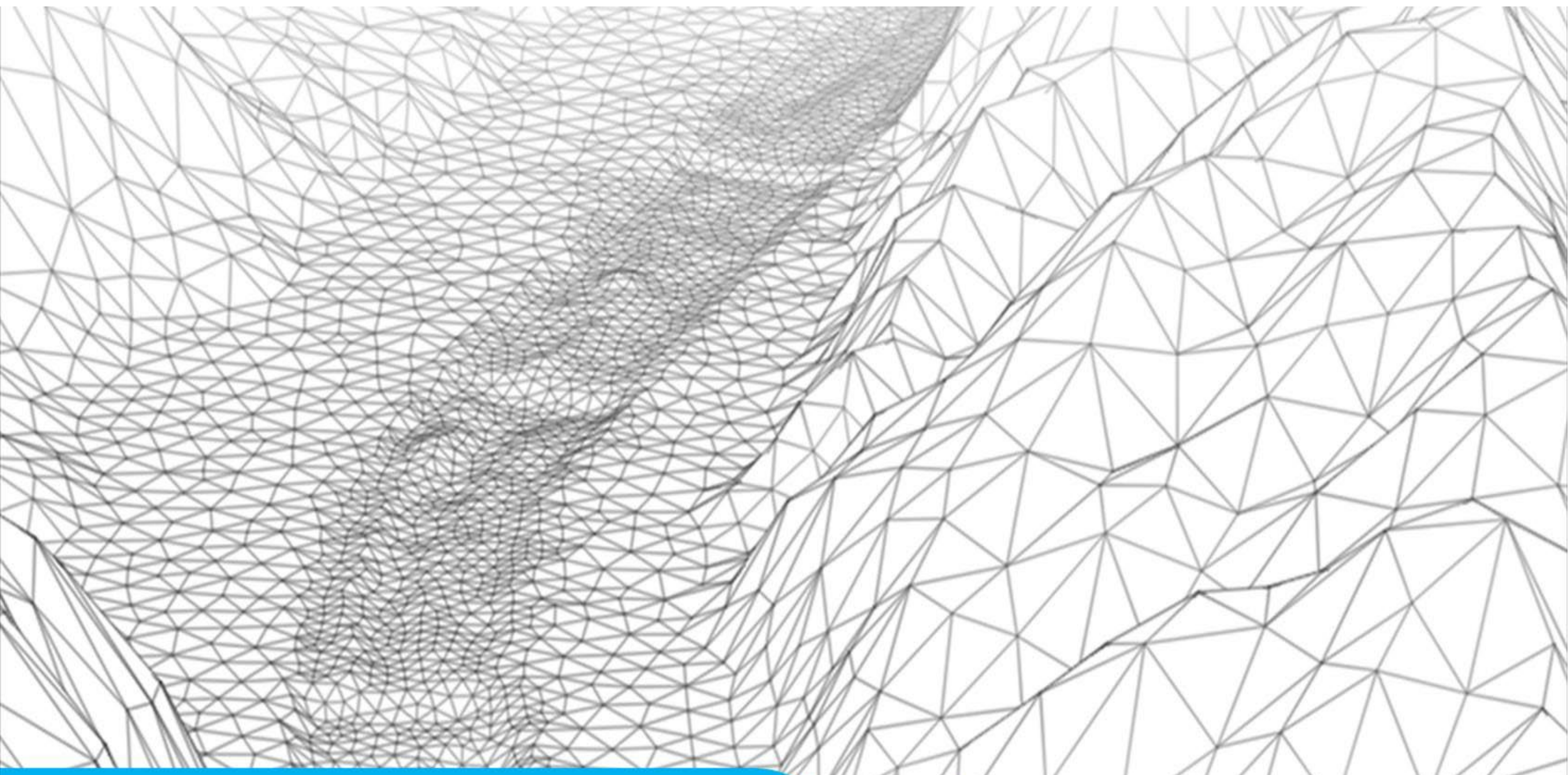
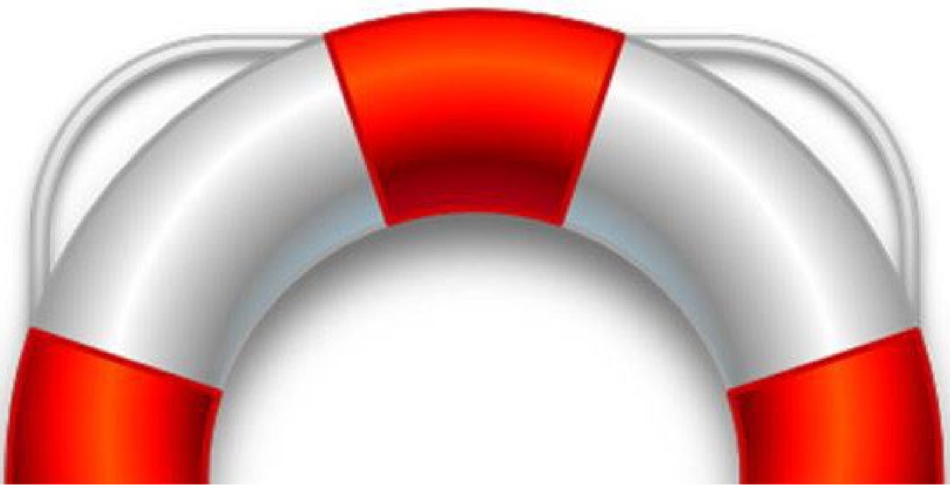


