



IMT Mines Alès
École Mines-Télécom

HSM HydroSciences Montpellier



Towards a better consideration of hydro-meteorological information for flash flood crisis management through machine learning models

Salma Sadkou, Guillaume Artigue, Noémie Fréalle, Pierre-Alain Ayral, Séverin Pistre, Sophie Sauvagnargues, and Anne Johannet



SUMMARY

Introduction

Material and
methods

Results

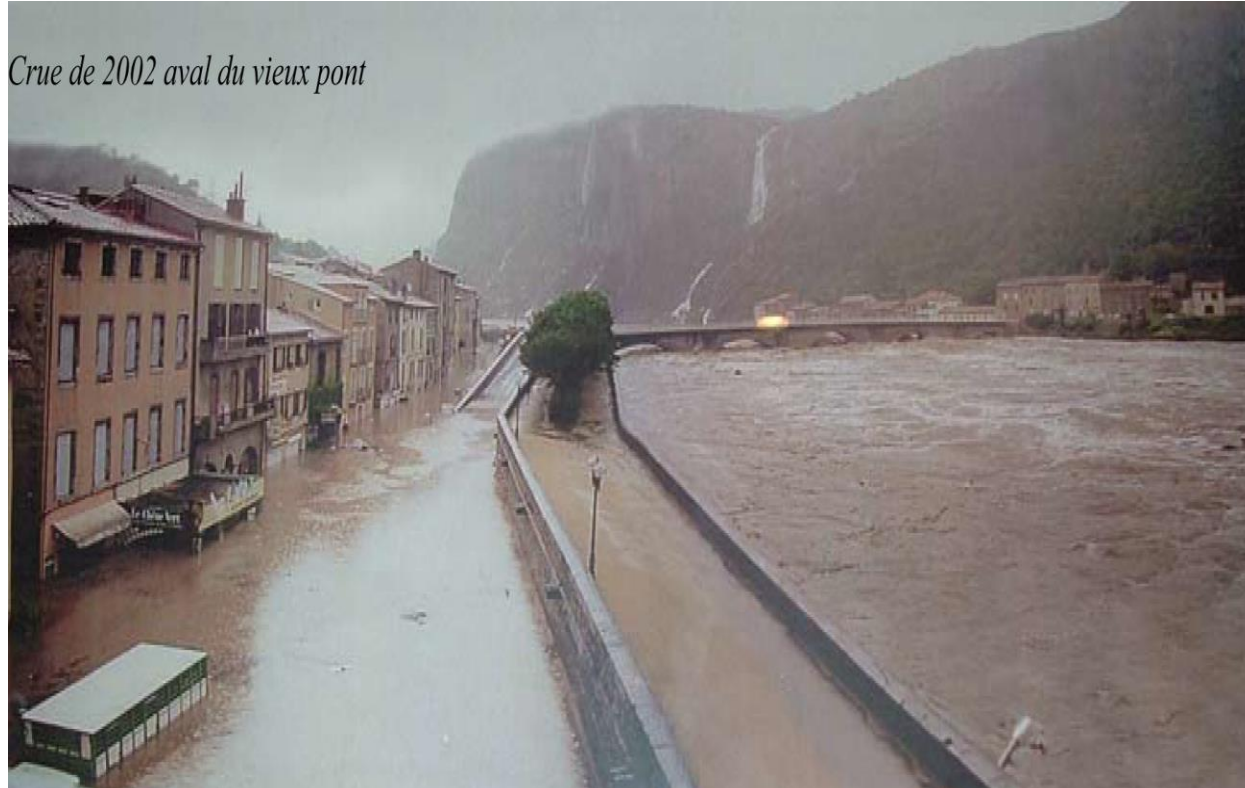
Analysis

Conclusion



Flash flood

Flood of short duration with a relatively high peak discharge (WMO & UNESCO, 2012)



Crue de 2002 aval du vieux pont

Flash flood event in Anduze, Gard, France – September, 2002
(Bianciotto, 2005)

Stakes

Human toll: 250 deaths in France 1988-2015 (Vinet et al., 2016)

Economic toll: e.g. Gard in 2002: 1.2 billion € in damages

Crisis management (CM) in France

Conducted by the municipality

Using a Communal Safeguard Plan (CSP)

Issues

- ▶ Forecasters and managers work separately
 - ▶ CSP is not based on discharge
 - ▶ Managers use criteria like: threshold exceedance, vigilance and alert
- Forecast bulletins need to be tailored to the managers needs to improve decision making
- ▶ **Objective of the study:**
Define the needs of the managers in terms of presentation and content of bulletins

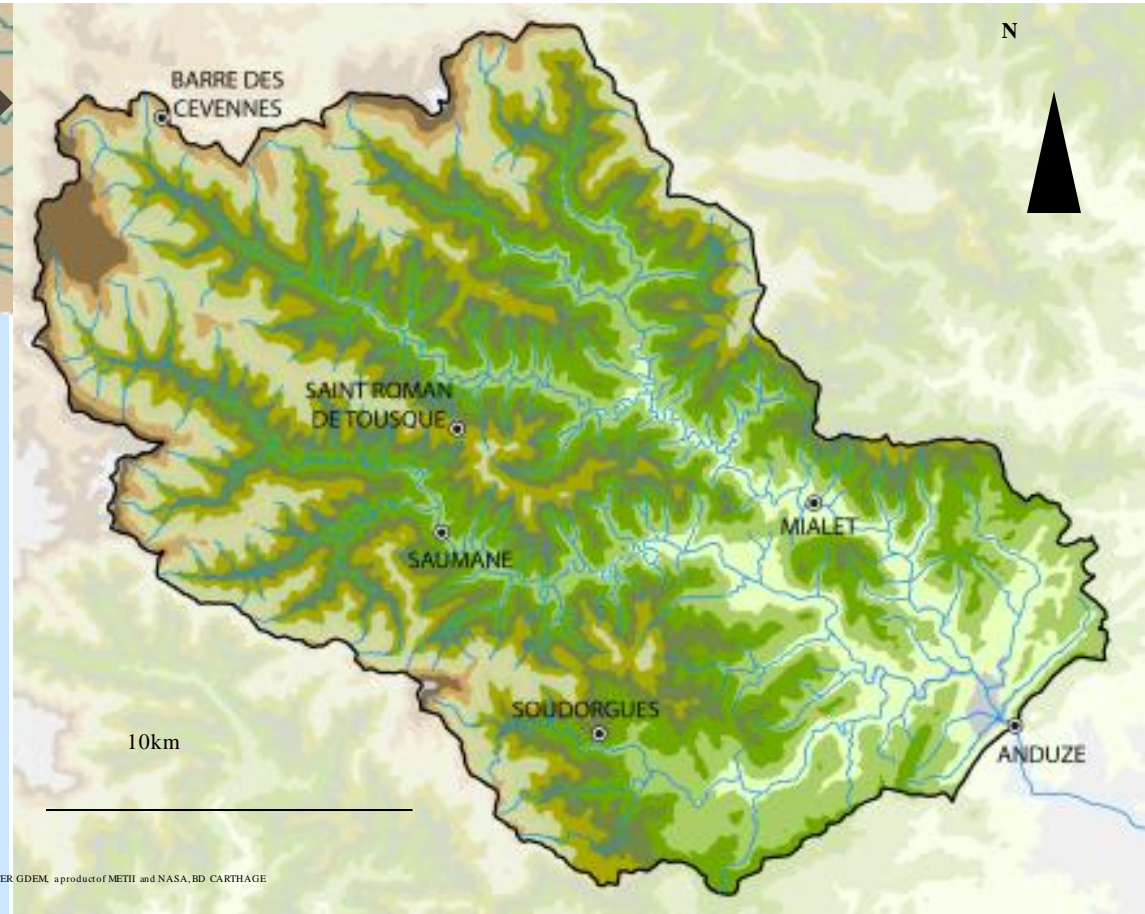
MATERIAL AND METHODS

Studied site and database

Watershed of Gardon d'Anduze

- ▶ Provided by SPC* Grand Delta
- ▶ Rainfall at 6 raingauges, water level and discharge in Anduze
- ▶ Period: 01/06/2002 to 15/10/2019
- ▶ 25 events
- ▶ Time step: 5 min → ½ hour

