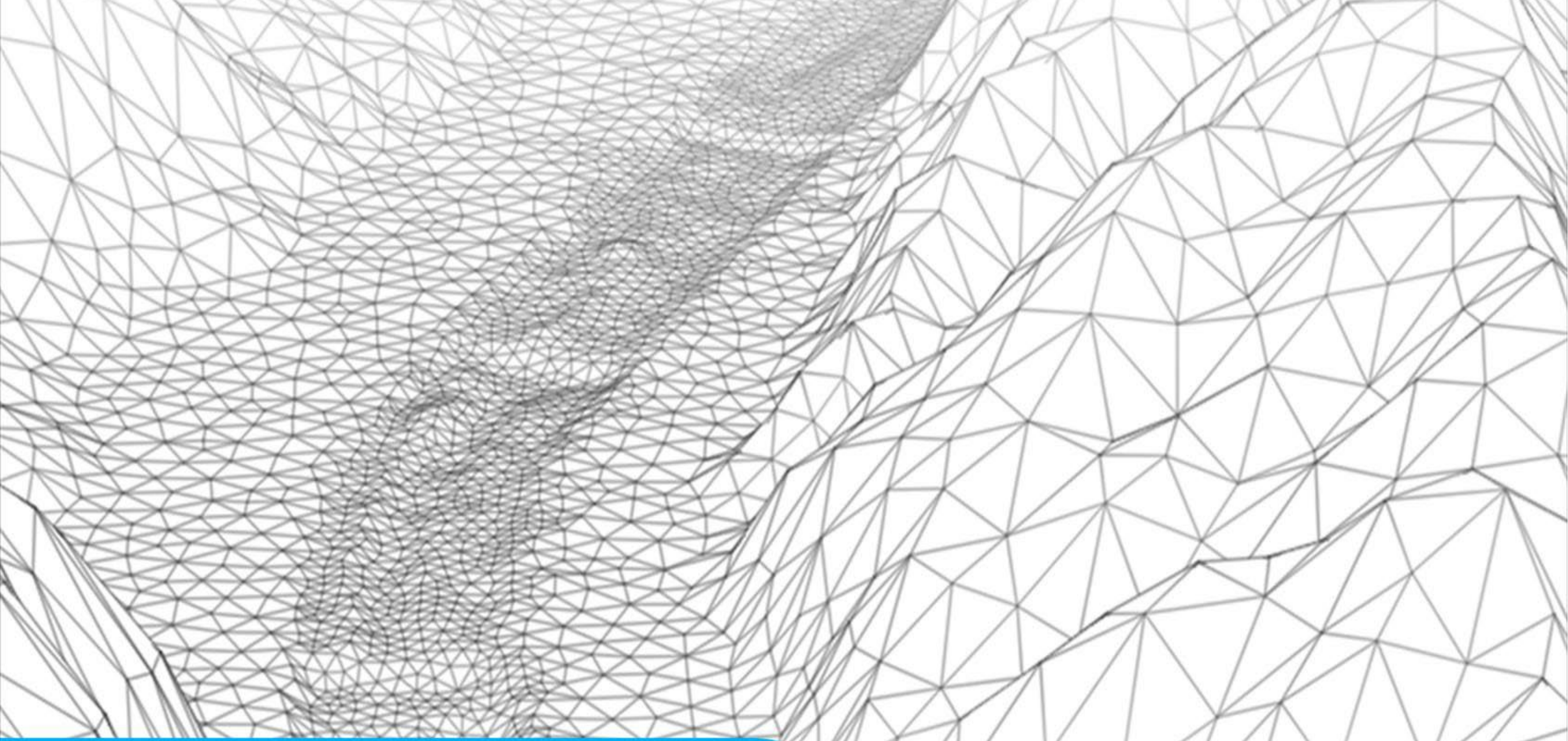

Climate Change

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HydroEurope

WP2: Uncertainty in Advanced Hydrological and Hydraulic Modelling
WP3: Climate Change Impacts on Flash Floods
Case Study La Tordera catchment (Spain)

Climate Change Impacts on Flash Floods: frequency analysis and hydrological modeling

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1. Introduction

The following teaching material is dedicated to understand the impact on Climate Change in flash flood events for the case of study of la Tordera (Spain). The information containing in this section deals with the impact of Climate Change (CC) on the frequency of high intensity event affecting the study area. At the same time aims to establish how flash flood events might change its frequency for the Tordera catchment. The analysis will consist on evaluating the historical situation of rainfall and discharge gauges to evaluate the actual frequency of events plus Climate Change projections of 10 models to evaluate changes in the future.

1.1 Main activities

The activities presented in this section are intended to be used to understand the present and historical conditions of the meteorological variables in the study area. For that purpose, historical data for precipitation and temperature are available from 1974 until the present days. Additionally, information provided by the Catalan Water Agency (https://sig.gencat.cat/visors/VISOR_ACA.html) and the *Ministerio de Fomento – DGC* (https://www.transportes.gob.es/recursos_mfom/0610300.pdf will be available concerning periods for the rainfall and the discharge.