Uncertainty analysis of the Gloria storm in catchment la Tordera

Gloria event in la Tordera – Uncertainity analysis in the catchment

Gonzalo Olivares & Ernest Bladé
Universitat Politècnica de Catalunya - Spain
gonzalo.olivares@upc.edu



1. Introduction

During the winter in 2020, a big storm affected Spain and the Mediterranean cost was hardly struck by it. The storm left a trail of destruction and significant impact on the affected areas which included the loss of four lives and damaged some parts of Catalan coast, causing millions of euros in losses.

The scale of the storm's impact was unprecedented, affecting not only specific locations but also encompassing the entire Catalan territory. The storm affected 389 municipalities, according to various sources such as press, regional councils, town halls, and social networks (ICGC, 2020). The repercussions of the Gloria storm exceeded mere environmental complications, manifesting themselves in substantial economic losses that have exceeded five hundred million euros, as reported by the Catalan Climate Change Office (ICGC, 2020).

The phenomena propelled the study of the lower part of the catchment in order to understand the consequences of the flood. For doing that, the hydrologic-hydraulic tool Iber was used in order to build a hydraulic model to study the event.

The analysis consisted on calibrating a model able to represent the storm using as observed data, the discharge recorded at the flow gage Can Simó.

The following task was to produce flood maps and the risk analysis in order to evaluate damages and losses produced by an event of this magnitude.

Some problems were faced in the building of the model and the calibration, that were part of the analysis concerning the uncertainties that can be derived from the data, the model and the lack of information of the situation.

This document analyzes those issues and try to respond to the unknows that the hydrologic-hydraulic analysis encounters.

Main characteristics of the event

Spanning between Sunday of January 19th to Thursday of January 23rd, this exceptional storm classified as historic in Catalonia, brought a combination of extreme weather events, including high winds exceeding 70 km/h (around 144 km/h in some coastal areas), waves surging to over seven meters widespread rainfall accumulations of up to 500 mm in certain locations, significant snowfalls across both elevated and low-lying areas, and powerful waves (Guzmán, 2020; Fernandez, 2022; ICGC, 2020). To be more specific, the distribution of rainfall covered a broad expanse within the region (figure 1). The peak values were primarily concentrated in the Pre-Coastal and eastern Pyrenees sectors. The most notable measurements reached 516 mm in Lliurona (Alt Emporda), 430.4 mm in Puig Sesolles (Montseny, Vallés Oriental), and 425.8 mm in Viladrau (Osona) (ICGC, 2020).

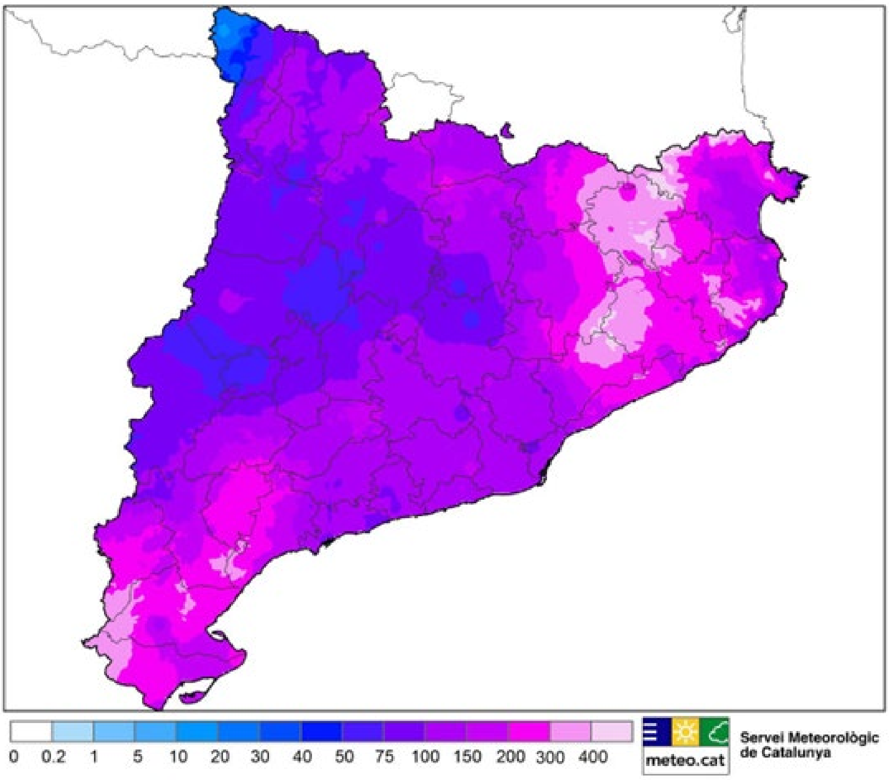


Figure 1. Accumulated precipitation (mm) Between 19 and 23 January 2020 (Source: METEOCAT, 2020).

