Conference Paper, Published Version

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Feasibility of a flash flood forecasting service

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***Abstract*— The feasibility of a flash flood forecasting service has been investigated for the Gardon river. This mission is part of the FP7 project SAFER [1] (Services and Application For Emergency Response) and consists in integrating real-time meteorological data such as rainfall and runoff into a numerical model of river flow. Aim of this mission is to create forecasting inundation maps to make easier decisions and intervention of civil protection.**

The methodology developed has to be easily transposable from one watershed to another and has to deliver a final product operational.

Thus, we present here general functioning of forecasting service and the new methodology with TELEMAC-2D to answer at mission needs.

I. INTRODUCTION

In some areas such as the Cevennes in France (Fig. 1), intense rain events and the specific configuration of watersheds create the phenomenon of flash flood. In France, especially during the flood of the Gardon River in September, 2002 [2], more than 800mm have been measured in two days in some place. This event has caused important damages:

- 13 deaths,
- an economic damage of 1.2 billion euros.

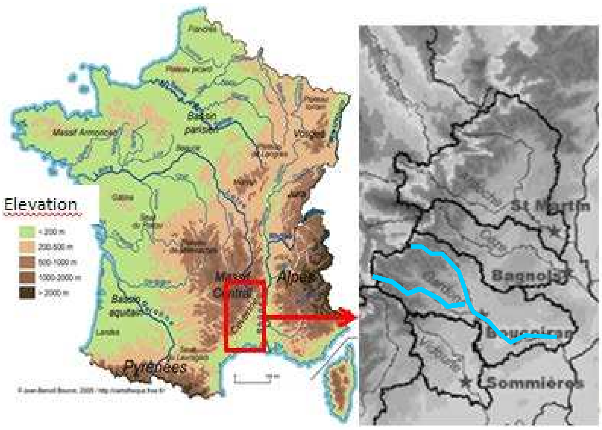

Figure 1. Gardon river location.

To protect the area against this terrible phenomenon, a feasibility of a flash flood forecasting chain has been implemented and validated on the Gardon river. This chain aims at creating inundation maps (Fig. 2) to assist final users (civil protection organisms, NGO...) in making decisions and in making easier interventions.

Figure 2. Example inundation map.

To carry out this mission, a partnership with Météo France (French meteorological service) and Spot Image (satellite picture and map making service) was established. Météo France was responsible for providing rainfall and runoff data which can be downloaded from a website created by Spot image. Spot image was responsible for publishing forecasting maps of the inundation areas.

This paper presents the different steps which have conducted to realize forecasting inundation maps since the reception of data from Météo France forecasting chain [3]. These tasks were performed with TELEMAC-2D and especially with the hydraulic model of the Gardonnenque plain of the Gardon River [4]. The lateral watershed was added to this model, to predict flow coming out from the watersheds as Meteo France forecasting chain cannot provide flow in the outlets of the watersheds. The final mesh covers the whole Gardonnenque plain (Fig. 3).

Figure 3. Presentation of the Gardonnenque plain and the lateral watersheds.

The final model is a mesh containing 19589 nodes. The mesh size varies from 40 meters in stream to 300m in lateral watersheds (Fig. 4).

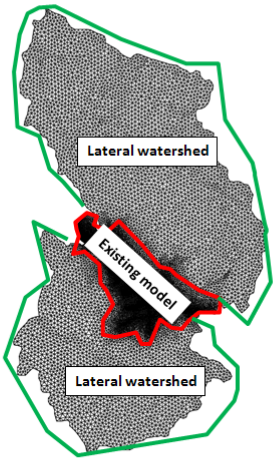

Figure 4. Gardonnenque plain model.

To take into account the contributions of the lateral watersheds it was necessary to perform rainfall/runoff transformations. That is why we decided to use TELEMAC-2D. This choice is explained in the third paragraph.

The development of a forecasting service with TELEMAC-2D implies two main challenges:

- integration of data from Météo France forecasting chain, and
- completion of rainfall/runoff transformation inside TELEMAC -2D.

This paper presents the approach used for both points.

II. Integration of Real-Time Data

A. General presentation

The first element used to perform integration of real-time data is a program which runs all the time and tests the FTP site (exchange data site) to check if new data are uploaded by Météo France (1, Fig. 5). If in the forecasted data the script detects an important value of runoff, then:

- Data are duplicated in a directory (2, Fig. 5) and used to launch a TELEMAC-2D simulation.
- A hydraulic model is launched automatically by the script (3, Fig. 5).