* SPC (Service de Prédiction des Crues): Flood Forecasting Service



Organization and scenario

Crisis management exercise/simulation

Simulation of a major event based on a credible elaborated scenario. It allows crisis managers to practice and to test their skills, tools and systems. (Boin et al., 2004; Lagadec, 2001; Lagadec, 2012; Lapierre et al., 2015)

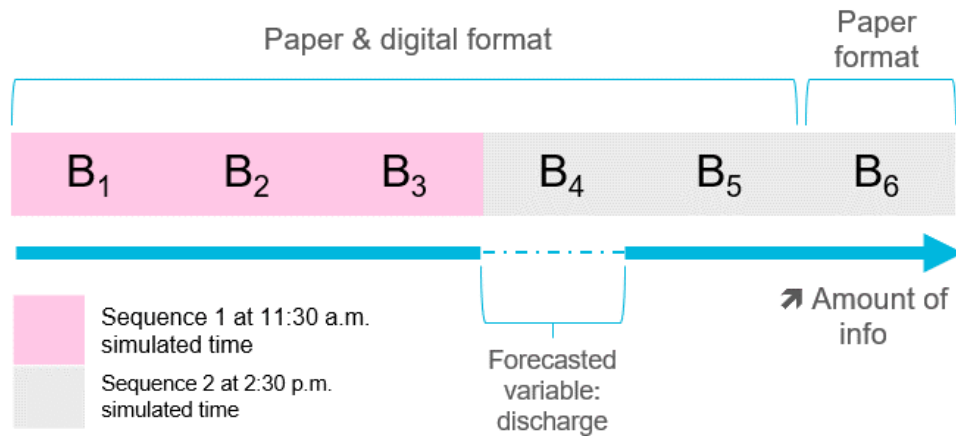
- ▶ Workshop elaboration inspired by the functioning of a crisis management exercise
- ▶ The workshop took place on: 27/06/2022
- ▶ The simulated date is: 05/09/2022
- ▶ Participants:
 - Group 1 (Anduze): the Mayor, the General Director of Services and two deputies
 - Group 2 (Alès): Major Risk Prevention professional assisted by a facilitator
- ▶ Follow-up: decision-records, surveys and observation sheets



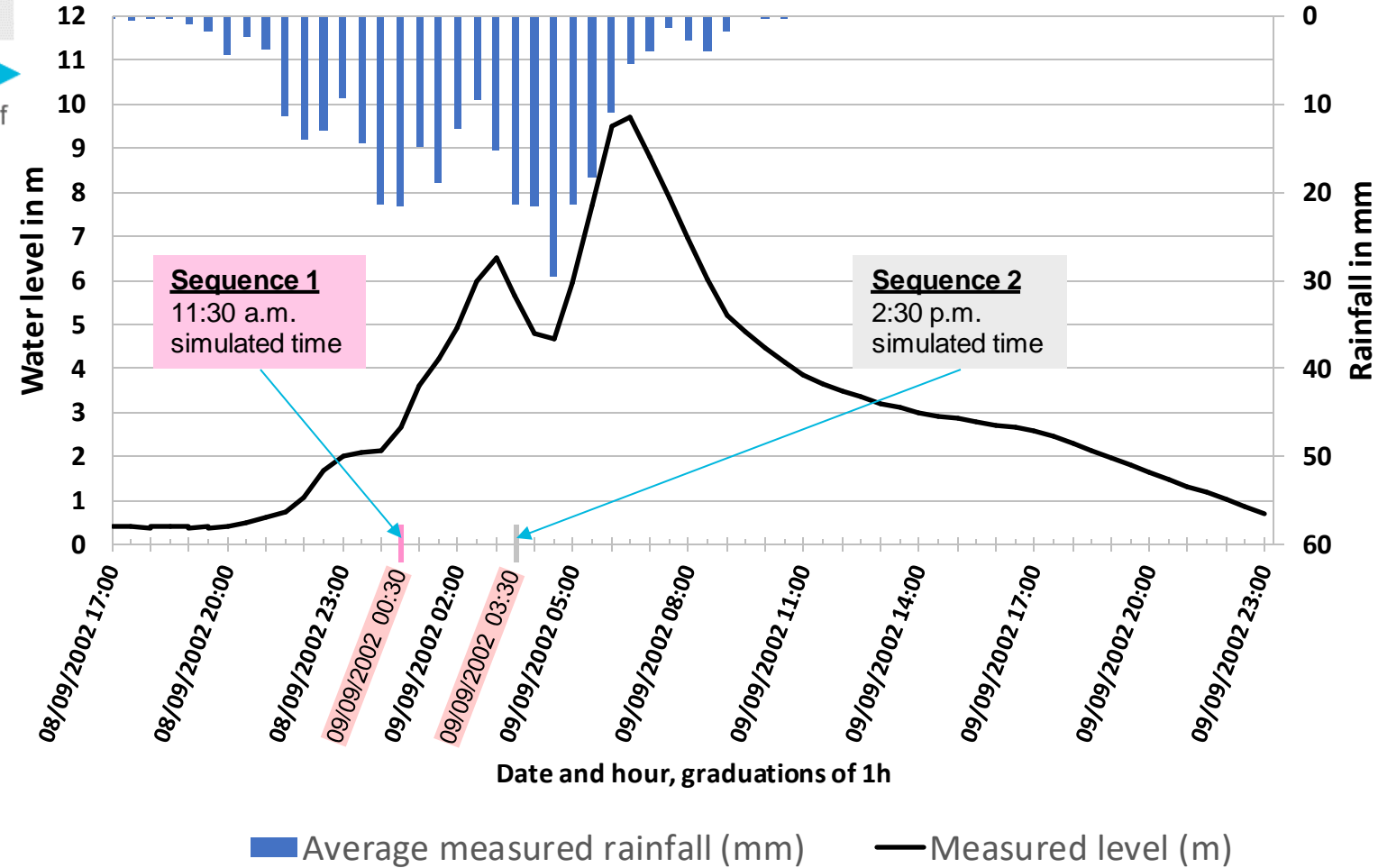
Workshop of bulletin evaluation in the city of Anduze on June 27th, 2022