The Mediterranean coast, particularly the Tordera Delta region, endured most of the storm's force, leading to widespread flooding and extensive damage to infrastructure (Fernandez, 2022). Notably, the storm caused the overflow of rivers, triggered slope movements, disrupted road and rail networks, isolated communities, and inflicted substantial harm along the coastline (Fernandez, 2022)

Location

The catchment is located in the región of Catalunya (Spain), between the *Vallès Oriental* and la *Selva* areas and it includes part of the mountain chain of the *Montseny*. The outlet of the catchment (river mouth) ends in the Mediterranean ocean between the limits of *Costa Brava* and the region of the *Maresme*. The catchment covers an area of 864 km^2 (figure 2).

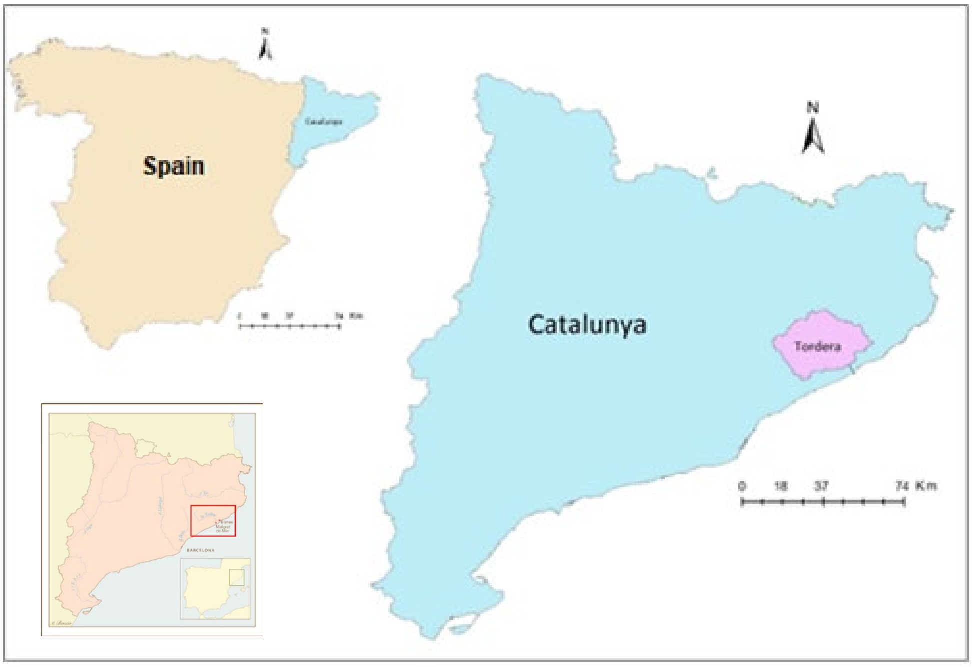


Figure 2. Catchment location in Spain.

Main issues

The main problem observed was the damage cause by the flood generated by the storm, mainly in the delta of the river. This flood caused the damage of bridges and the inundation of urban zones and the delta. Losses in agriculture and infrastructure were observed affecting the local communities that live in the sector. The figure 3 show an image of the effect of the storm in the mouth of the river Tordera during the storm.

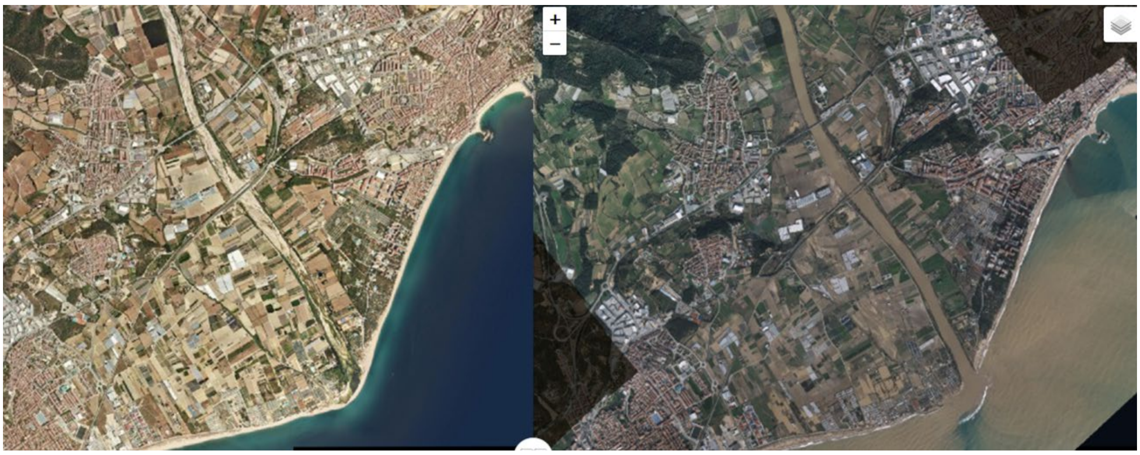


Figure 3. Effect of the storm in the delta of the river Tordera.

