0.00	0.00	0.42	5.91	0.00	9.36
31 18	0.00	0.00	0.00	0.42	8.14	0.00	9.32
31 24	0.00	0.00	0.00	0.42	0.19	0.00	9.27
1 06	0.00	0.00	0.00	0.42	-2.37	0.00	9.22
1 12	0.00	0.00	0.00	0.42	5.75	0.00	9.18
1 18	0.00	0.00	0.00	0.42	6.41	0.00	9.14
1 24	0.00	0.00	0.00	0.42	1.54	0.00	9.10
2 06	0.00	0.00	0.00	0.42	-0.08	0.00	9.06
2 12	0.00	0.00	0.00	0.41	2.58	0.00	9.03
2 18	0.00	0.00	0.00	0.41	2.59	0.00	8.99
2 24	0.00	0.00	0.00	0.41	-4.02	0.00	8.96
3 06	0.04	0.09	0.09	0.41	-2.02	0.10	8.93
3 12	0.31	0.21	0.21	0.41	5.70	0.00	8.93

Figure 3. The Tultable corresponding to each point from the catchment area

The significance of the column titles is the following: .RAIM – rain and melt values; .MAP – mean areal precipitation; .MAPX – radar mean areal precipitation; .SSTG – stage; .MAT – mean areal temperature; .SWE – simulated water equivalent; .QINE – discharge inflow.

The forecaster has to proceed through a series of making adjustments to a segment, rerunning and then moving to the next segment downstream in order to obtain a realistic forecast for the next 4 days and a tendency of the river flows for the next ten days.

The parameters that may be modified are: CHBLEND – used to adjust the number of periods used to calculate a blend from observed stream flow values into the simulated hydrograph; IGNORETS – sets the data types that are to be ignored (automatic or manual measurements); MFC – changes the melt factor correction value; RAINSNOW – sets whether precipitation during a period is rain or snow; ROCHNG – changes the runoff values; RRCHNG – changes the moisture input time series to a rainfall/runoff model; RRMULT – multiplies the moisture input time series to a rainfall/runoff model by a specified value; SACBASEF –modifies the Sacramento base flow runoff by a constant; SACCO – changes the Sacramento soil moisture carryover values; SETMSNG – sets values in a time series to missing; SWITCHTS – indicates that the secondary time series to be used as input; WEADD – adds the value of snow water equivalent for a specified date; WECHNG – changes the value of snow water equivalent for a specified date.

All these adjustments must be done daily by hydrologists in order for the program to work properly and to have as a result a realistic forecast.

When the user is finished with an IFP session, should select **quit** in the IFP_Map File menu the IFP will begin the shutdown process. Selecting **yes** the information will remain available for later use.

The information processed by the program can be visualized on the HydroNet Briefing Terminal application.

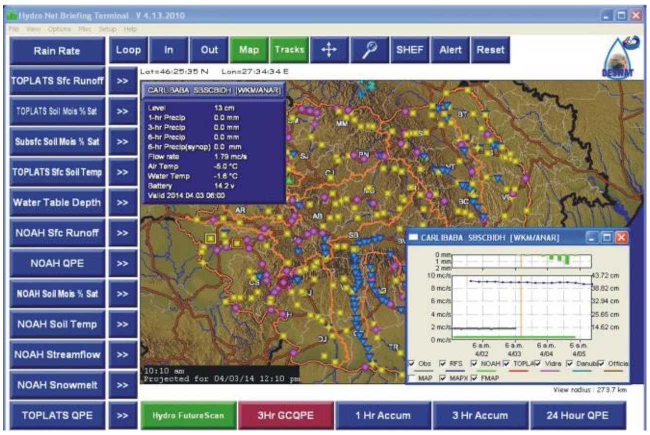

Figure 4. The HydroNet Briefing Terminal application interface

The HBT provides comprehensive real-time river, forecast and weather information in both textual and graphical formats for ready reference. The large buttons and limited pull down menu options enable the user to create any desired view of the weather because the data and mapping elements are flexible and not composed of pre-saved picture components. The HTN application is more complex than the HBT application and it provides real-time information. It can also signal when at a certain point the river overlaps the defense shares (the hydrological sign colors in yellow-defense, orange-flood or red-danger, depending on the overlapped defense share).

4.2 The simulation of a flash flood on Bistrita catchment

To show the usefulness of RFS program we run a simulation of a fictional flood on the main course of the river Bistrita. In the figure below are displayed the hydrographs for possible flash floods that could develop if a rainfall of 50 l/m^2 in an interval of 24 hours on a background of medium saturated soil is to be recorded.