MATERIAL AND METHODS

Scenario and organization



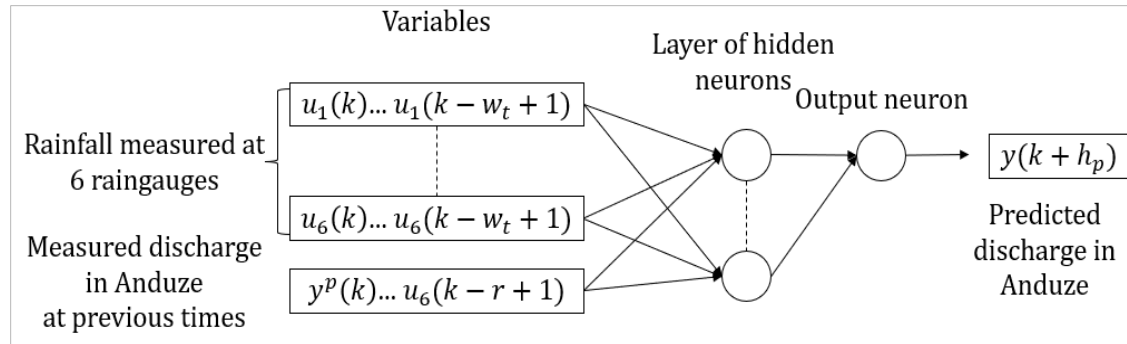
Observed flood hydrograph of September 8th and 9th, 2002 event



Bulletin conception: forecasting level and discharge

Forecasting discharge (Toukourou, 2009)

Bulletin 4



Feedforward neural network model for flow prediction

Model used in bulletins

- Linear connections added (Bornancin-Plantier, 2013)

$u_i(k)$: measured input at discrete time k
 w_t : temporal window
 h_p : forecasting horizon

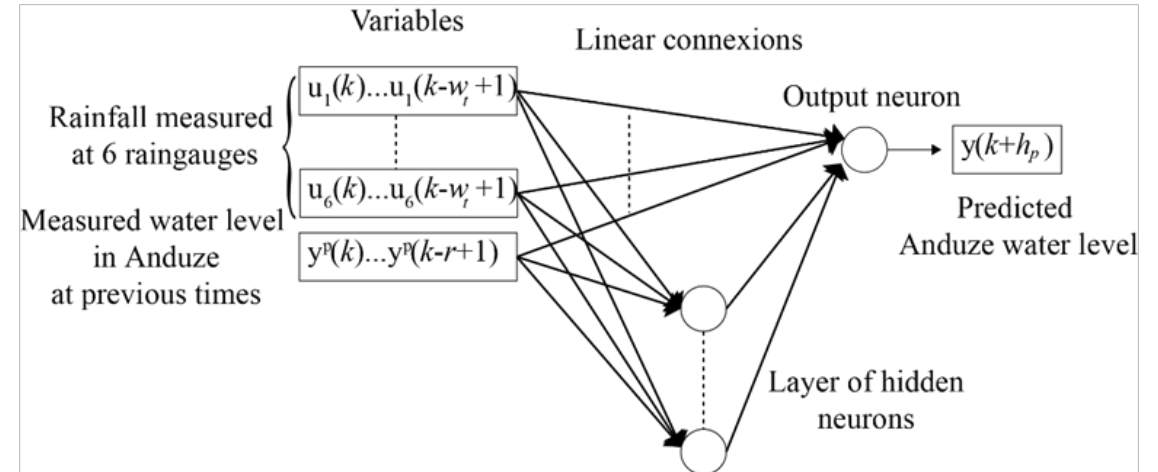
- Selected model

3 hidden neurons ; $w_t = 1.5$ hours ;
 $h_p = 3$ hours

r : model order
 $y(k + h_p)$: predicted output
 $y^p(k)$: measured output

Forecasting level (Bornancin-Plantier, 2013)

Bulletins 1,2,3,5,6



Feedforward neural network model for water level prediction with linear and non-linear connections (Bornancin-Plantier, 2013)

Model used in bulletins

- Updated database instead of previously used database (1994-2008)

- Selected model

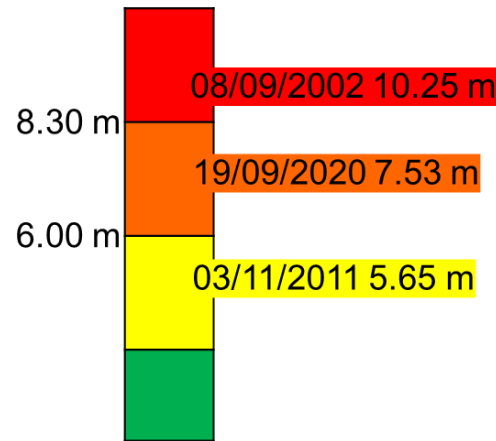
3 hidden neurons ; $w_t = 1.5$ hours ; $h_p = 3$ hours

MATERIAL AND METHODS

Bulletin conception : added data

Vigilance levels

(SPC Grand Delta, 2021)



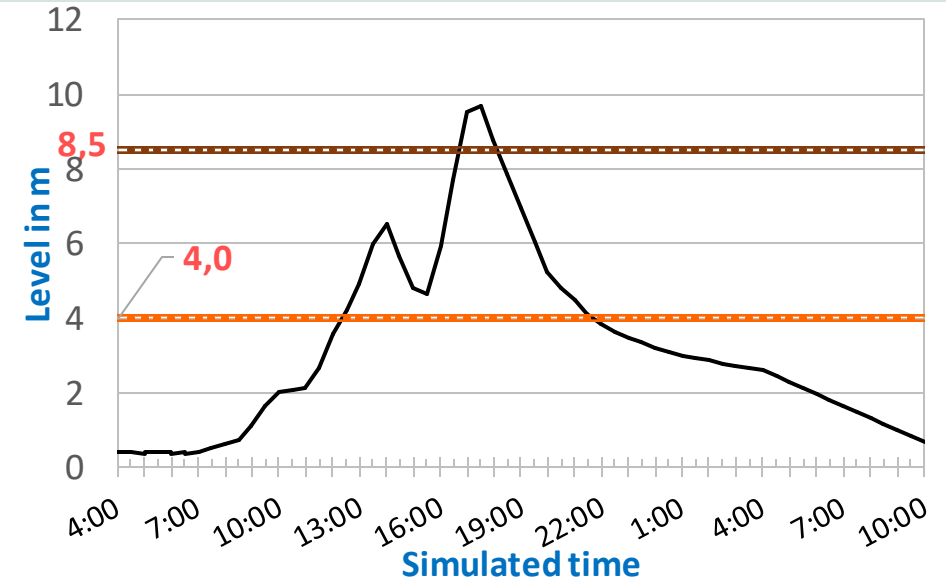
Thresholds

At 8.5 m

Inundation of plan de Brie (main city square)

At 4 m

Submersion of Noyé bridge (submersible bridge)



Measured level/discharge in upstream stations (Mialet & Saint-Jean du Gard))

Managers estimate 1h for discharge to travel from Mialet to Anduze

“forecasted” average rain

Manually randomized observed rainfall

Potential flood zone map

(Vigicrues, n.d.)