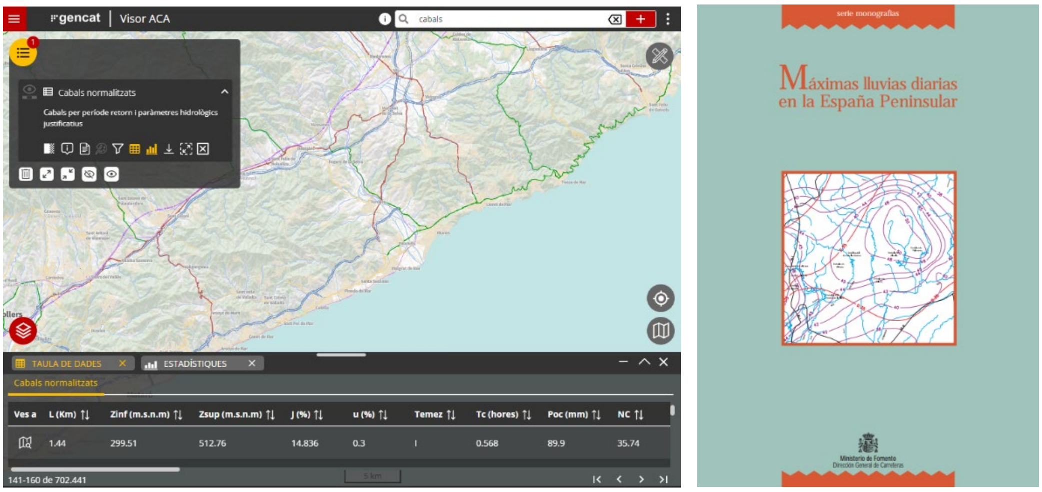

Figure 1. Sources of information for maximum rainfall and discharge for different return periods.

The information will allow to evaluate the results obtained from the different tasks taking in consideration the values previously calculated by the official agencies, calibrating and validating the different tools used to carry out with the activities.

As one of the main objectives is to evaluate frequency of the high intensity events in the future, a new frequency analysis will be carried out for the rainfall projections using the scenarios of the sixth report of the IPCC. This information will give a first approximation of the frequency of future events in the area, concerning the rainfall.

Additionally, a hydrological model build using historical information will be developed calibrating and validating the historical condition of the catchment. This model will be used later on with the projections of the Climate Change scenarios selected for the analysis (minimum 2). The results of the hydrological model will give a probable future situation of the discharge regime of the catchment under different projections (models) and CC scenarios. Using that information, a new frequency analysis will be carried out to understand changes in between the historical and future conditions.

The task can be resumed as follows:

- Data analysis of the historical information using the rainfall discharge gauges present in the area (seasonality and annually). Description of the tendencies observed in the catchment and its meteorological conditions.
- Rainfall and discharge frequency analysis with the historical information.
- Comparison of the results obtained from the rainfall frequency analysis with the official values.
- Definition of different return periods of the rainfall for the duration available.
- Rainfall frequency analysis of the rainfall for the CC projections.
- Selection of the CC models and scenarios for analysis (statistical analysis for selection).
- To build a hydrological model in the long term for the evaluation of the discharge, using information available of, soil, land use, evapotranspiration, topography, etc.
- Calibration and validation of the hydrological model with the historical data.
- Evaluation of the projections of CC for the scenarios selected of the rainfall and temperature (evapotranspiration) in the hydrological model to determine the discharge in the Tordera catchment.
- Discharge frequency analysis of the discharges obtained for the climate projections.
- Evaluation of changes in the return period between past and future.
- Impact of the frequency changes in the flood risk assessment in the last part of the catchment (river mouth).

1.2 Data available

The projections needed for the analysis for each one of the meteorological stations of the study area, can be obtained from the following models:

- ACCESS_CM2/
- BCC-CSM2-MR/
- CMCC-ESM2/
- CNRM-ESM2-1/
- CanESM5/
- EC-EARTH3/
- ERA5/
- MPI-ESM1-2-HR/
- MRI-ESM2-0/
- NorESM2-MM/
- UKESM1-0-LL/

The figure 2 shows the different locations of the stations in the catchment.

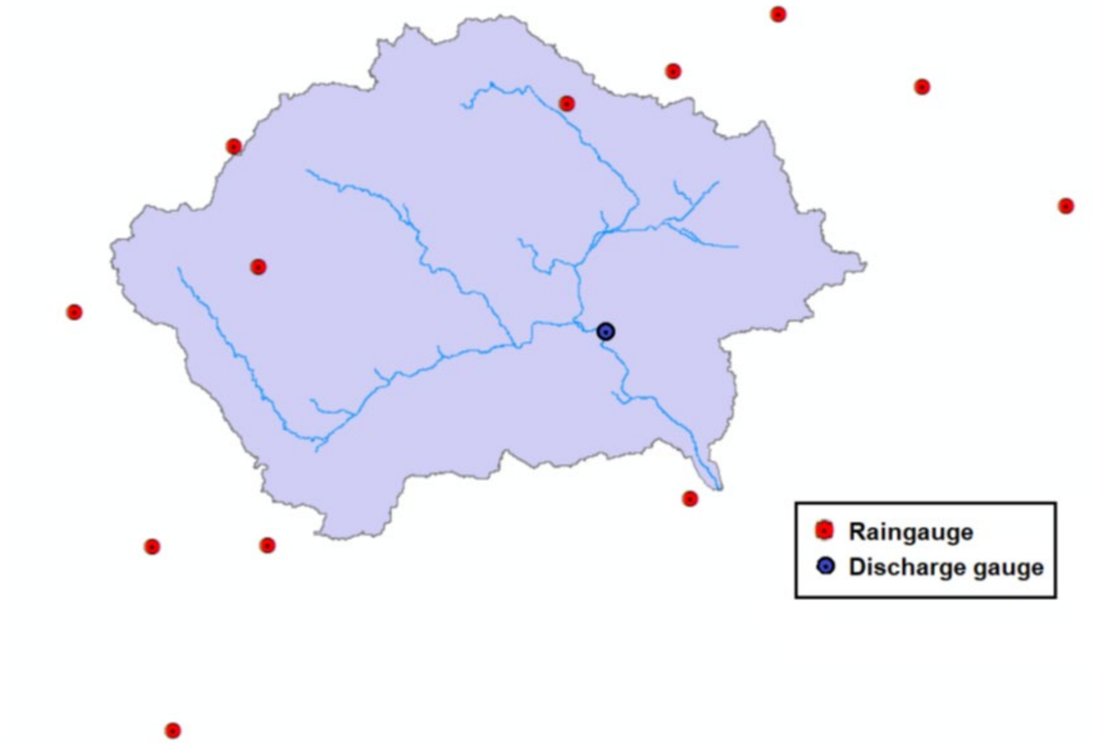

Figure 2. Location of the hydrometeorological stations in catchment la Tordera.