Then TELEMAC-2D [5] is used to calculate depths and vertically-averaged horizontal velocites in the Gardonnenque plain. At the end of each hour simulated, we provide a result as TELEMAC-2D (4, Fig. 5). Only depths and vertically-averaged horizontal velocities are in the result file. This file is then treated to realise inundation maps.

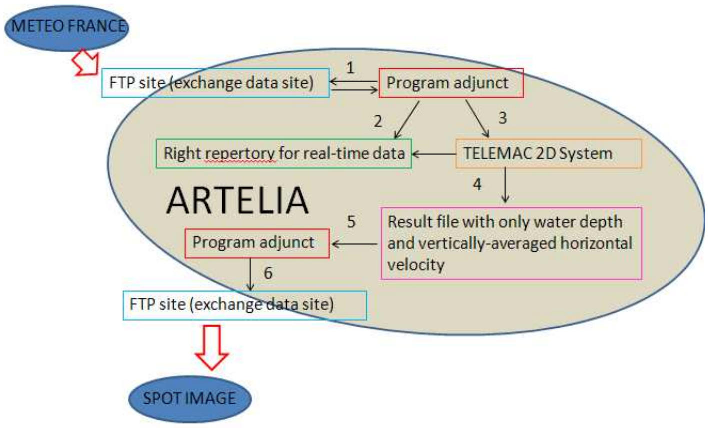

Figure 5. Description of real-time forecasting chain.

The integration of data in real time asked a significant modification of TELEMAC-2D programs such as the creation of the final file each hour simulated. The program designed to launch simulation is also used to publish result file on the FTP site. (5 and 6, Fig. 5).

B. Integration of forcasted runoff and rainfall

1) Integration of forecasted runoff: Integration of runoff is made using an existing program of liquid boundaries file. In our case, one simulation models 30 hours of runoff. Runoff is updated every 6 hours and flood may last several days. It means that 4 simulations are run per day. Generally flow lasts between 2 and 4 days. Thus we have to anticipate c. 16 successive simulations.

Most of the time forecasted flow data from Météo France are very different for the same date from one simulation to the next (examples in Figs. 6 and 7).

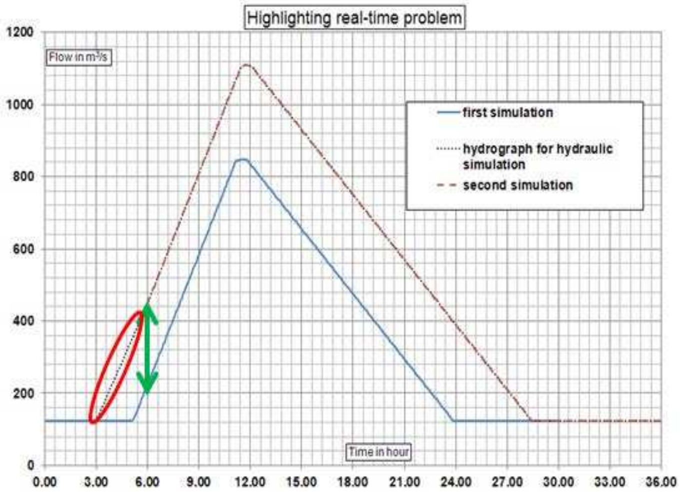

Figure 6. Flow data from Météo France for two different simulations.

Forecasted flow for hydraulic simulation has the most important part concerning calculation of water level in the Gardonennque plain. It causes problem particularly when the initial flow of the next simulation (Simulation 2 in Fig. 7) is different of the sixth flow of the previous simulation (Simulation 1 in Fig. 7) for the same date. Indeed there is an important gap of flow (green arrow Fig. 6) and consequently of volume. Volume variable is very important in our case to make inundation map.

In order to avoid comitting this error we have chosen making a linear interpolation between the third flow of previous simulation and the first flow of next simulation (red circle Fig. 6). The third flow of the first simulation was selected because this flow comes from observed rainfall and first flow of second simulation two.

