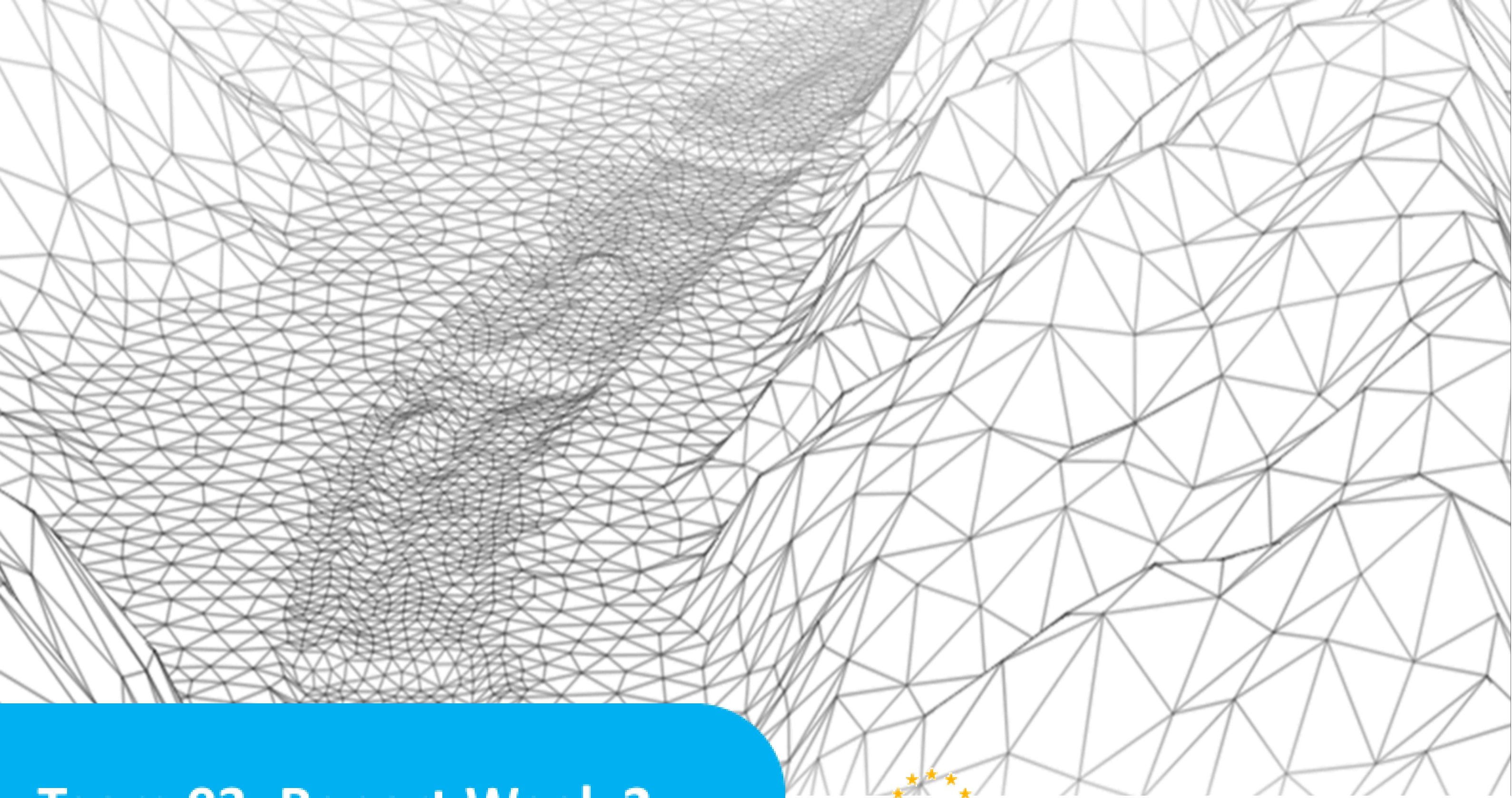


Team 03: Report Week 2

HYDROEUROPE

Erasmus+ Programme Cooperation Partnerships
2022-1-FR01-KA220-HED-000089658
HydroEurope

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

Team 3 - Report Week 2:
GIS Pre-Processing of Spatial Catchment Data

A.B. and C.D, Team 03
Version 2.1 - 12 Jan 2023

1 Introduction

During this final week of hydrological investigations in the Tordera River Basin, our focus is directed towards three major objectives. Firstly, we are engaged in constructing a hydraulic model using the powerful tool Telamac. This process is crucial for a deeper understanding of the complex dynamics of the region and for anticipating hydrological variations.