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 3 shows the Digital Elevation Model (DEM) and the land use cover for the basin.

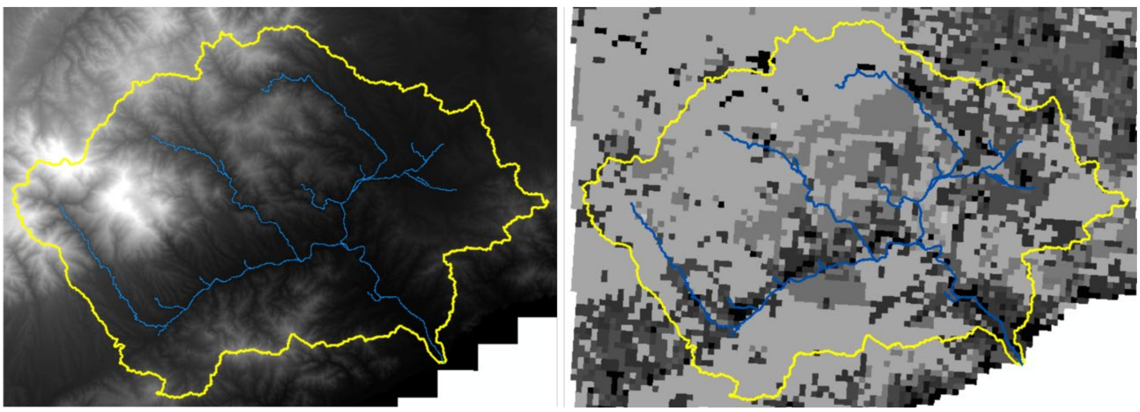

Figure 3. DEM and land use in the la Tordera catchment.

For the building of the hydrological model a semi- distributed tool is advised, because a long-term simulation will be needed to evaluate the discharge.

Considering that the model has to be able to represent the conditions of the catchment in the long term (water balance) the model has to be built using methodologies not only able to describe rainfall – runoff process but the groundwater interaction. This means that the model has to be based in some physical conditions of the catchment that has to be properly represented by the different methodologies.

It is proposed to work with the semi-distributed software HEC-HMS (figure 4) due to allow the users to build models using method and routines able to represent the physical condition in an accurate way. At the same time, its friendly interface allows the users to work fast and efficiently.

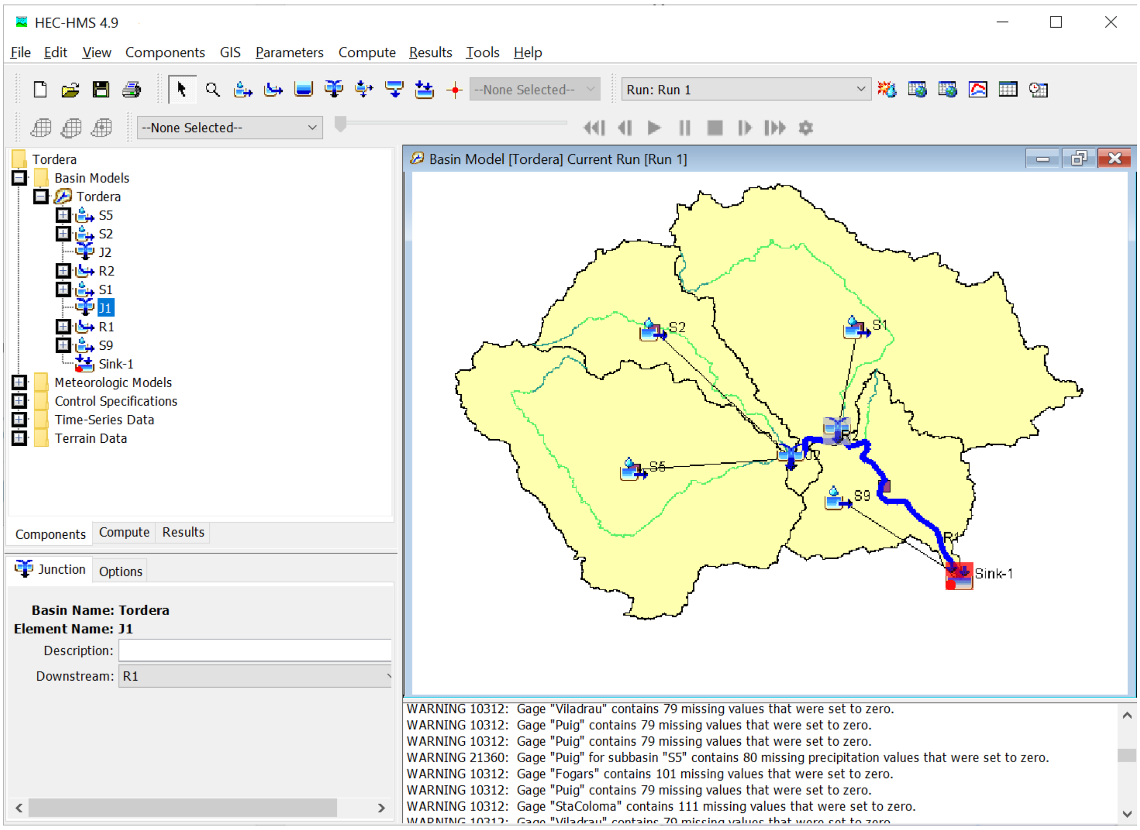

Figure 4. Semi-distributed model for la Tordera built with HEC-HMS.