Simulation 1 11/03/2011 18:00		Simulation 2 11/04/2011 00:00		
Time	Flow (m3/s)	Time	Flow (m3/s)	
03/11/2011 18:00	189.034	**04/11/2011 00:00**	**398.01**	Flow from observed rainfall
03/11/2011 19:00	231.494	04/11/2011 01:00	511.46	
03/11/2011 20:00	269.861	04/11/2011 02:00	586.084	
03/11/2011 21:00	289.986	04/11/2011 03:00	584.847	Flow from forecasted rainfall
03/11/2011 22:00	305.711	04/11/2011 04:00	496.567	
03/11/2011 23:00	334.301	04/11/2011 05:00	375.848	
04/11/2011 00:00	**370.151**	04/11/2011 06:00	322.406	
04/11/2011 01:00	488.855	04/11/2011 07:00	310.087	
04/11/2011 02:00	542.69	04/11/2011 08:00	284.857	
04/11/2011 03:00	471.576	04/11/2011 09:00	273.162	
04/11/2011 04:00	388.304	04/11/2011 10:00	227.973	
04/11/2011 05:00	316.569	04/11/2011 11:00	221.879	
04/11/2011 06:00	288.304	04/11/2011 12:00	237.913	

Figure 7. Flow data values from Météo France for November 2011 event.

2) *Integration of forecasted rainfall:* Forecasted rainfall has been modelled like source point. Rainfall data is in the form of a grid in which each value is a georeferenced data of rain. The five first lines of data file give information for geo-referencing.

Rainfall data are provided on a regular grid and are interpolated over the irregular TELEMAC grid. Formula used for interpolation is based on the inverse of distance. Interpolation has been restricted to four rainfall data. Thus the formula used is the following (1):

$$R_{mesh} = \frac{\left(\frac{R_{data1}}{D_{data1-mesh}} + \frac{R_{data2}}{D_{data2-mesh}} + \frac{R_{data3}}{D_{data3-mesh}} + \frac{R_{data4}}{D_{data4-mesh}}\right)}{\left(\frac{1}{D_{data1-mesh}} + \frac{1}{D_{data2-mesh}} + \frac{1}{D_{data3-mesh}} + \frac{1}{D_{data4-mesh}}\right)} \quad (1)$$

R is the abbreviation for rainfall. R_{mesh} is rainfall to apply to one node of model. R_{datai} represents the four rainfall data nearest to one computation node. D is the abbreviation for distance between considered computation node and the four rainfall data nearest.

This formula is applied to give rainfall data for each computation node. Soil conservation Service (SCS) Methodology [6] has been used to perform transformation between rainfall and rain which contributes to runoff. Rainfall data are also updated every 6 hours. Météo France forecasting chain simulate 30 hours rainfall for one simulation. Meteo France also provides rainfall data recorded by a network of rain gauges 15 minutes after the hour which just happened. Fig. 8 shows the location of different input data in the Gardonnenque plain.

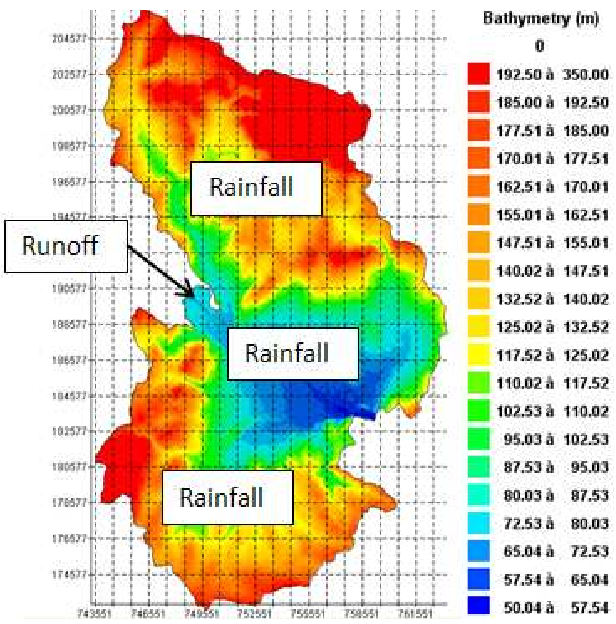

Figure 8. Localisation of flow and rainfall injection.