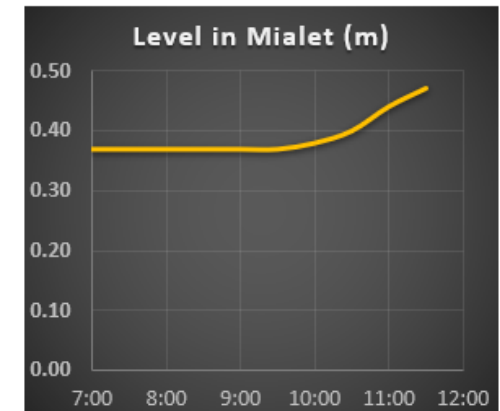
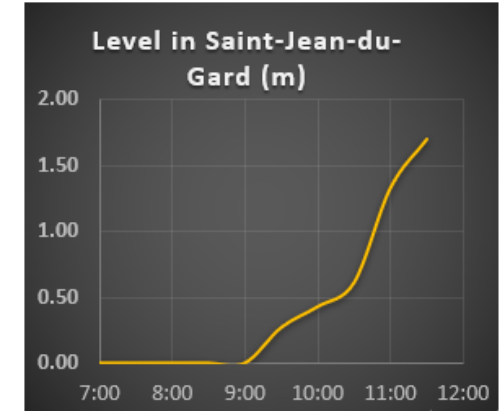
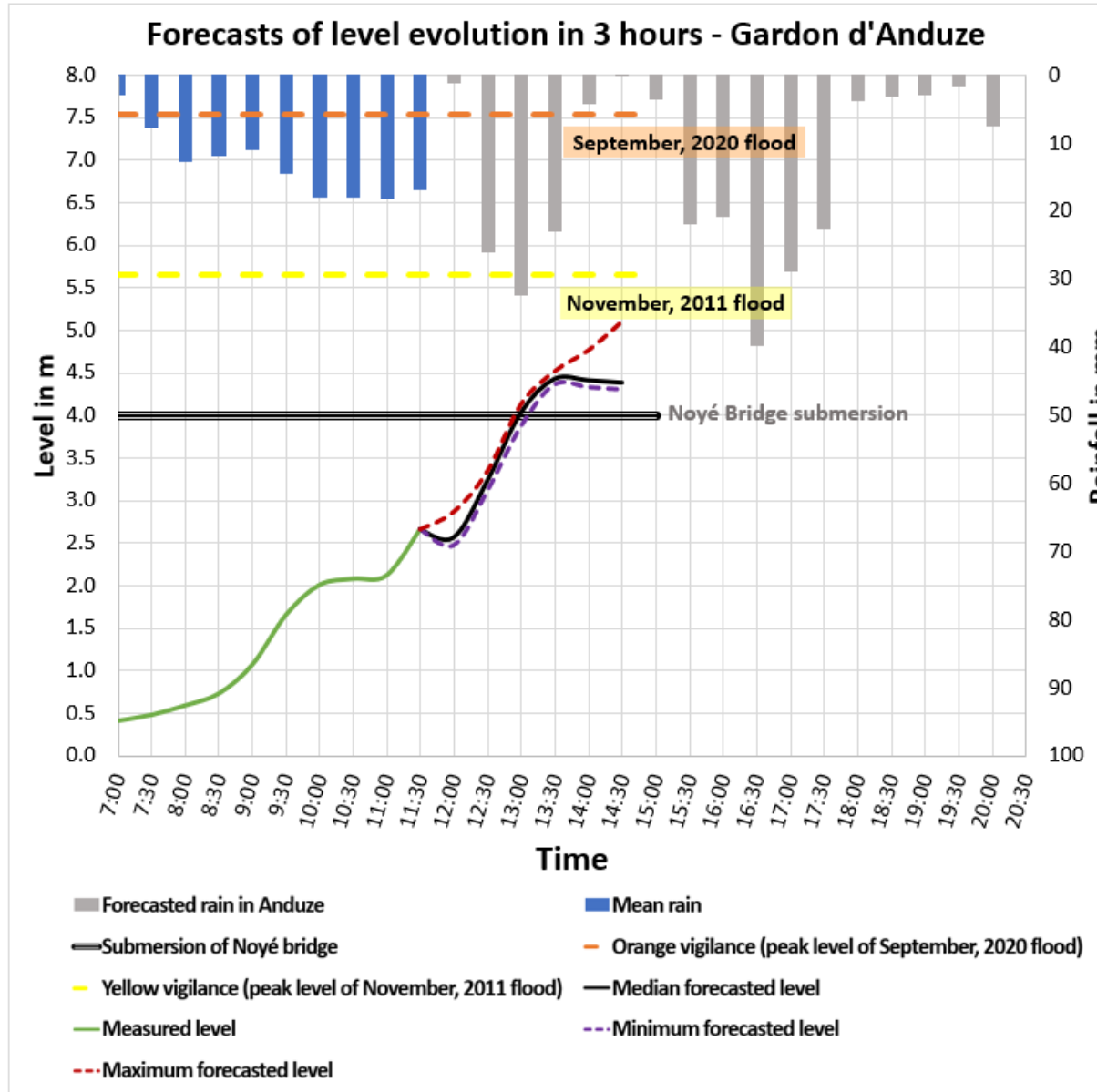
Based on the results of different models considering various hydrological and flow hypothesis

Sources: City of Anduze, SPC Grand Delta, Vigicrues and on the ground observations