2. Climate Change

The Climate Change projections and the future scenarios represent and important challenge for the society, due to affect directly in the water cycle, causing problems related with consumption and managements. Even though consumption can be critical at the moment in some part of the globe, basically due to recurrent droughts, in some other parts the effects can be associated to natural disasters (floods, hurricanes, etc.), affecting infrastructure and casing harm to people.

The effect of the CC, as a consequence of the warming of the atmosphere (Greenhouse effect), may lead in some part of the globe to an increment of rainfall events, affecting their frequency and intensity. Those can be probably the case in humid medium latitudes with an increment of the frequency of rainfall events over shorter periods of time (IPCC, 2013). Additionally, specific regions like the one study in this project, can be also affected by this type of situation, increasing the probability of damages and losses, specially in places with dense populations.

Nevertheless, the projections of the rainfall remind a complicated issue to predict, due to its variability at large scale and its random behavior. Even when this task reminds complicated and without uncertainty, the historical register provides some insight about the frequency of rainfall events in the las 70 years. It has been observed that floods episodes associated to rainfall events has been increasing since the 50's at a global scale, even tough there are still places where these events have decreased demonstrating the high variability at local level.

Due to these probable increments of rainfall events (floods), specially in Europe, it is expectable and increment of natural disasters and damages caused by them. The figure 5 shows statistical produced by the European Environment Agency for the number of natural disasters between 1980 – 2022.

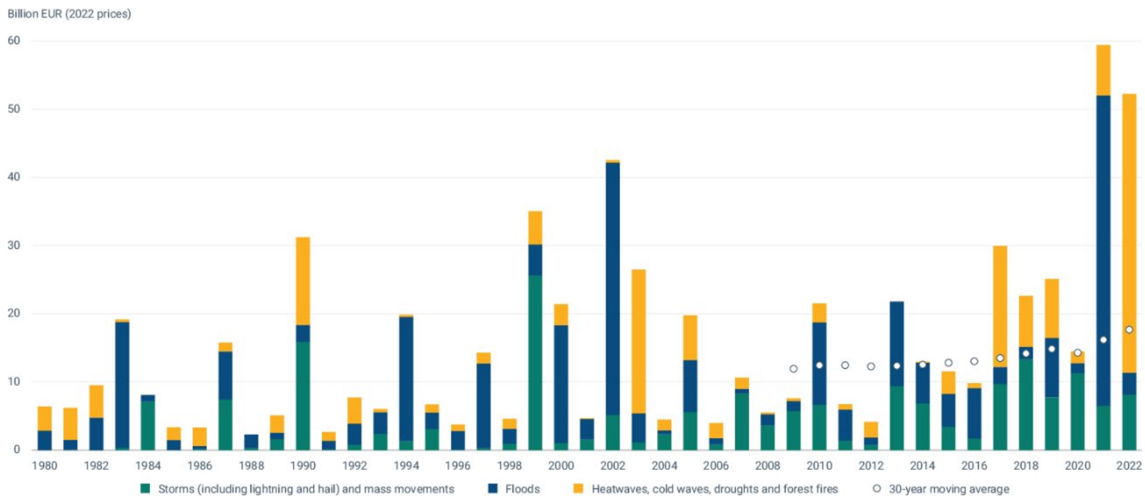

Figure 5. Annual economic losses caused by weather – and climate – related extreme events in the EU Member States (source: European Environment Agency)

According to the agency, between 1980 and 2022, climate related extreme events amounted to an estimate of EUR 650 billion in the EU. Hydrological hazards (floods) account for almost 43% and meteorological hazards (storms, including lightning and hail, together with mass movements) for around 29% of the total. For the climatological hazards, heat waves cause around 20% of the total losses while the remaining +/-8% are caused by droughts, forest fires and cold waves together. The most expensive hazards during the period 1980-2022 include the 2021 flooding in Germany and Belgium (EUR 44 billion), the 2022 compound drought and heat events over the whole continent (EUR 40 billion), the 2002 flood in central Europe (EUR 34 billion), the 1999 storm Lothar in Western Europe (EUR 17 billion), the 2003 drought and heatwave across the EU (EUR 17 billion), and the 2000 flood in France and Italy (EUR 14 billion), all at 2022 prices.

2.1 Climate conditions in Catalunya and la Tordera catchment

2.1.1 Rainfall frequency

The changes in rainfall events have a direct impact on flash flood events, altering their occurrence and distribution. In that sense, it is necessary to evaluate how changes in the future climate, can affect the frequency of episodes in the area of study.

Some specific tasks have been already developed in the are to evaluate changes in the frequency. As usual the availability of information is crucial, so results are not extent of uncertainty and they must be considered as an approximation of the reality to try to understand the probable conditions of the area under CC scenarios.

Studies carried out in Catalonia, shows that several techniques can be used to estimate changes in the frequency of the rainfall. For example, figure 6 shows how to produce different trajectories of the rainfall associated to a return period using extreme value distributions (EVI). This process allows to select what are the trajectories more plausible considering different thresholds.