III. Rainfall/Runoff transformation

A. Choice of TELEMAC-2D

Several possibilities have been considered to perform rainfall/runoff transformation. The aim of this study is to find a methodology which can be transposed from one watershed to another. That's why using of classic hydrological model is not interesting. Indeed, these models often take a long time to be calibrated because they depend on too many parameters. TELEMAC-2D depends only on two parameters:

- 1 hydraulic parameter: Strickler coefficient which represents soil roughness, and
- Curve Number (CN) which is the rainfall/runoff transformation of SCS methodology.

The new concept is to use TELEMAC-2D to make rainfall/runoff transformation. Alès watershed has been defined to perform tests. Two past events have been chosen to calibrate and validate the new methodology.

B. Preliminary tests

1) Mass conservation: We have tested two different options of tidal flats to see if rain volume was conserved in the model.

First option solves Barré-De-Saint-Venant equations everywhere and applies a correction for element considered as tidal flats.

In the second option, processing is done in the same way as in the first case, but a porosity term is added to half-dry elements. Tests consist to inject rainfall in Alès watershed divided into 6 subwatersheds.

Then, we compared rain injected and volume collected at each red point (Fig. 9) for both option. Volume takes into account the flow that has passed through the outlets (red dots) and standing water in the sub-watersheds (Fig. 9).

Results are given Table I. The first option gives the smallest error on mass conservation. This option will be kept for the other simulations.

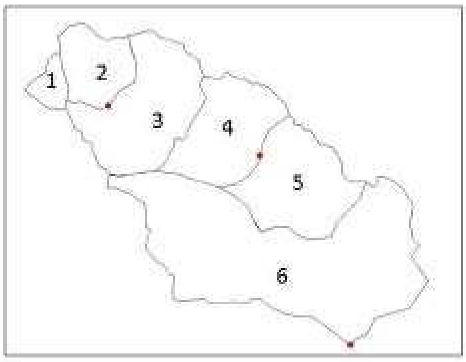

Figure 9. Outlets (red dots) for mass conservation test.

TABLE I. Results Synthesis for Mass Conservation Test

	Subwatersheds 1 and 2		
	rainfall volume injected	volume calculated at outlet	errors in percent
Option 1	**4.91 Mm3**	**5.35 Mm3**	**8.90%**
Option 2	**4.91 Mm3**	**0.78 Mm3**	**84.00%**
	Subwatersheds 1,2,3 and 4		
	rainfall volume injected	volume calculated at outlet	errors in percent
Option 1	**20.49 Mm3**	**21.11 Mm3**	**3.00%**
Option 2	**20.49 Mm3**	**10.47 Mm3**	**49.00%**
	Whole Alès watershed		
	rainfall volume injected	volume calculated at outlet	errors in percent
Option 1	**55.42 Mm3**	**53.95 Mm3**	**2.70%**
Option 2	**55.42 Mm3**	**42.90 Mm3**	**22.60%**

2) Mesh and hydrograph propagation: We defined several meshes to define a compromise between accuracy and computational speed. Tests have been done to see if a simplified geometry (Fig. 10) can properly propagate the flood wave. Indeed, generally the hydrograph propagation is better when the stream geometry is the closest to the reality (Fig. 10).

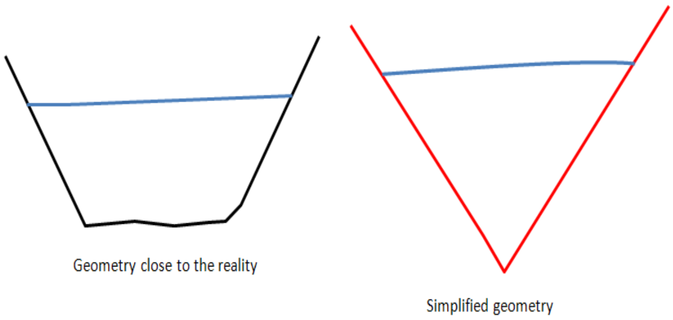

Figure 10. Geometry used for simulation.

We have compared TELEMAC-2D propagation time with MASCARET 1D [7] model for the simplified geometry. Triangular mesh of TELEMAC-2D is done with only one wet node in a cross section (Fig. 11). The propagation test is done in a channel of 3700m long and the slope is 0.006.

Results of this comparison show that TELEMAC-2D can correctly propagate with a simplified geometry (Fig. 12).