RESULTS

Presented bulletin: an example

Bulletin 3



RESULTS

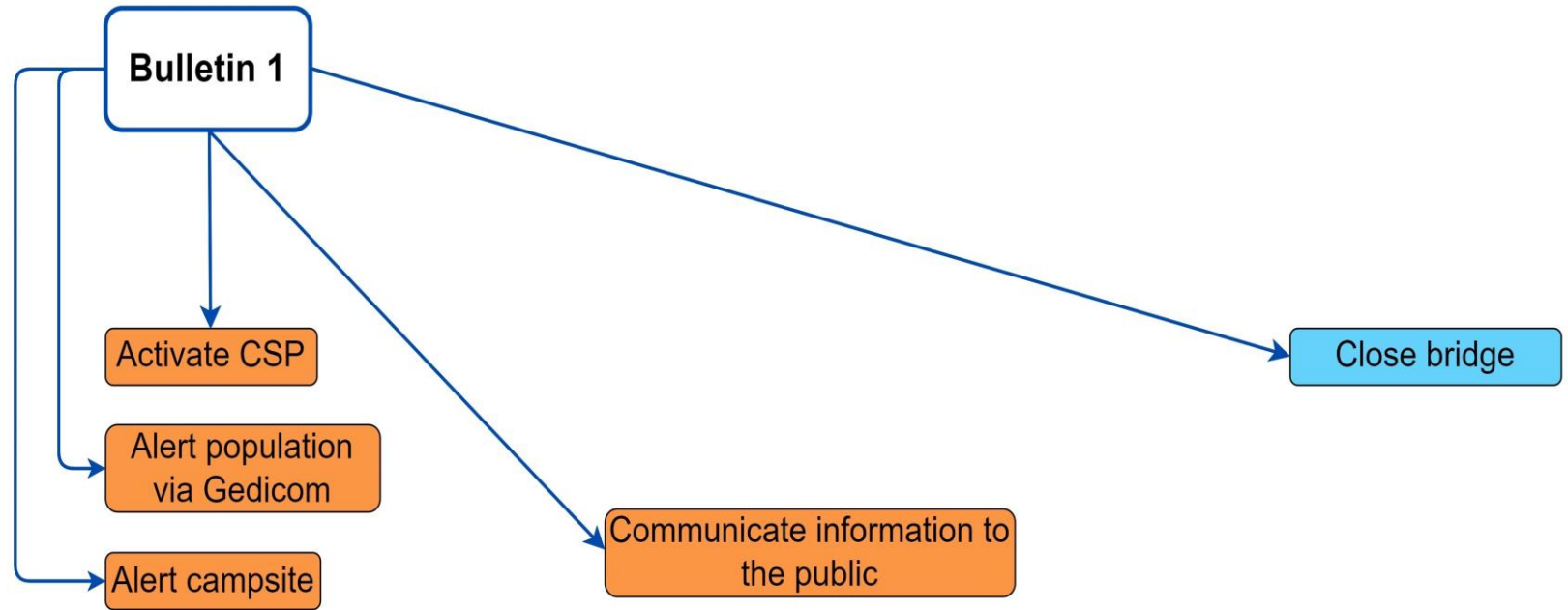
10

Decision records: sequence 1 (at 11h30-simulated time)

Bulletin	Added data
1	<ul style="list-style-type: none">• Measured level• Median, maximum and minimum forecasted level

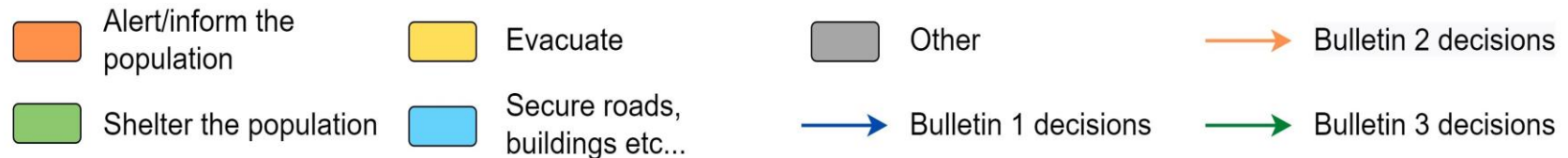
Expected decisions; mobilization phase of CSP:

- Inform the population
- Follow on the ground situation
- Restrict access to exposed roads
- Secure roads, camps and parking lots
- Consult with other actors



➔ Decisions made are appropriate but insufficient

Legend



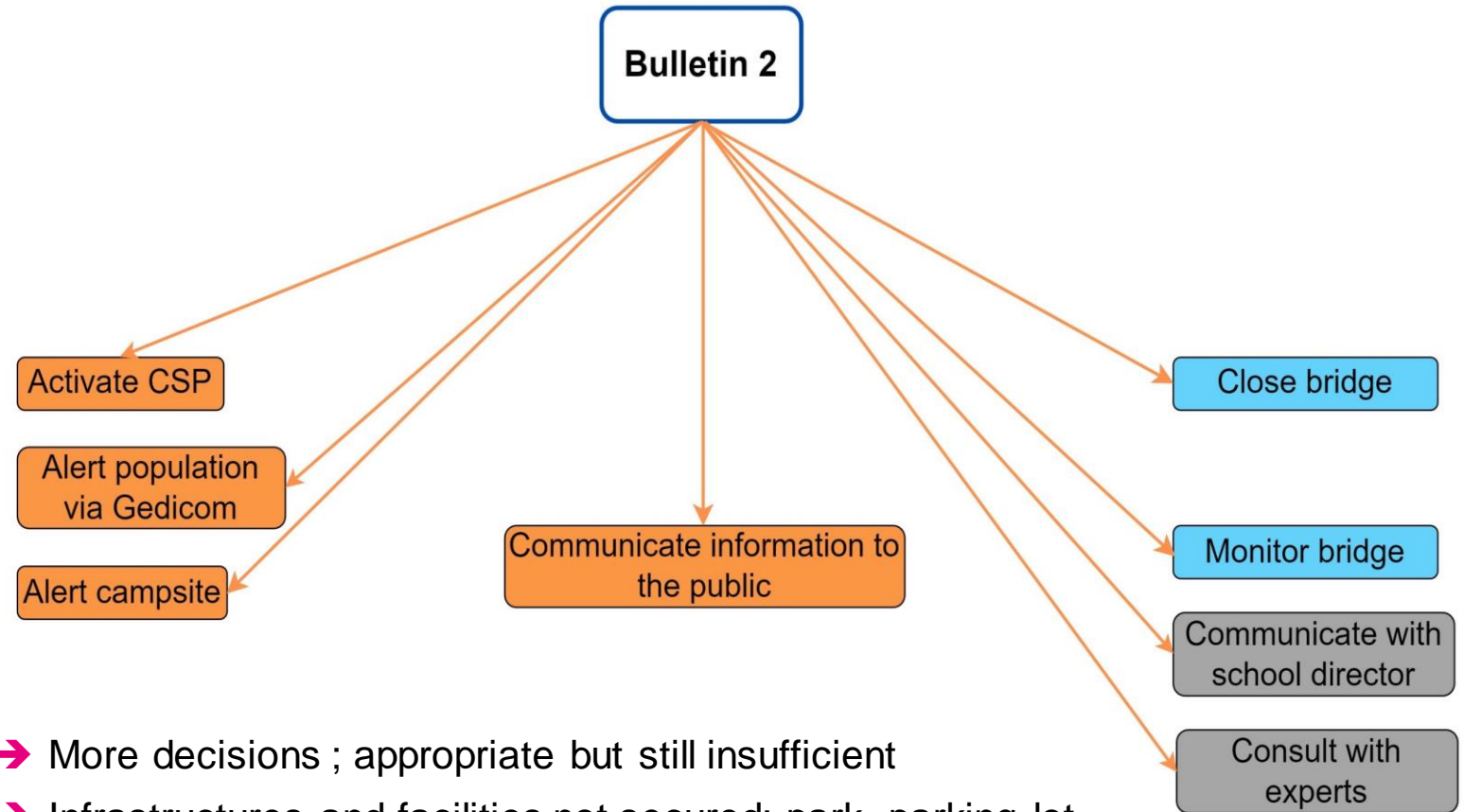
RESULTS

Decision records: sequence 1 (at 11h30-simulated time)

Bulletin	Added data
2	<ul style="list-style-type: none"> • Threshold markers: submersion of submersible bridge, yellow vigilance, orange vigilance • Average measured rain

Expected decisions; mobilization phase of CSP:

- Inform population
- Follow on the ground situation
- Restrict access to exposed roads
- Secure roads, camps and parking lots
- Consult with other actors



- ➔ More decisions ; appropriate but still insufficient
- ➔ Infrastructures and facilities not secured: park, parking lot and roads

Legend

 Alert/inform the population	 Evacuate	 Other	➔ Bulletin 2 decisions
 Shelter the population	 Secure roads, buildings etc...	➔ Bulletin 1 decisions	➔ Bulletin 3 decisions