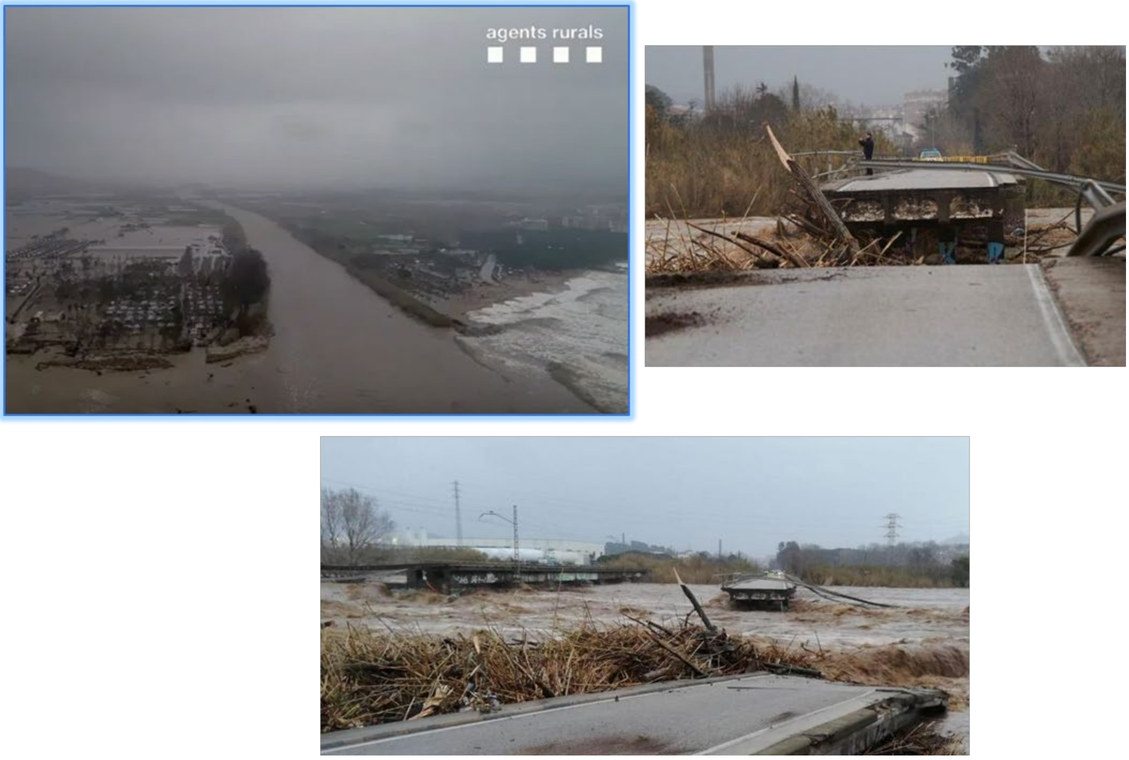


Figure 4. Damages caused by the flood in the delta of the river Tordera.

The damages caused by the event propelled the need for studying the area and the problems caused by the event. For doing this, a flood risk analysis was carried out for the last part of the river using the hydrograph generated in the catchment and recorded at Can Simó station.

For doing the analysis depth and velocity maps were obtained using the hydraulic code Iber, which is able to propagate overland flow using an unstructured mesh in a bidimensional domain.

The hydrograph used as the inlet boundary condition of the model was the real discharge recorded at the Can Simó gage discharge located in the last part of the catchment. The figure 5 shows the location of the gage in the river.

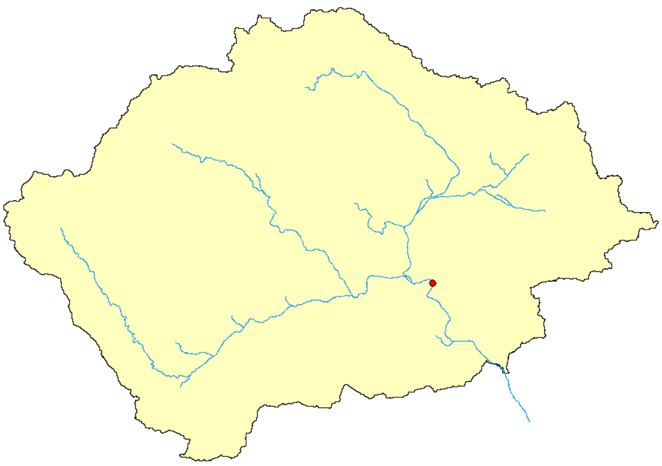


Figure5. Location of the flow gage in river la Tordera.

Figure 6. Flow gage Can Simó in Catchment la Tordera.

For the register of the discharge a flow gage (*Can Simó*) is located in the medium-last part of the catchment. This station registers more than 80% of the surface of the catchment and yield information of hourly and daily discharge (Figure 6).

The station is built in concrete and located in a section that allows to evaluate the response of the catchment properly before rain events. At the same time allows to understand the behavior of the water balance in the long run.

During the event, the station recorded the hydrograph generated by the basin. This discharge curve was the one that probably caused the damages observed in the last part of the river (delta). The figure 7 shows the discharge curve.