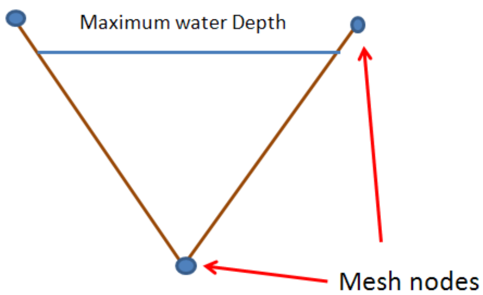

Figure 11. Triangular cross section used.

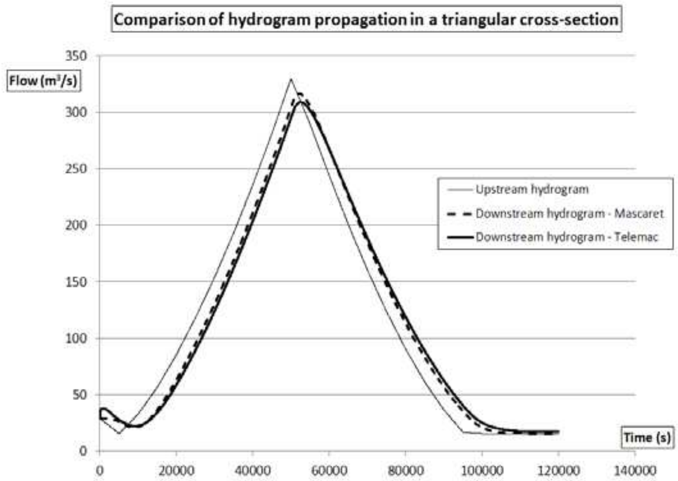

Figure 12. Comparison of propagation time between TELEMAC-2D and MASCARET 1D.

The second test for propagation permits to evaluate if simplification of geometry leads to important errors concerning propagation time. We have compared propagation time with TELEMAC-2D between a real geometry and a very simplified geometry. Test has been performed with the same channel length than in the previous test. Cross sections are obviously the same as the cross sections on Alès stream. Several hydrographs with different peak flow were tested and the channel slope was changed.

We can observe (Fig. 13) that time propagation is quite different for flows non-overflowing (until 40% of lateness). Fortunately for high flow the error is considerably reduced (10% early). The methodology developed here is used for very high flows, which explains this result. Moreover, steeper is the slope, the less significant is the difference in propagation time.

In Alès and lateral Gardonnenque watersheds slopes are steep and flows are high.

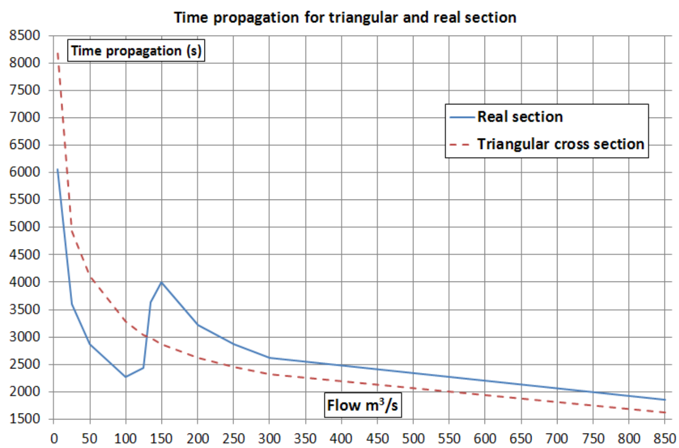

Figure 13. Comparison of propagation time between real geometry and simplified geometry.

Tests have shown that TELEMAC can perform correctly rainfall/runoff transformations. Simplification of geometry for watersheds with steep slopes allows having good propagation of peak flow compared to real cross section. However the flow studied must be overflowed. This methodology can be applied on the Alès watershed.

C. Calibration and validation on Alès watershed

1) Calibration: Simplified stream geometry is applied to the Alès watershed. Mesh size is 300m to reduce computational time. Calibration was done according to:

- Hydrograph volume
- Peak flow value
- Peak flow time

Then, we have compared these 3 points between observed values and simulated values.

To obtain the final calibration (Fig. 14), the parameter used to perform rainfall/runoff (CN) wad set at 35. This value means that soil was dry before rainfall event.