Simultaneously, our goal is to complete the hydrological model utilizing the Hydrologic Modeling System (HMS). By refining parameters and incorporating the latest data, we aim to provide the most accurate representation possible of the water flows within the Tordera Basin.

Lastly, a significant portion of our efforts is dedicated to verifying potential errors identified during the first week, with particular attention to the peculiarities observed in the Intensity-Duration-Frequency (IDF) curve. This validation step is of paramount importance to ensure the reliability of our results and to gain a better insight into the hydrological specifics of the region.

In summary, this week will be marked by a methodical and in-depth approach, focusing on the construction of the hydraulic model, the completion of the hydrological model, and the resolution of any anomalies detected earlier, contributing to a better understanding of the hydrological dynamics of the Tordera Basin.

2 Resume online phase

2.1 Catchment Characteristization

Building upon the overview of the Tordera catchment presented in Week 1, we delve deeper into our study during this current week. Situated in the northeastern part of Spain within Catalonia, the Tordera catchment spans 872.40 km^2 and encompasses a significant altitude range of approximately 1705 meters, as illustrated in Figure 1, showcasing the digital terrain model of our study area. Notably, the highest elevations predominantly cluster in the North-West, creating a topographical contrast with the flatter terrains in the North-East and South-East regions.

The composition of the catchment's land use is a noteworthy aspect. Forests dominate the landscape, covering approximately 73% of the total area, making them the most prevalent land use category in the basin. Agricultural land follows closely, constituting 19% of the catchment, while urban areas account for 6.2%. Figure 2 visually represents the distribution of these land uses across the basin and for a detailed breakdown of percentages.

Understanding the intricate interplay between these diverse land uses and their potential implications on the hydrological dynamics of the Tordera River Basin is pivotal for our ongoing study. This week, our focus on constructing hydraulic and hydrological models, as well as addressing anomalies identified in the first week, aims to enhance our comprehension of the basin's unique characteristics and contribute to effective water resource management in the region.