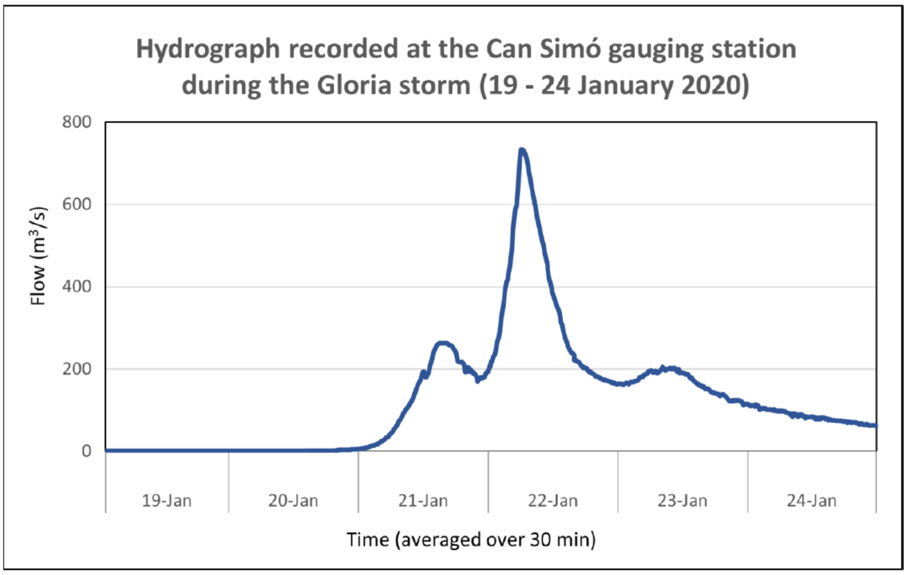


Figure 7. Observed hydrograph obtained from the Can Simó gage station.

2. Activities

A first face was carried out in order to study the hydrograph of figure 7. For that, a hydrological model was built using HEC-HMS using all the information available.

The first step was to collect the meteorological information of the area for the Gloria event. The figure 8 shows the meteorological stations used for the analysis.

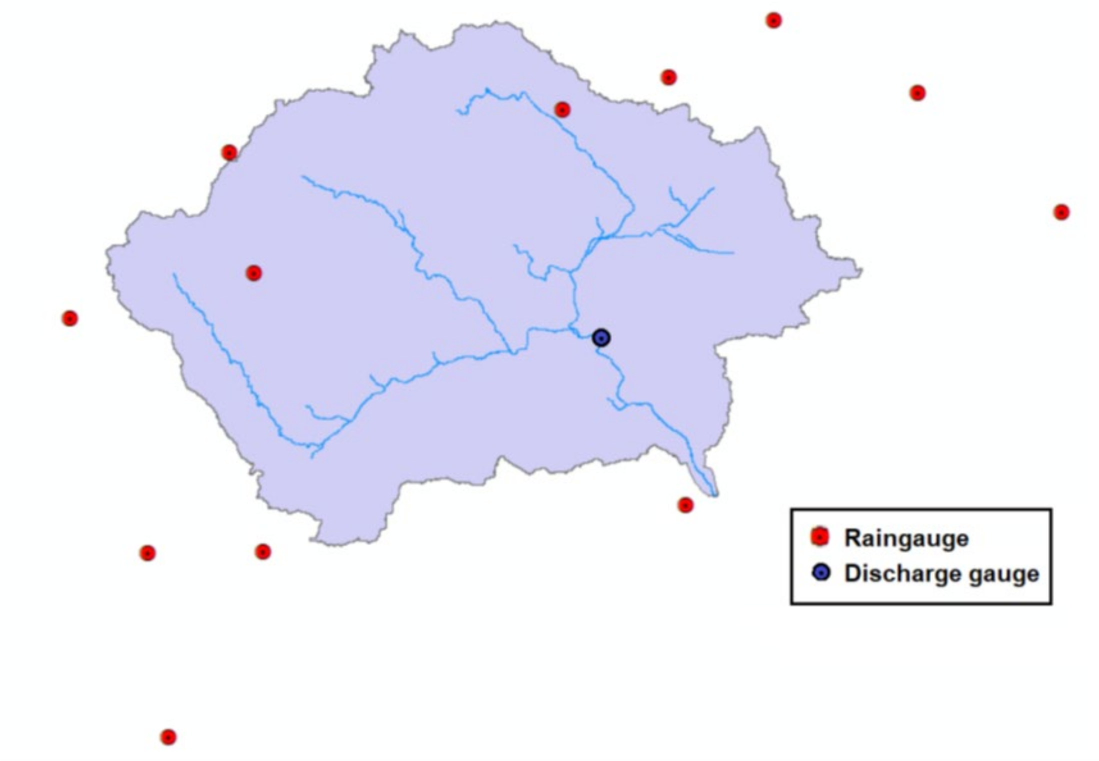


Figure 8. Location of the hydrometeorological stations in Catchment la Tordera.

The stations recorded the rainfall produced during the Gloria event. The figure 9 shows the records of the event for the station Puig Sesolles.