The only hydraulic parameter is the Strickler coefficient (which represents soil roughness). To manage calibration, values were set to 50 for overland flow and 35 for stream flow. We have used a high value of Strickler coefficient to represent small drains and gullies that are not represented mesh size of 300m.

A comparison between measurement and modelled flows shows a good agreement (Table II).

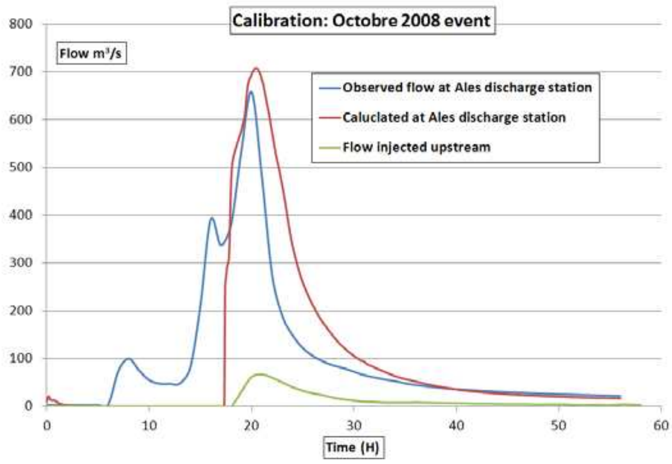

Figure 14. Calibration results.

TABLE II. CALIBRATION RESULTS

	Measured	Calculated	Error (%)
Hydrograph volume	20.3	20.7	2
Peak flow (m^3/s)	658	708	8

	Measured	Calculated	Error (%)
Peak flow time (h)	20	20.5	<1

Next step is the validation for two different events.

2) Validation

a) November 2008 event : Validation on Alès watershed: This event happens just after the calibration event and consequently the soil was wet. According to the formula from SCS methodology with humid conditions CN was set up to 56. Hydraulic parameters were kept equal to the calibration parameters.

Concerning the hydrograph volume, 77.3 Mm^3 were measured and simulation give 76.4 Mm^3. The error made is 1%.

T the time of peak flow (Fig. 15), 493 m^3/s were observed compared to 441 m^3/s for the model (Error made =11%).

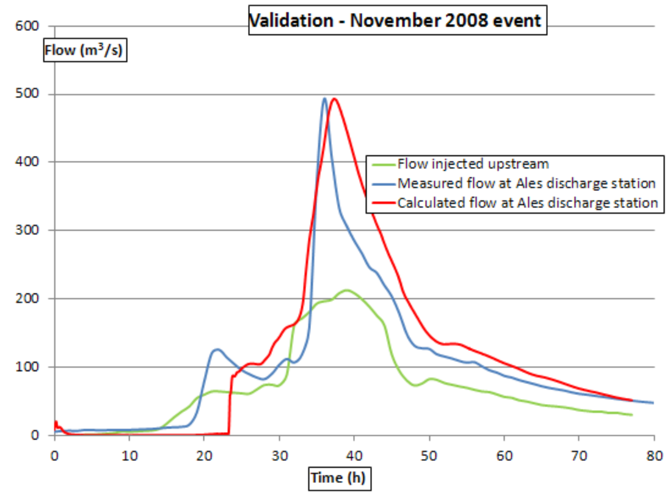

Figure 15. Validation results.

Peak flow time is also well respected. The error made is only 3% (37.00h measured against 38.25h calculated).

Results from first validation are very satisfactory and encouraging. Moreover calculation time is very low. A simulation of 50hours on the Alès watershed takes 1 hour.

b) September 2002 event: validation on the whole Gardon watershed: September 2002 is a historical event because the surface of impact was approximatively 5000 km². Small rainy event happened before the studied event. According to the SCS methodology, soil was humid. CN was set up to 56.

Results from this validation are also very good for this bigger area (Fig. 16). The rainfall/ runoff transformation and the flood propagation runs well with TELEMAC-2D.