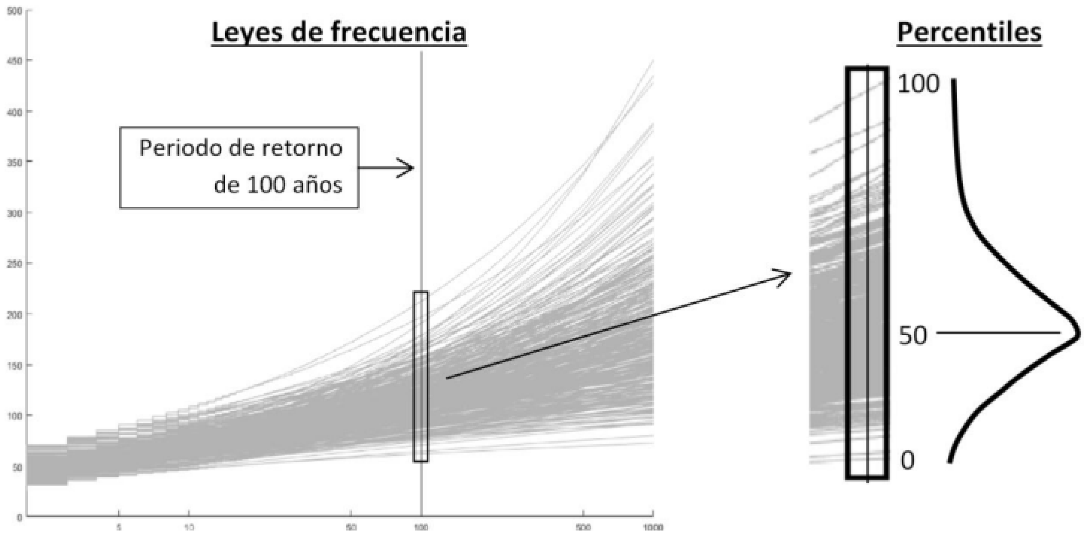

Figure 6.

Figure 9. Threshold selection for the maximum daily rainfall for the return period of 100 years for 10000 frequency distributions obtained by a Monte Carlo approach (source: https://aca.gencat.cat/web/.content/30_Plans_i_programes/20_Gestio_del_risc_inundacions/2n-cicle-de-planificacio/APRI/07_Canvi_Climatic_CA.pdf).

The use of projections allows to obtain information about the possible changes in the rainfall frequency of the future compared with the past. At the same time, the use of specific CC scenarios yields important information about the range in which these changes might move.

The figure 7 show the maximum precipitation in 24h for the return period of 100 years for CC scenarios RCP 4.5 and RCP 8.5 in relation to the actual situation.

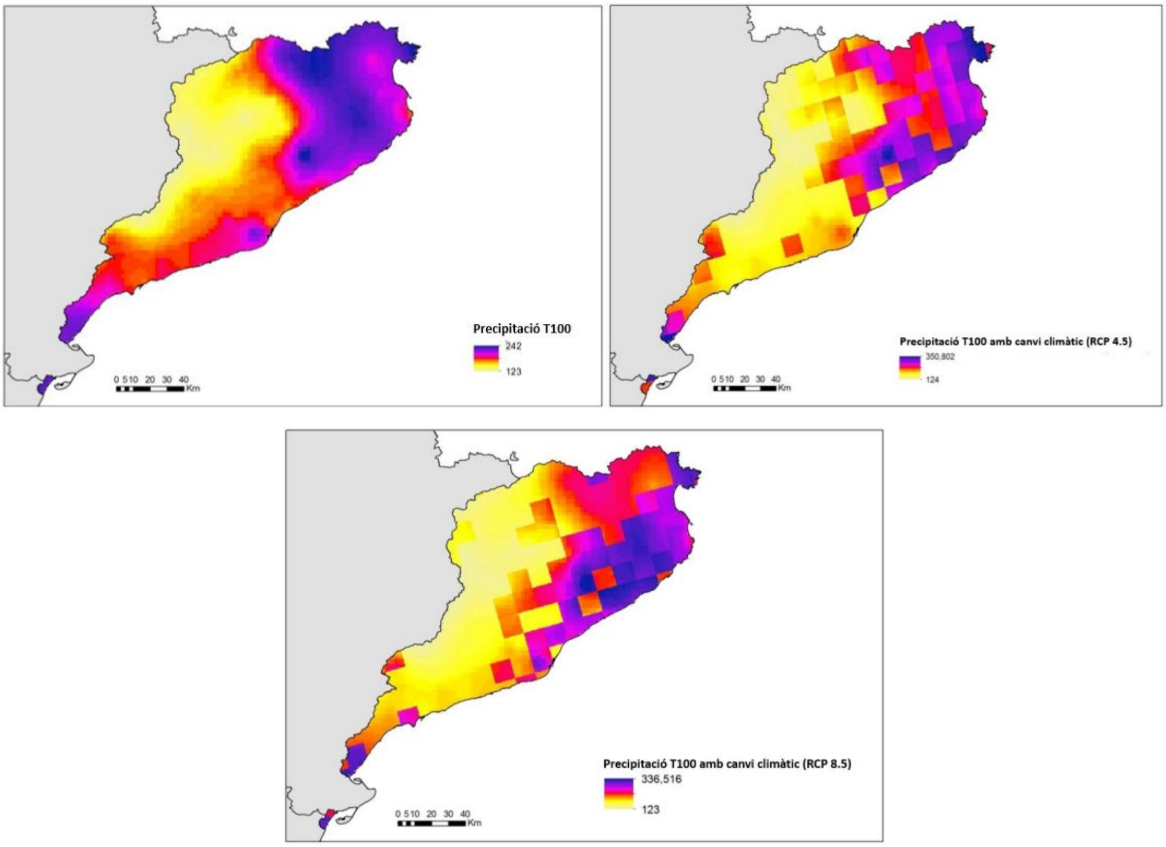

Figure 7. Daily maximum precipitation for a return period of 100 years, for the actual period (up left), the RCP 4.5 (up right) and the RCP 8.5 (bottom) (source: https://aca.gencat.cat/web/.content/30_Plans_i_programes/20_Gestio_del_risc_inundacions/2n-cicle-de-planificacio/APRI/07_Canvi_Climatic_CA.pdf).