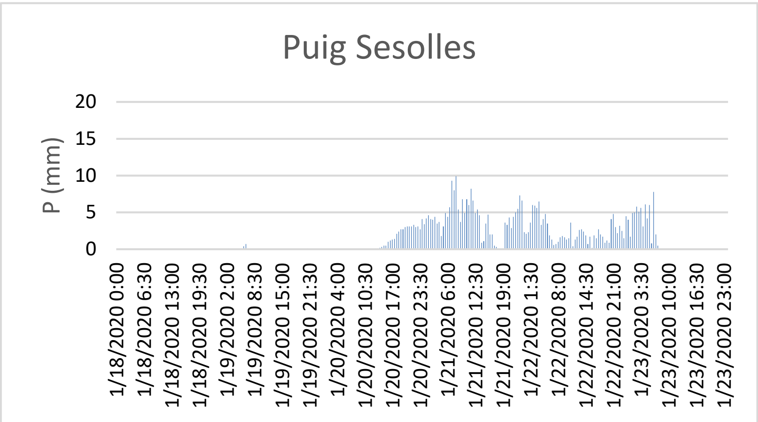


Figure 9. Pluviograph for the Gloria event at Puig Sesolles raingage.

For the assessing of the spatial distribution of the rainfall during the event, the area was divided using the Thiessen method. This implied that each raingage station had an area of influence in the basin, describing a partial spatial distribution of the rainfall.

Figure 10. Thiessen polygons defined in the basin.

The other important information needed for building the hydrological model is the one describes the topography and the land use conditions of the area. The topographical information allows to define variables like, main stream, basin slopes, longest flow paths, main streams slopes, etc. The land use allows to define variables like runoff coefficients, infiltration rates and soil conditions in general. The figure 11 shows the Digital Elevation Model (DEM) and the land use cover for the basin.

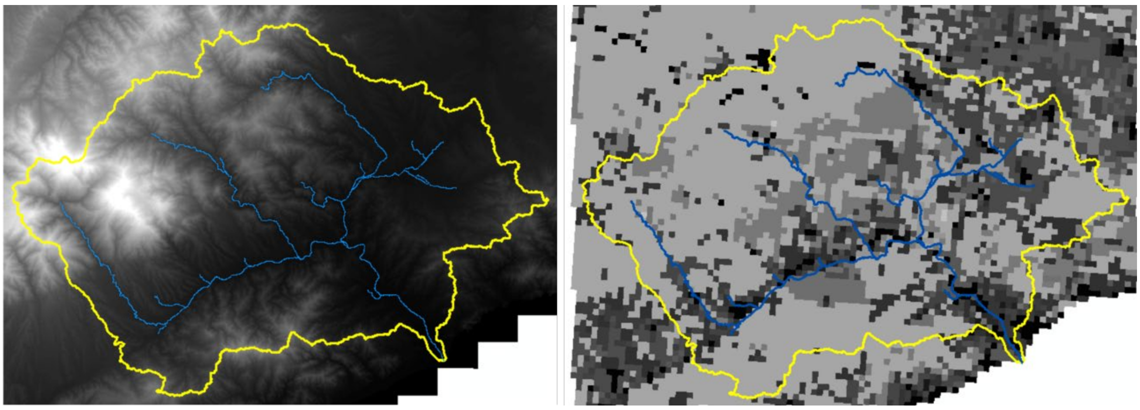


Figure 10. DEM and land use in the la Tordera catchment.

From the land use map, a value for the Curve Number was obtained for the parametrization of the loss method, that helps to build the hydrological model.

With all the information available, the model was finally built and parametrized using the following routines:

- Loss: Curve Number.
- Transform: SCS Unit Hydrograph
- Propagation: Muskingum.

- Base Flow: recession method.

The figure 11 show the model built in HEC-HMS.