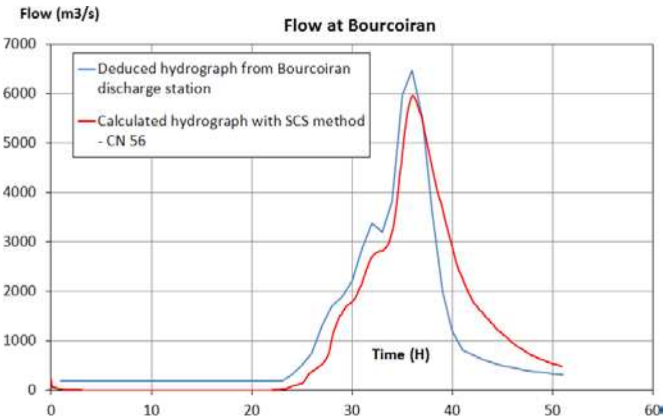

Figure 16. Validation on the whole Gardon watershed.

IV. REAL-LIFE TEST FOR THE FLASH FOOD FORECASTING CHAIN

At the time of November 2011 event (1-7 November) we had possibility to test the whole forecasting chain service.

Indeed, during these 6 days rainfall reached from 600 to 700mm and even more (until 900 mm) in some location. This event engendered a flash flood and caused some damage.

Test has been realized since 3rd of November at 18 hours until 4th of November at 18 hours. Forecasted rainfall and runoff were updated every 6 hours. Consequently 5 simulations with TELEMAC were performed (Fig. 17).

We can observe (Fig. 17) that from simulation to simulation there is an important difference. Curve with continuous black line represents flow obtained with observed rainfall until 4th of November at 18 hour and later it is only prediction.

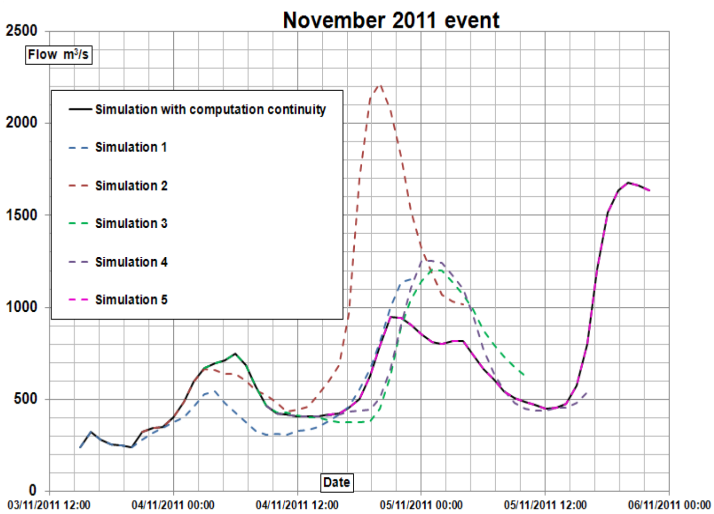

Figure 17. Simulation of November 2011 event.

During this test, beyond results, the main preoccupation was to observe if all the flash food forecasting chain runs and specially the transition between the three partners.

However, the main problem is the calculation time of forecasting chain. Indeed Météo France needs 5h30 of calculation to supply us with hydro meteorological data. Then 2h are necessary to simulated 33h of simulation with TELEMAC-2D.

Thus, computation time lasts about 8 hours. Consequently 8 hours have already happened and we can predict for only 22 hours. It means that we have to begin calculation 1 or 2 days before rainy events to be sure to cover the rise of water level.

V. Conclusion

Realisation of a flash flood forecasting chain is now operational.

During SAFER project, improvements concerning tools used by all the partners have been performed. These improvements were crucial to manage this project. Concerning TELEMAC-2D, adaptations and conception of new methodology for rainfall/runoff transformation have allowed integrating TELEMAC-2D to the forecasting chain.

The Methodology developed here can be easily transposed to other watershed prone to flash food where spatial rainfall is available.

Several improvements could be done in order to optimize computation time. Especially with TELEMAC-2D, it will be interesting to parallelise the computational code to reduce the calculation time.

However, we have seen in the previous paragraph that from simulation to simulation results can be quite different. To avoid false alarm and make easier decisions of final users, it will be certainly interesting to do for each Météo France rain forecast a spatial statistic analysis to estimate the probability that forecasting occurs at a given area.

Acknowledgement

Thanks to CVMHO (Cévennes-Vivarais Mediterranean Hydro-meteorological) for rainfall and runoff data. We also acknowledge Spot Image for its contribution for this project.

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