2.1.2 Flow frequency

In Catalunya, according to Llasat et al., (2005), Barrera-Escoda and Llasat (2015) and Llasat (2014) in general, there not observable trends about flash flood events episodes. However, a positive trend is observed for extraordinary floods events are considered. For the period 1301 – 2012, a slight positive trend is also show for catastrophic floods in the Costal Basins, and, specially for the area of Barcelona.

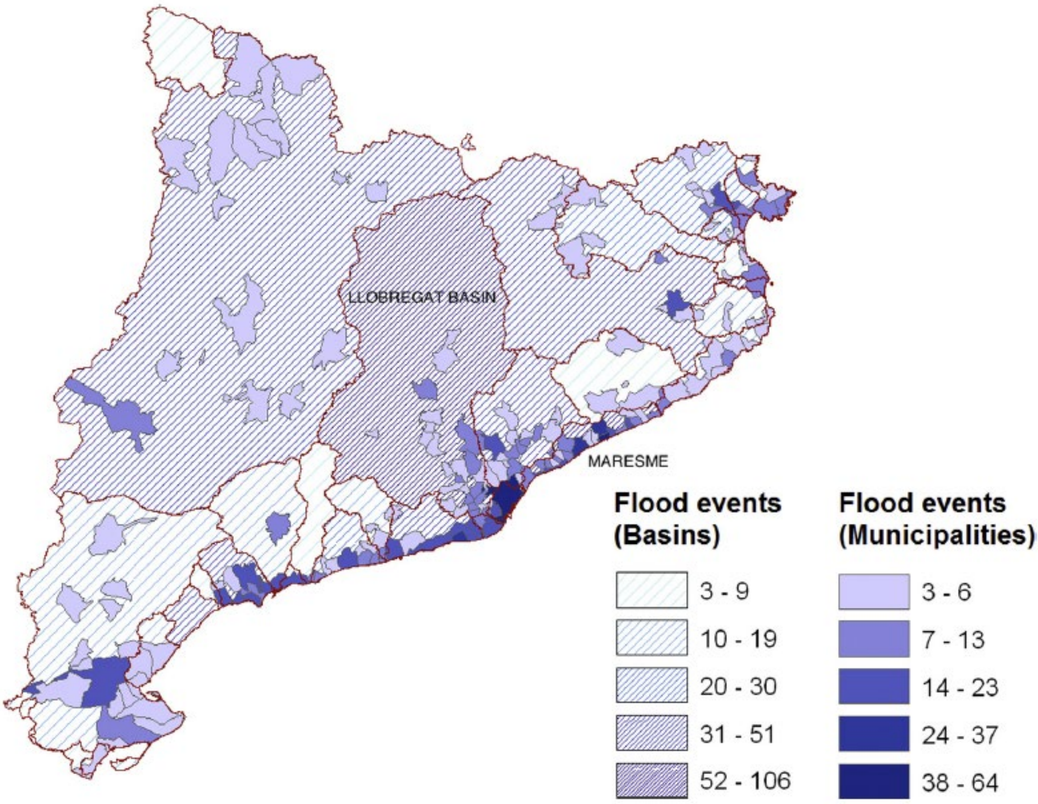

Figure 8. Distribution of the number of flood events in Catalonia by catchment (1981 – 2010). The municipalities that have recorded three or more flood events during this period are displayed (source: Llasat et al., 2016).

The figure 9 show how flood events have evolved in Catalonia, from the period 1900 – 2011.

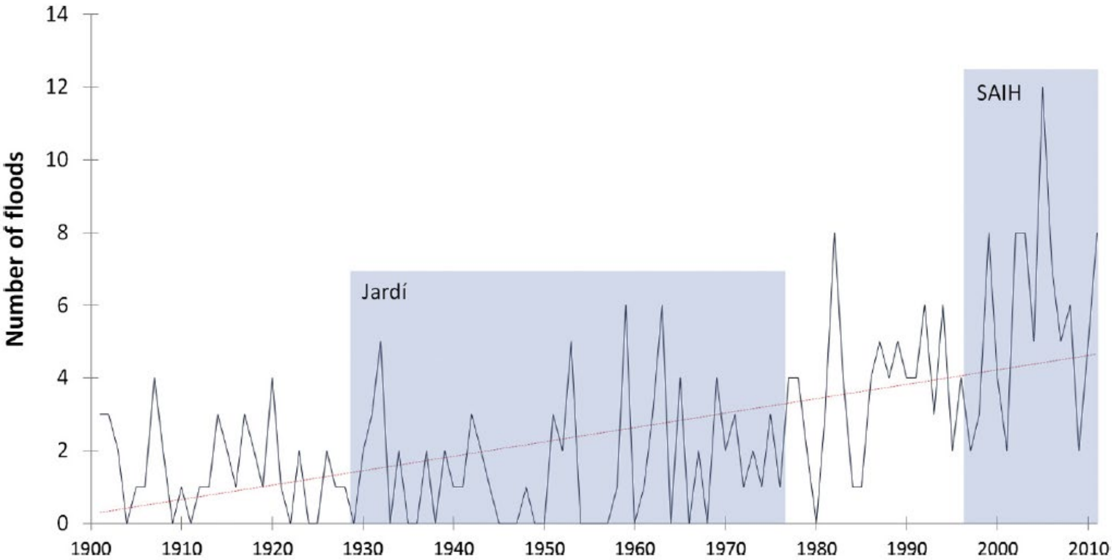

Figure 9. Flood event evolution in Catalonia (1900 – 2011). The line shows the linear trend (significant at 95% following Man Kendall method) from 1900 to 2011 (source: Llasat et al., 2016).