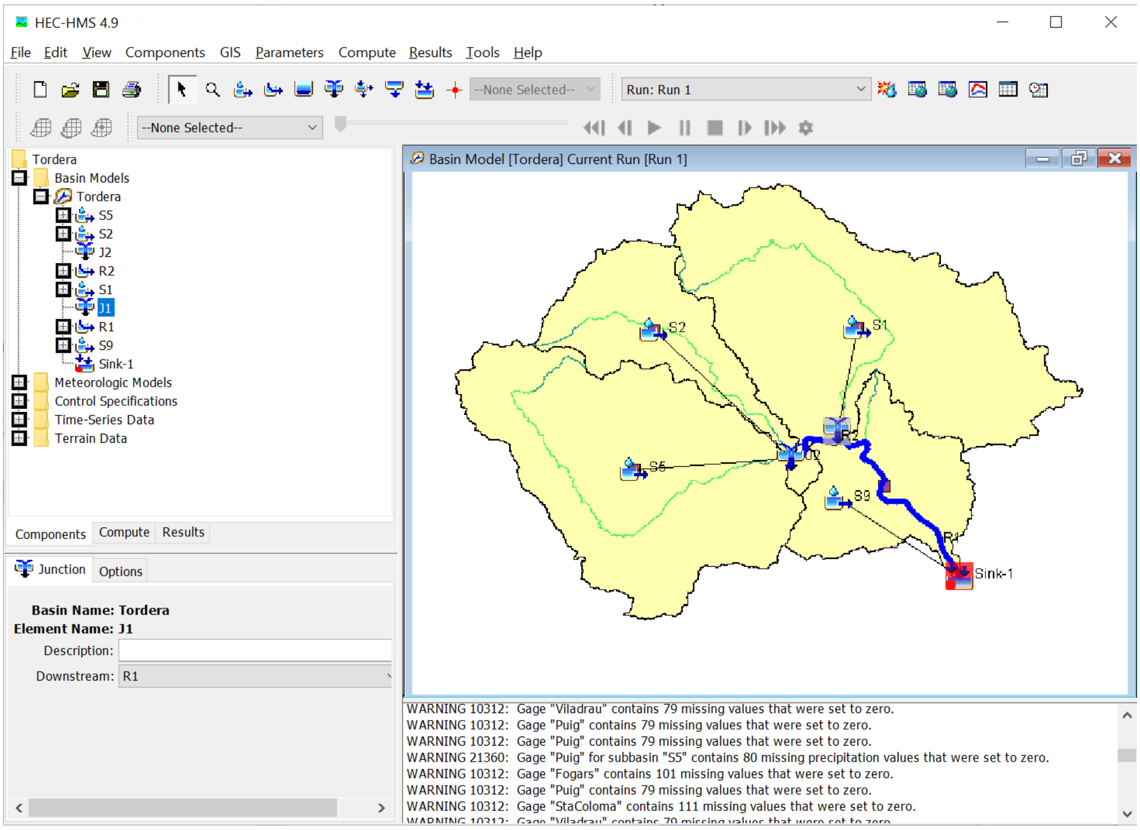


Figure 11. Semi-distributed model for la Tordera built with HEC-HMS.

The model allowed to study the basin response during the event and to evaluate its capacity to predict the hydrograph. As it existed an observed value recorded in the river, a calibration of the event was carried out.

Uncertainty and its implications

The results of the models were used to understand and to assess the capacity of the hydrological model to simulate the actual event. From the results it was observed that the model was not totally able to describe the hydrological response of the basin recorded at Can Simó discharge gage station. If the model is not able to perform as expected, many may be causes of this situation. One of these reasons is that is not possible to have the whole knowledge of the system, therefore the tool used and the information used is subjected to uncertainty. Analyzing this uncertainty and evaluating the main sources of it, helps to improve the models and to explain the results and the inconsistencies obtained from the simulation. As an example, the figure 12 the results obtained for the simulation of the discharge carried out by the hydrological model, compared with the observed that.

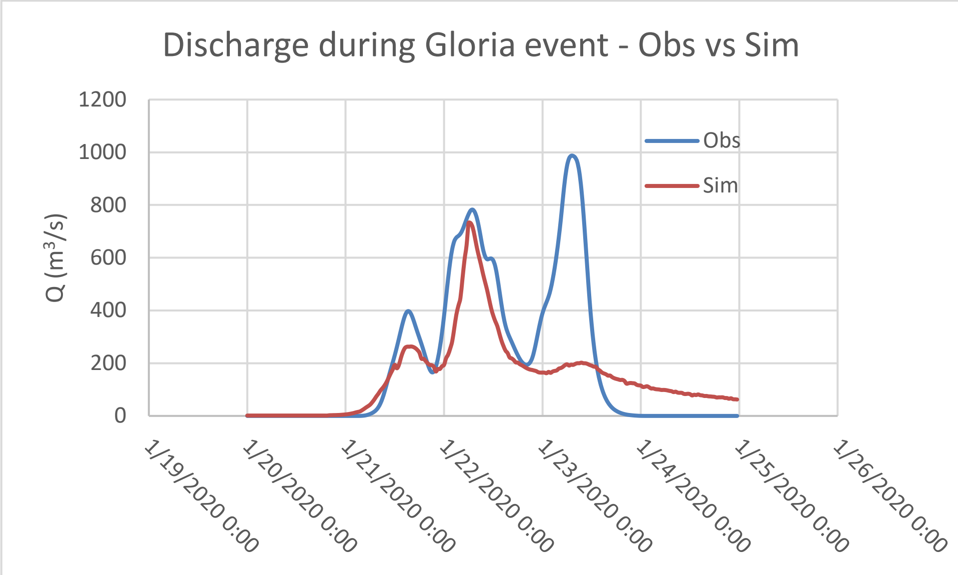


Figure 12. Observed and simulated discharge obtained with HEC-HMS.

Many can be the sources of uncertainty and one of the tasks of the study is to determine it. For example, there could be problems related to the recording of the discharge, there could be problems associated the register of the rainfall (lack of stations, unable to describe the spatial variability of the rainfall), there could be problems with the structure of the model, among others. Those uncertainties may affect the results of the flood risk analysis, in the case that the hydrological model is used to simulate the basin respond under circumstances similar to the event. This implies that the hydrological models have to be properly calibrated and validated to be useful for prediction of discharge events prone to produce floods and damages.

3. Methodology

The situation can be study using different tools, for example, according to hydrological code classifications, the task could be carried out using distributed models (Iber, MIKESHE, SHE-TRANS, etc.) o lumped semi-distributed (HEC-HMS, SWAT, etc.). Both philosophies for modeling rainfall-runoff process, can produce powerful results that can help the hydrologist to understand the situation. The setting up of these codes will varies according to the scale of the study, the information available, the time consuming and the expertise of the user.