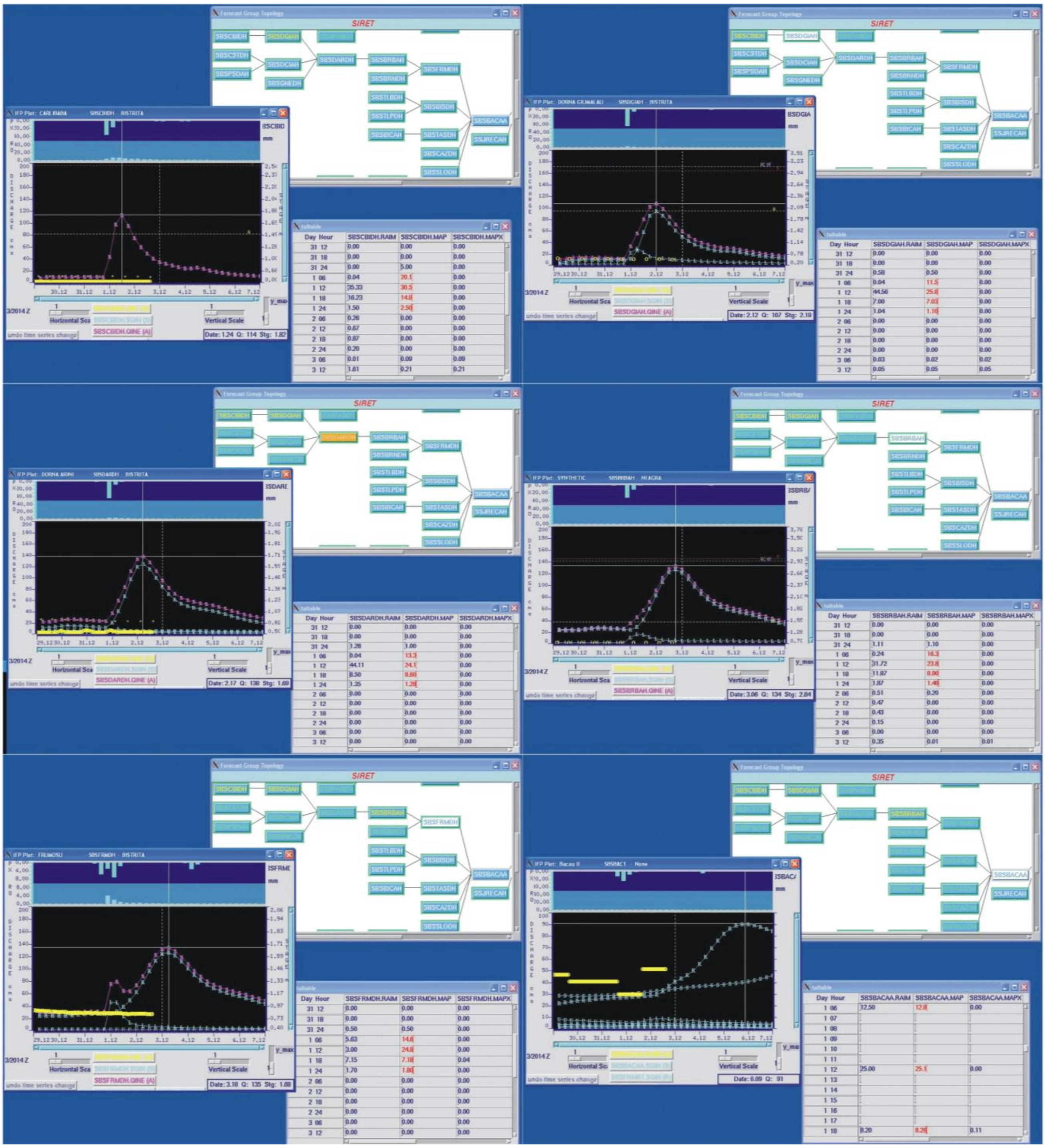

Figure 5. The evolution of the flash flood hydrographs at the hydrometrical stations from the main course of Bistrita catchment area: Carlibaba, Dorna Giumalau, Dorna Arini, Brosteni, Frumosu and Bacau II

Considering that the snow melt with approximately three weeks before carrying out the simulation and that there were no significant rainfall amounts up to that point, we may consider we have an average saturation of the soil the moment we simulated the flood. The quantities of accumulated precipitation (6 to 6 hours) and the total amount of precipitation accumulated per 24 hours, for each hydrometrical station, are in the table below.

Table 2. Registered precipitation amounts (6 to 6 hours and the total amount) at the hydrometrical stations along the main watercourse of Bistrita catchment area (l/m^2)

Time slot	Carlibaba	Dorna Giumalau	Dorna Arini	Brosteni	Frunzeni	Bacau II
06:00 am	15.0	11.5	13.0	16.3	14.6	12.8
12:00 am	25.0	25.8	24.0	23.8	24.8	25.1
06:00 pm	10.0	7.0	8.5	8.9	7.2	8.2
12:00 pm	2.0	1.1	1.3	1.4	1.7	1.3
total	**52.0**	**45.4**	**46.8**	**50.4**	**48.3**	**47.4**

In Figure 5 are represented the flood hydrographs and their evolution depending on the amount of rainfall and propagation time slot from one hydrometrical station to another. We see that an amount of rainfall of about 50 l/m^2 leads to water flows that exceed 100 m^3/s at all hydrometrical stations. We can also see that all hydrographs from each station outdated the defense shares (some only the defense share, other also the flood share, but none passed the danger share). We can observe that the program run correctly the input data, because the maximum flow can be found at the hydrometrical point downstream. The time slots are also correctly calculated according to the surface of the basin.

Based on this information can be conveyed warnings in order to take the necessary measures to avoid disasters. The advantage of this program is that it runs real-time data, which helps us react quickly and take action.

5 CONCLUSIONS

In conclusion, the effects of the floods are complex and are always so dependent upon the vulnerability of the area and poor development strategies put into practice in the hydrological basin of Siret and implicitly of the Bistrita River basin. In order to achieve relevant hydrological forecasts we need to ensure a fair weather background, so a close collaboration between meteorologists and hydrologists is obligatory. At Siret Water Basin Administration, the Bureau of hydrology works 24 hours a day in order to get precise analysis of the hydrological regime and to improve the quality of life of people. The modernization of the Forecast Center by purchasing instruments and software for analysis and forecasts lead to performance in this field. The RFS (River Forecast System) program, even if for the moment it is an experimental program, provides important information, especially in the periods with heavy rains, which lead to flooding. The actual life saving, the protection of properties, natural resources and the environment are only a few direct consequences of forecasts and warnings made by Hydrology Forecast Centre.

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