It was observed that over this period, 216 flood events were extraordinary and 61 events caused catastrophic damage. The positive trend observed can be due to increase in related extraordinary events in terms of vulnerability and exposure changes, land uses changes, precipitation trends or the criteria used to record floods (Llasat et al., 2016).

The later period also shows a psotive trend in flash floods caused by precipitations that lasted les than 1 day. The seasonal analysis reveals that this trend is mainly due to a positive trend in July-August-September period which is especially important over the last decade. 0.3 flash flood events per decade and 0.8 flash flood events per decade (95% significance) for the periods 1900 – 2011 and 1981 – 2011, respectively (Llasat et al., 2016).

Additionally, the figure 10, shows changes to floods in Catalonia for the 1928 – 2011 for which sub-daily precipitation data is available. The first period does not show ant trends, and 1959 was the year with the highest number of flood events (6); a total of 78 flood events (ordinary events no included) were recorded (69 extraordinary, 31% catastrophic). 46% of the extraordinay events and 38% of these catastrophic events were caused by precipitation that lasted less than 1 day. Between 1996 and 2011, the total of 85 events showed a higher frequency of intermediate events (75% extraordinary flash floods) while 64% of them were caused by events that lasted less than 1 day (Llasat et al., 2016).

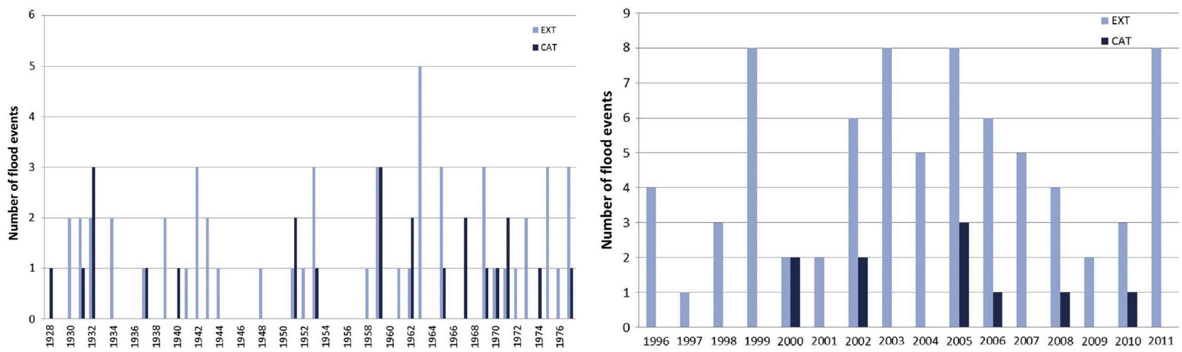

Figure 10. Flood events in Catalonia (1928 - 2011). EXT: Extraordinary flood events; CAT: Catastrophic flood events (source: Llasat et al., 2016).

2.1.3 Impact of the Gloria event in la Tordera and Climate Change implications

The effect of the Gloria storm was highly perceived in the costal region of Catalonia. The storm caused damages in infrastructure and human losses. Rainfall events reached to a maximum of 254 mm (Girona) and the return period of the event was considered to be 117 years. As It was analyzed in the point 2.1.2, the data show a positive trend on the frequency of this kind of events, and that might be attributed to the CC. The figures 11 and 12 show the effect and the damages produced by the Gloria event in January 2020 in the mouth of the river Tordera.

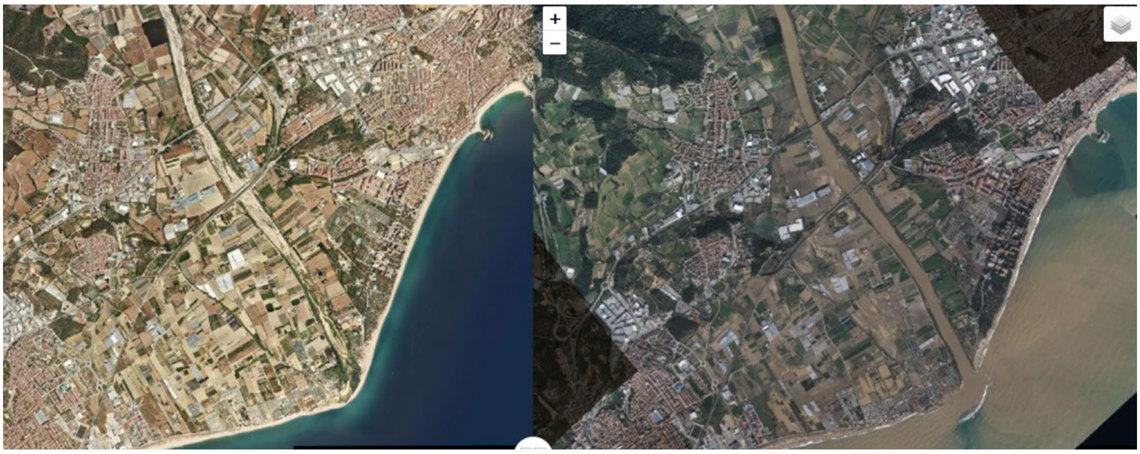

Figure 11. Effect of the storm in the delta of the river Tordera.