Once studying the situation under the hydrological perspective, it will be clear that some problems exists to calibrate the model, so the engineer needs to ask her/himself, why are those problems encountered? For answering that question, it is first needed to understand the concept on uncertainty, sources and ways to decrease it.

It is important to understand that when the probability of occurrence assigned to future events are unknown, the decisions are taken under uncertainties. Thus, due to randomness of events and processes (e.g. rainfall), the lack knowledge to determine uncertainty might create problems in the estimation.

Three are the distinctive aspects to consider with uncertainty:

- To understand it
- To quantify it

- To reduce it

To tackle those three problems, these actions can be taken:

- Having better data
- Having better hydrological-hydraulic models
- Having better techniques aiming to extract better knowledge of available information

Additionally, when using hydrological – hydraulic codes to evaluate the rainfall-runoff process in a basin, the model built up for that purpose, needs to also be tested and studied to avoid problems (also sources of uncertainty) related to:

- The structure of the model (approximations, simplifications, limitations, etc.)
- The parametrization (physical meaning, lack of full characterization, assumptions, etc.)

And finally, which should be one of the first and main task in a hydrological-hydraulic project is to study the input data, validate and filter it, if need, because the main sources of uncertainty will be due to the quality of the data or the lack of it.

As it is expected, the first part of the task is:

- Full hydrological analysis of the catchment for the 2020 Gloria storm event. Task can be carried out using lumped or distributed hydrological tool
- Calibration of the model with the observed data
- Uncertainty analysis of the results. Possible explanations and probable sources of uncertainty

Once the hydrograph is obtained, a full flood risk analysis in the last part of the river la Tordera is carried out using the observed hydrograph obtained from the discharge gage.

The figure 13 show an image of flood caused by the Gloria event in the delta of the river.

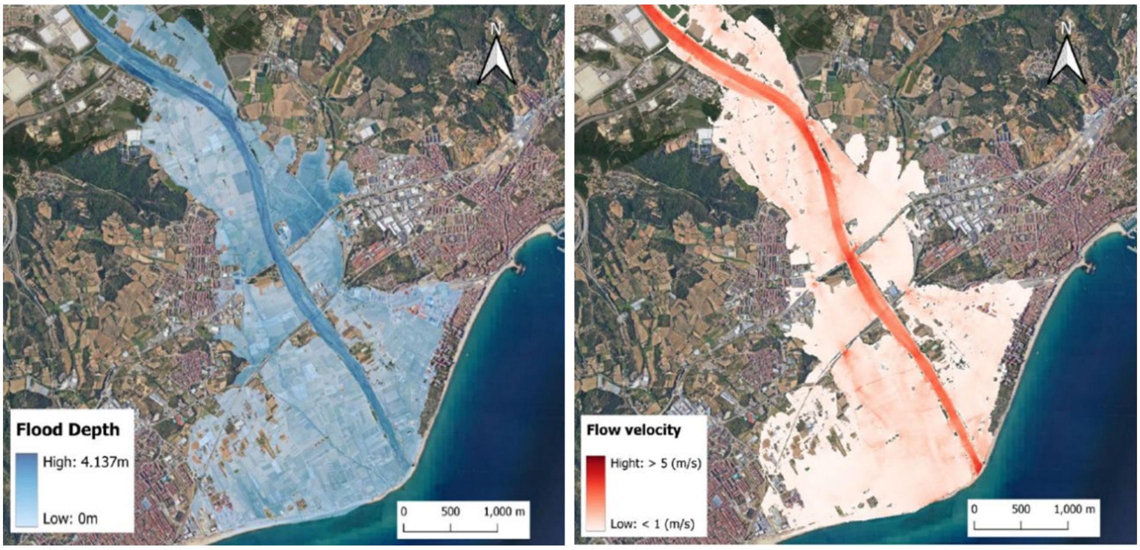


Figure 13. Depth and velocity maps observed for the Gloria event.

A second analysis is carried out using the hydrograph obtained from the hydrological model.

So, the question of uncertainty is relevant because it can be propagated to the flood risk analysis, that can lead to wrong decisions and planification for future events.

The propagation of the hydrographs in the delta of the Tordera river, presented in the figure 12 (observed and simulated), will yield different flood maps, because the shape and volume of the hydrographs are different. If hydrological models are used to be trusted, this sort of issues need to be addressed so the uncertainty that causes it.

4. References

Guzmán, P. (2020). *"Lessons learned from Storm Gloria"*. Retrieved from Creaf blog: https://blog.creaf.cat/en/noticies-en/lessons-learned-storm-gloria/.

Fernandez, I. C. (2022). *"Effects of the Gloria Storm in the Delta of Tordera River, and Evaluation of the Previous Analysis to Delimitate the Flood Areas".* IAHR. doi:https://doi.org/10.3850/IAHR-39WC252171192022613.

ICGC. (2020). *"El temporal Gloria: Els efectes dels processos geològics sobre el territori".* Barcelona: Institut Cartogràfic i Geològic de Catalunya.