RESULTS

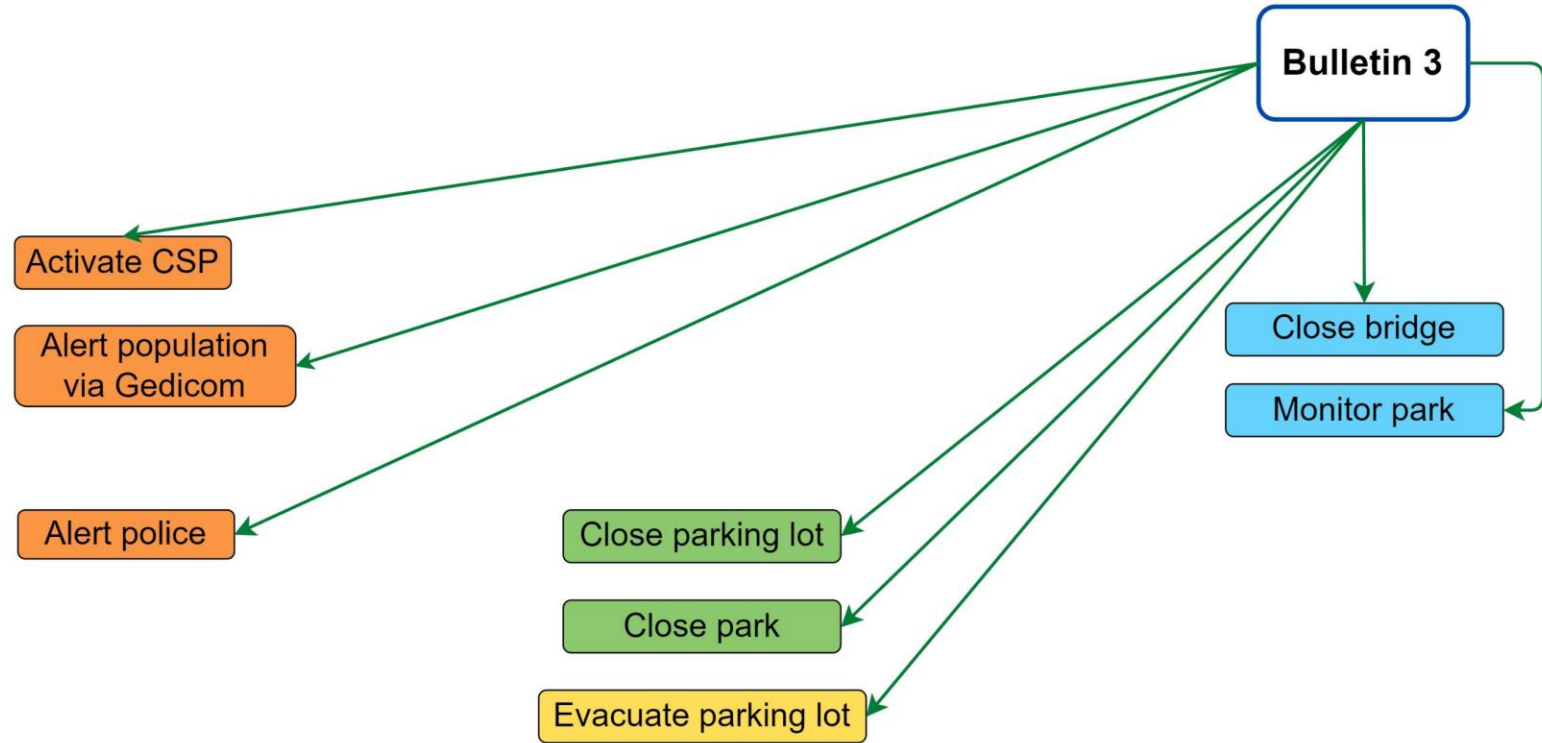
12

Decision records: sequence 1 (at 11h30-simulated time)

Bulletin	Added data
3	<ul style="list-style-type: none">• Future rain in Anduze• Measured level in two upstream watersheds

Expected decisions; mobilization phase of CSP:

- Inform population
- Follow on the ground situation
- Restrict access to exposed roads
- Secure roads, camps and parking lots
- Consult with other actors



➔ Decisions are generally adapted

➔ Roads not secured sufficiently

Legend

Orange box: Alert/inform the population

Yellow box: Evacuate

Grey box: Other

Orange arrow: Bulletin 2 decisions

Green box: Shelter the population

Blue box: Secure roads, buildings etc...

Blue arrow: Bulletin 1 decisions

Green arrow: Bulletin 3 decisions

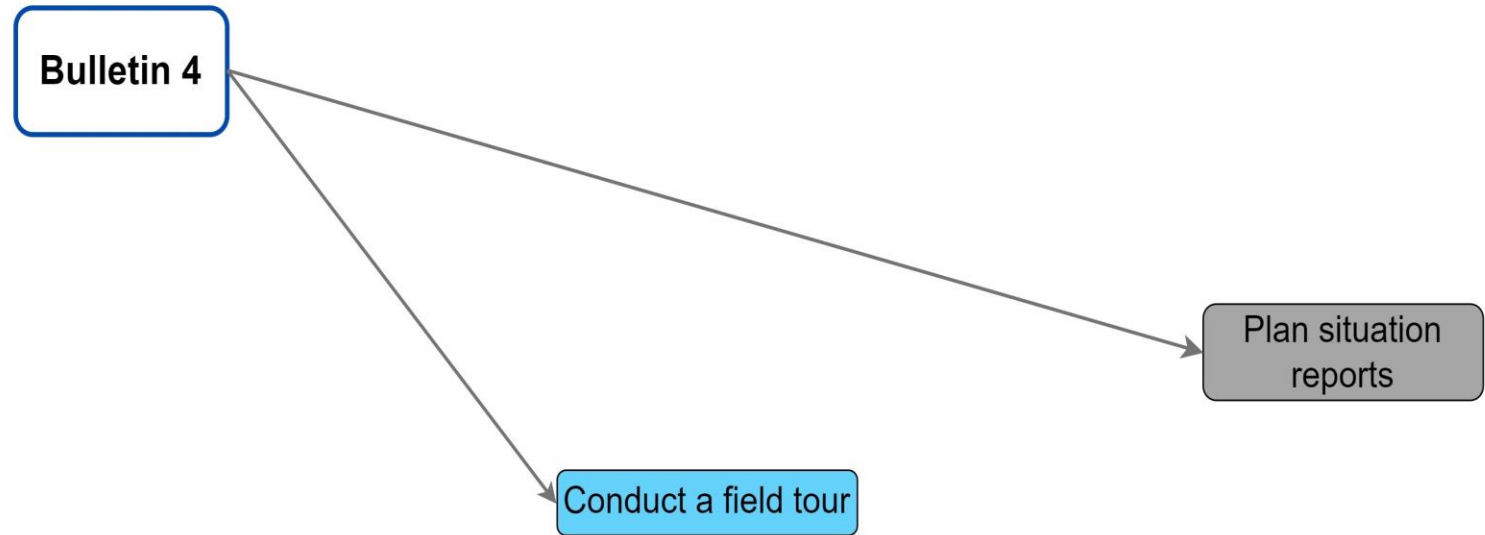
RESULTS

Decision records: sequence 2 (at 14h30-simulated time, 3 hours later)

Bulletin	Added data
4	<ul style="list-style-type: none">Level is replaced by discharge variable









Expected decisions; securing phase of CSP:

- Alert the population
- Secure the population
- Remain in contact with teams on the ground
- Open emergency accommodation
- Plan and conduct situation reports
- Consult with other actors
- Continue to secure roads, buildings etc....