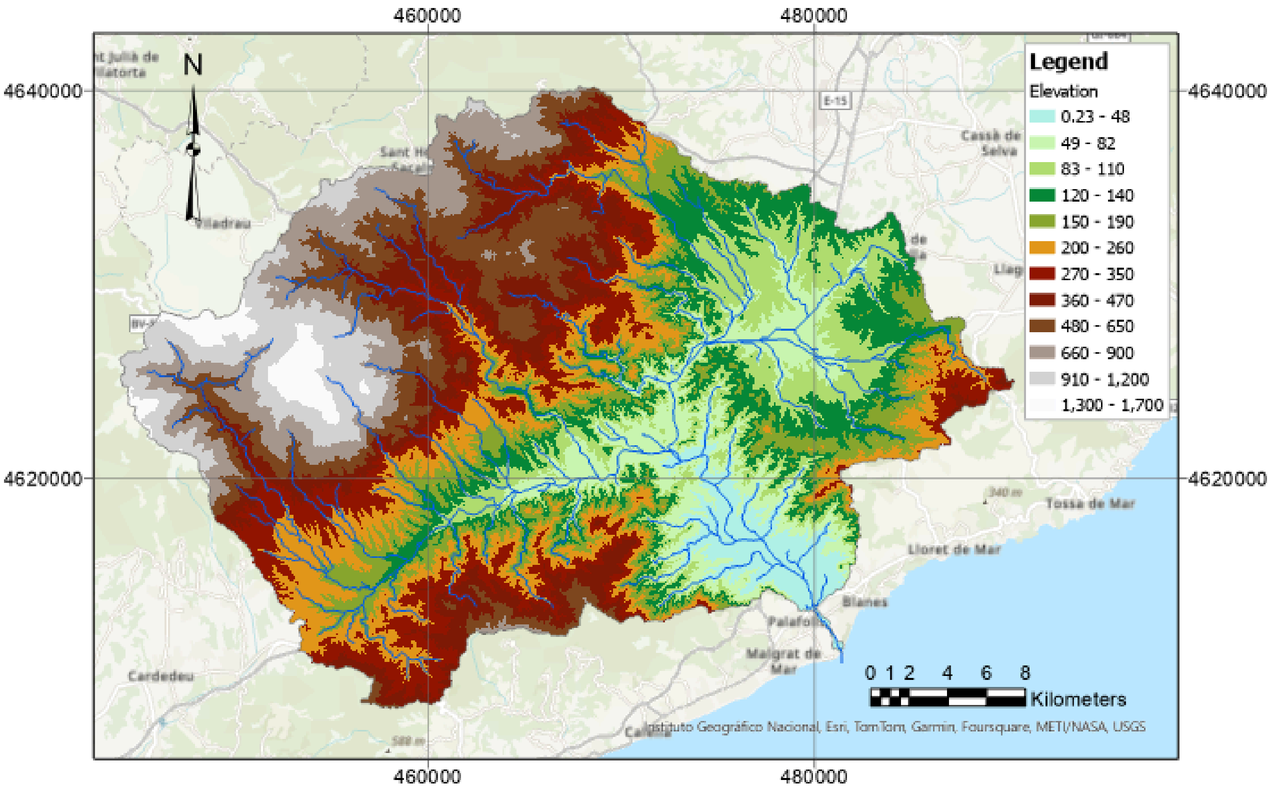


Figure 1: Tordera catchment digital elevation model.

Hydrological and meteorological data, in the form of time series obtained from measurement stations, constitute the foundational information for constructing the hydrological model of the catchment. In this context, the Can Simó flow gauge station is identified as the outlet for the catchment. This smaller basin is deemed representative of the entire catchment, encompassing 89% of the total contributing area, equivalent to 775.70 km2. The delineation of the basin from the Can Simó station is depicted in Figure 3. To enhance our understanding of the hydrological characteristics of the catchment and provide additional detail to the study, the catchment has been subdivided into four subcatchments, as illustrated in Figure 2.

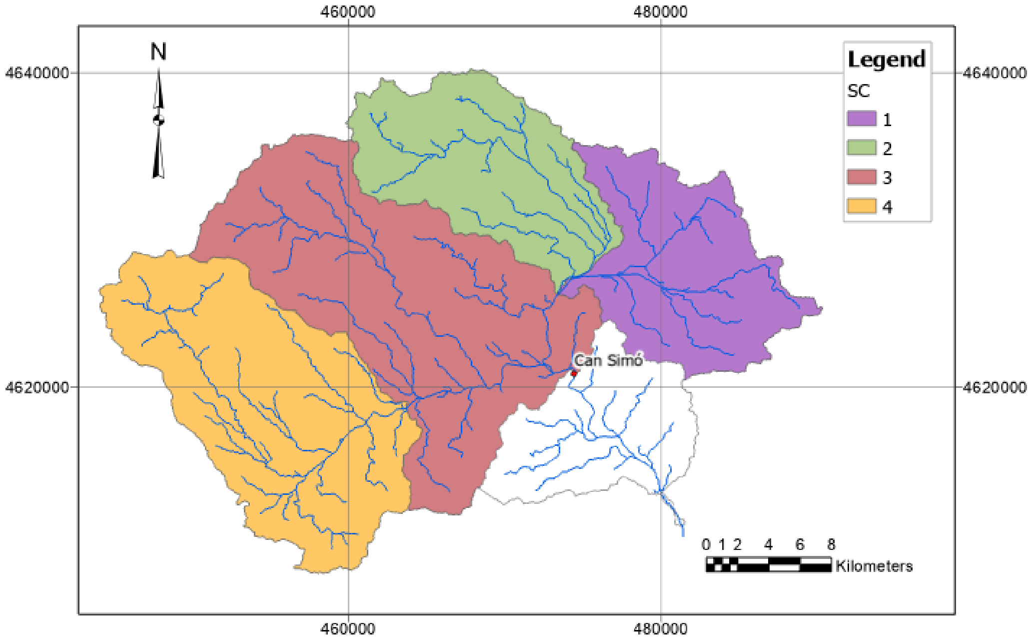


Figure 2: Subcatchments considered.