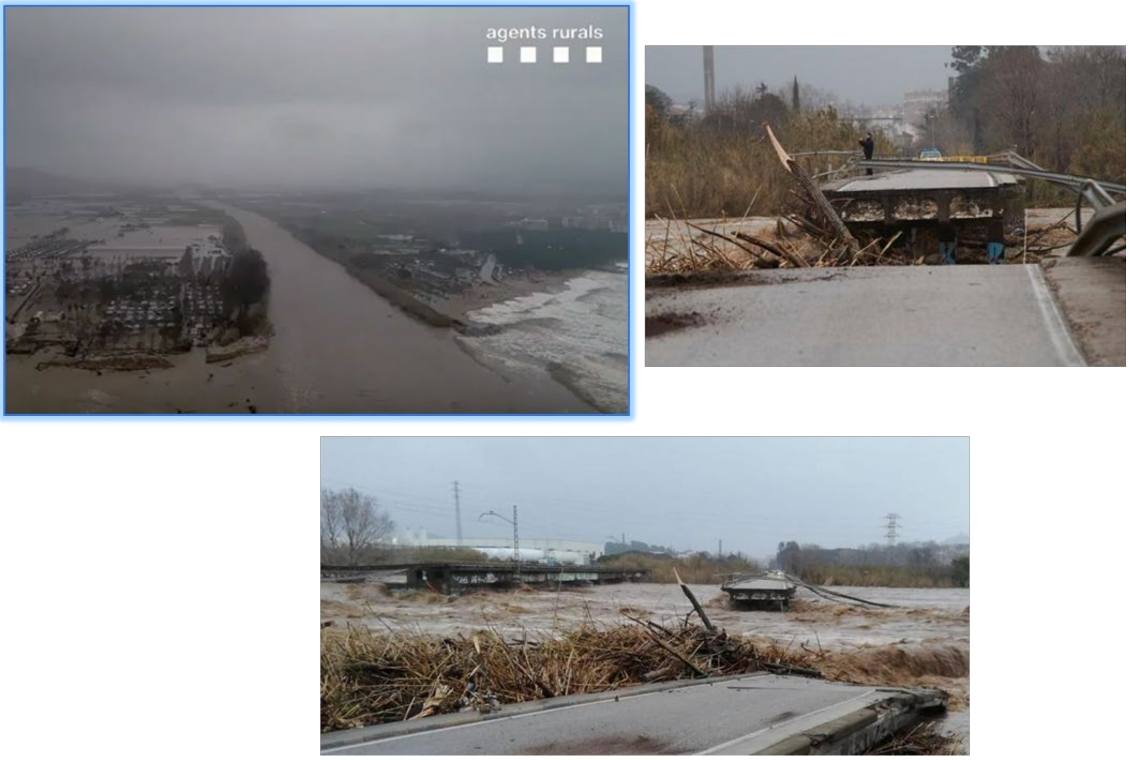

Figure 12. Damages caused by the flood in the delta of the river Tordera.

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 (figure 13).

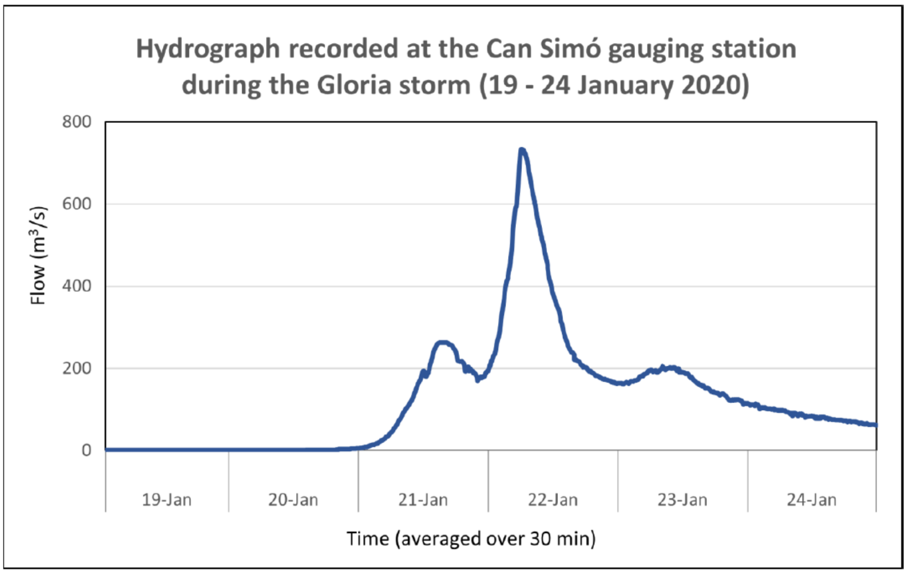

Figure 13. Observed hydrograph obtained from the Can Simó gage station.

Future endeavors must be in the line of the information presented in this report. This include the evaluation of the last CC scenarios (SSP) in order to update the current information and at the same time to propose valid methodologies to assess the impact of the CC in flash flood events. These impacts cannot be only assessed in term of analytical calculations, they also need to be linked to actual impact on population, which means that the analysis need to be projected locally and available to the public and stake holders. Thus, it is necessary the use of risk and flood assessment tools in order quantify impacts and provide strategies to mitigate future events that might be propelled by the Climate Change processes.

3. References

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