- ➔ Decisions are inadequate
- ➔ Population is exposed to significant risk

Legend

 Alert/inform the population	 Open emergency accommodation	 Other	 Bulletin 5 decisions
 Shelter the population	 Secure roads, buildings etc...	 Bulletin 4 decisions	 Bulletin 6 decisions

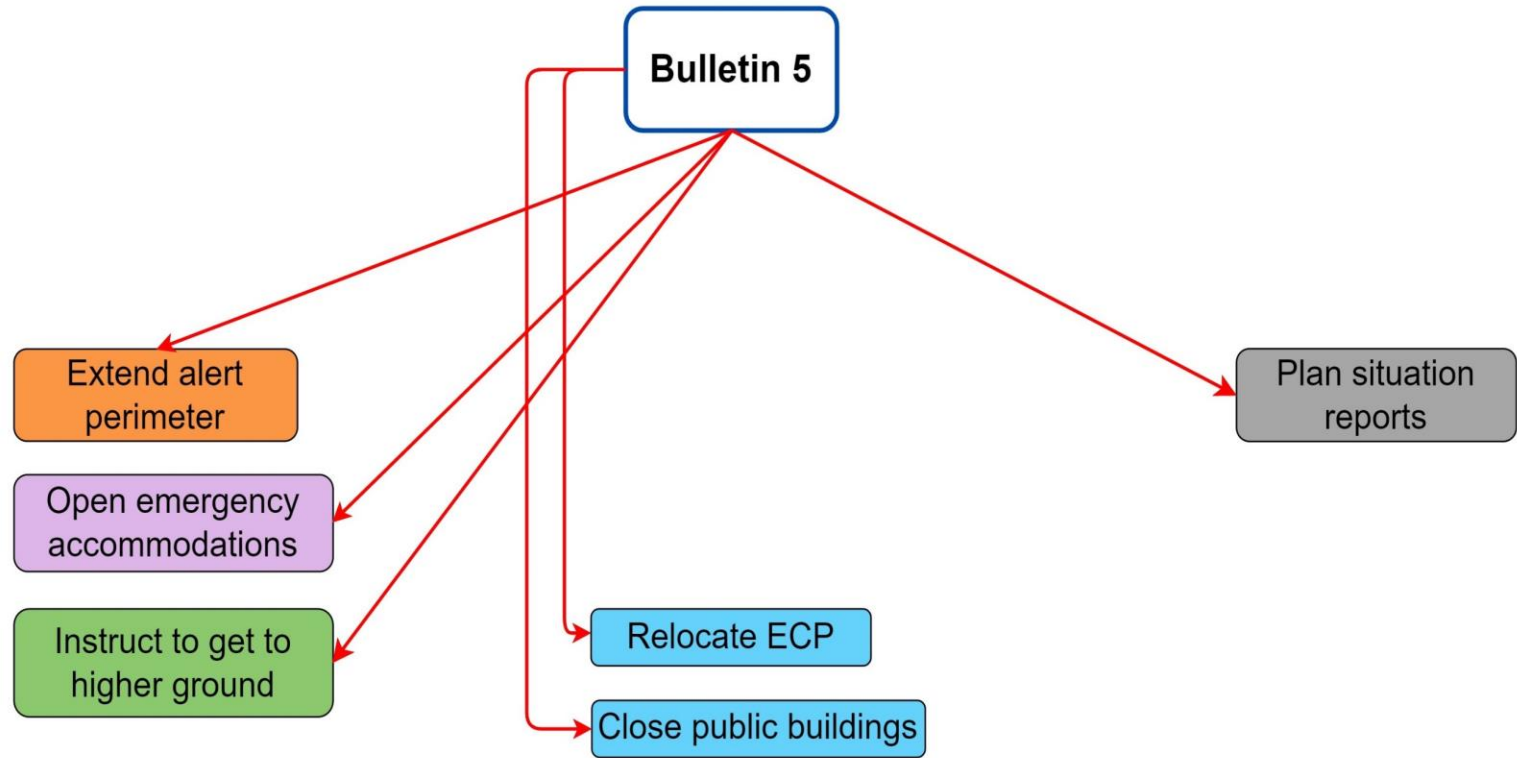
RESULTS

Decision records: sequence 2 (at 14h30-simulated time, 3 hours later)

Bulletin	Added data
5	<ul style="list-style-type: none">• Level variable is restored• Threshold marker of red vigilance• Threshold of inundation of main city square (plan de Brie)

Expected decisions; securing phase of CSP:

- Alert population
- Secure population
- Remain in contact with teams on the ground
- Open emergency accommodation
- Plan and conduct situation reports
- Consult with other actors
- Continue to secure roads, buildings etc....



- ➔ Managers realize magnitude of the event
- ➔ Decisions are adequate with expectations

Legend

Alert/inform the population	Open emergency accommodation	Other	Bulletin 5 decisions
Shelter the population	Secure roads, buildings etc...	Bulletin 4 decisions	Bulletin 6 decisions

RESULTS

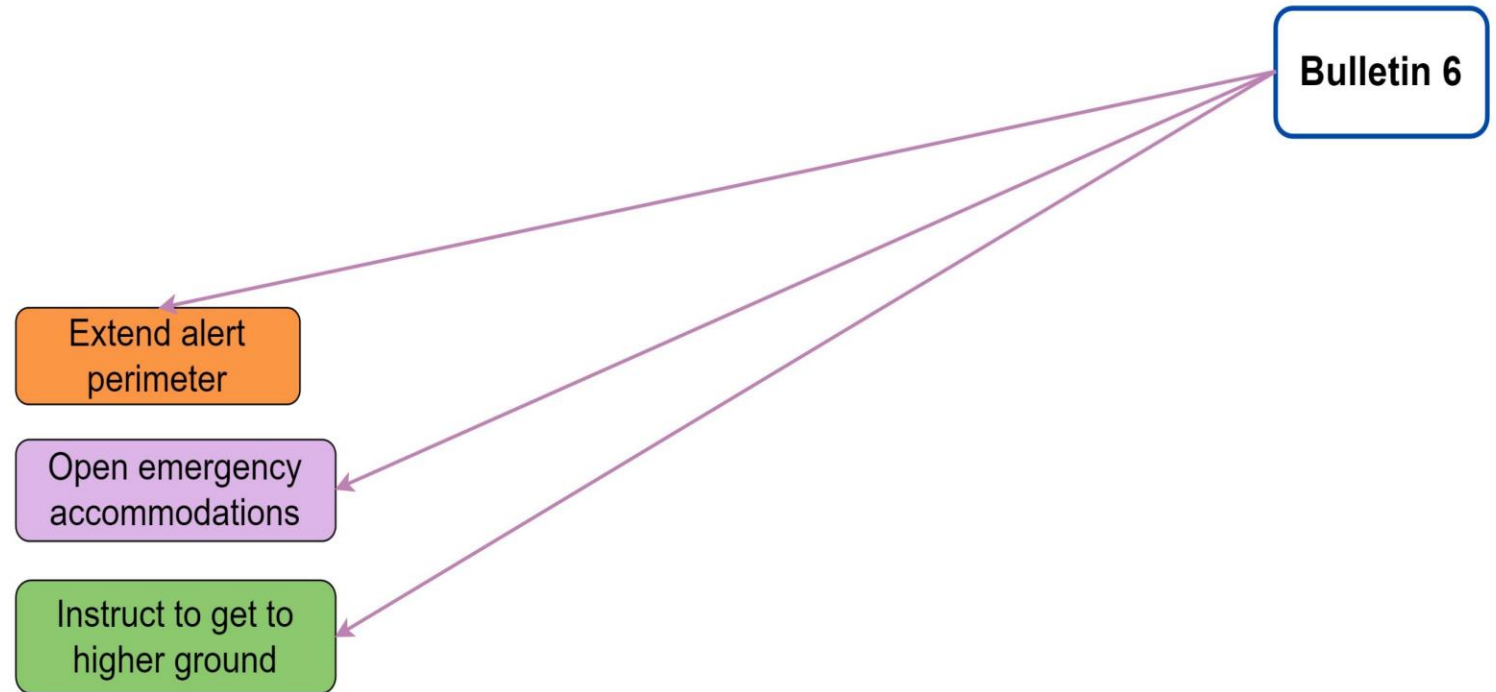
15

Decision records: sequence 2 (at 14h30-simulated time, 3 hours later)

Bulletin	Added data
6	• Potential flood zone map

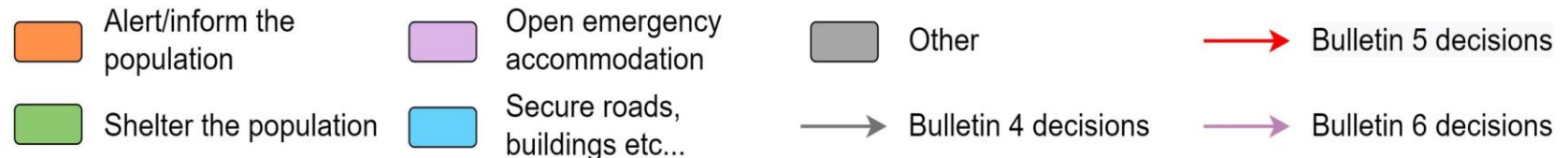
Expected decisions; securing phase of CSP:

- Alert population
- Secure population
- Remain in contact with teams on the ground
- Open emergency accommodation
- Plan and conduct situation reports
- Consult with other actors
- Continue to secure roads, buildings etc. ...



- ➔ Decisions are appropriate but insufficient
- ➔ The lack of registered decision could be unintentional (decision stated but not written)

Legend



- ▶ The anticipation level was quite high (except for bulletin 4)
- ▶ The ease of decision making varied from relatively easy to moderately difficult (except bulletin 4)
- ▶ Opinions on the bulletins were similar by the end of the workshop
- ▶ Most appreciated bulletins: bulletin 5 for group 1 and bulletin 6 for group 2

Main observations

- ▶ Nature of info:
 - Thresholds: interesting thresholds (e.g. parking lot, plan de Brie)
 - Hydrological data needs to be observable on the ground (level preferred over flow)
- ▶ Reference to past events: focus on recent events → more familiar
- ▶ Managers were able to get used to new representation of data (rain)
- ▶ Quantitative data: want to consult with experts for proper interpretation
- ▶ Amount of info: upstream measured and forecasted rainfalls and levels desired
- ▶ Map: useful but scale needs to be limited to municipal level

- ▶ The workshop configuration is compatible with the set objective and allows
 - Familiarization with the bulletins
 - Focus solely on the bulletins
- ▶ Importance of indicators and additional information
 - September, 2002 event not recognized (simulated time is different, in 2002, the event began during the night, and the major peak occurred in morning)
 - B1 → each manager had a different apprehension and relied on their personal experience
 - B6 → a certain degree of interpretation homogenization
 - Managers were able to make the best decisions with high levels of info/indicators
- ▶ Discharge variable is not only absent from the CSP, it is not «observable »

- ▶ The workshop format allows to focus on one aspect (hydrometeorological bulletin)
- ▶ Positive impact of bulletins on decision making
- ▶ Higher amount of info allows better decision making
- ▶ Positive impact of the workshop on risk education

Perspectives

- ▶ Reconduct in a more digitized version (detail decision logging terms, conditions similar to reality and adapted to current tools)
- ▶ Replace thresholds with forecasts of crisis management variables
- ▶ Include interpretation of quantitative data

- Bianciotto, L. (2005). *Les crues du Gardon sur la commune d'Anduze: Approche historique et enjeux* [Master I]. Université Paul-Valéry Montpellier III.
- Boin, A., Kofman-Bos, C., & Overdijk, W. (2004). Crisis Simulations: Exploring Tomorrow's Vulnerabilities and Threats. *Simulation & Gaming*, 35(3), 378–393. <https://doi.org/10.1177/1046878104266220>
- Bornancin Plantier, A. (2013). *Conception de modèles de prévision des crues éclair par apprentissage artificiel* [PhD, Paris 6]. <http://www.theses.fr/2013PA066015>
- Lagadec, P. (2012). *Du risque majeur aux mégachocs*. Éd. Préventique.
- Lapierre, D., Bony-Dandrieux, A., Tena-Chollet, F., Dusserre, G., Tixier, J., & Weiss, K. (2015). Developing a tool to assess trainees during crisis management training for major risks. In L. Podofillini, B. Sudret, B. Stojadinovic, E. Zio, & W. Kröger (Eds.), *Safety and Reliability of Complex Engineered Systems* (Vol. 26, pp. 195–202). CRC Press. <https://doi.org/10.1201/b19094-30>
- SPC Grand Delta. (2021). *Règlement de la surveillance, de prévision et de transmission de l'Information sur les Crues*.
- Toukourou, M. S. (2009). *Application de l'apprentissage artificiel à la prévision des crues éclair* [Phdthesis, École Nationale Supérieure des Mines de Paris]. <https://pastel.archives-ouvertes.fr/pastel-00005626>
- Vigicrues. (n.d.). *Vigicrues*. Retrieved November 9, 2022, from <https://www.vigicrues.gouv.fr/>
- Vinet, F., Boissier, L., & Saint-Martin, C. (2016). Flashflood-related mortality in southern France: First results from a new database. *E3S Web of Conferences*, 7, 06001. <https://doi.org/10.1051/e3sconf/20160706001>
- WMO, & UNESCO. (2012). Glossaire International d'Hydrologie. In *Flash flood* (3rd ed.).

Many thanks to:

- The Flash flood Forecasting Service of Grand Delta
- The city hall of Ales and in particular Mrs. Sarah Garcia
- The city hall of Anduze and in particular to Mr. Mathieu Bergerot
- To all whom participated in the workshop



Flash flood of the September, 2020 in Anduze