2.2 Hydrometeorological data analysis: Historical Data

Similarly, we had: Figure 4 illustrates the positions of hydrometeorological stations, totaling 14, where time series data for rainfall and temperature are available, along with flow data for Can Simó, covering various time periods. Within the basin boundaries, 13 of the 15 stations are situated; however, the remaining two, Blanes and Airport Girona, although slightly outside the basin, provide valuable data and will be included in the analysis. Notably, three stations—0267A, 0267B, and Breda—are located within 300 meters of each other. In this specific instance, the time series will be scrutinised to select only one dataset for constructing the model and subsequent climate change analysis.

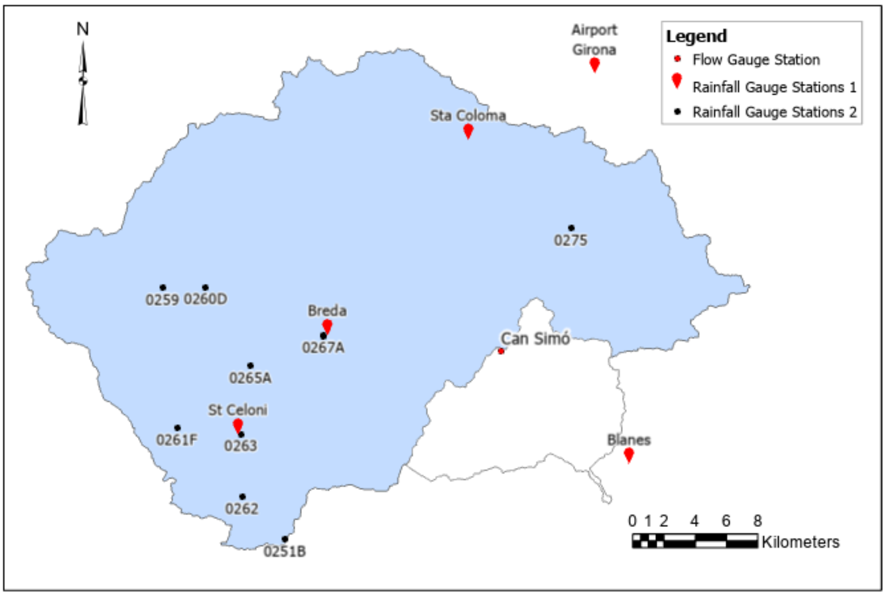
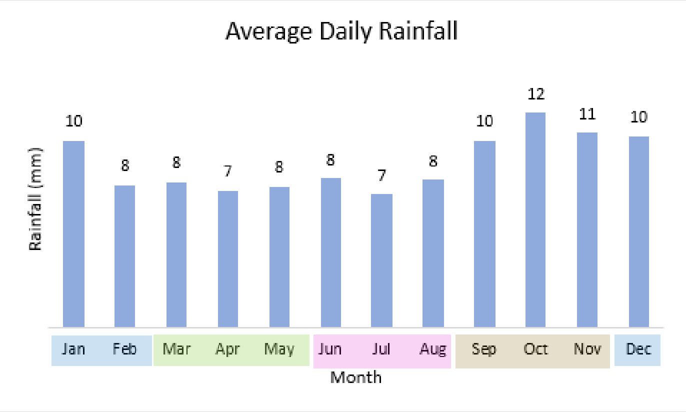


Figure 3: Location of Hydrometeorological stations.

Two main aspects are considered in the rainfall analysis, averages and maximums. The seasonality is of special interest within the frame of this study, and for this the historical data is analysed in monthly terms, considering the average and maximum values of precipitation across all stations. The wettest period in the catchment happens during fall time, where the maximum daily rainfalls have been recorded, 270 mm and 230 mm, in September and October, respectively. Nevertheless, heavy rainfalls have also occurred during the months of January and April. The aforementioned is also reflected in the average daily rainfall, where the wettest period is during fall, followed by winter, and the driest period occurs during summer.



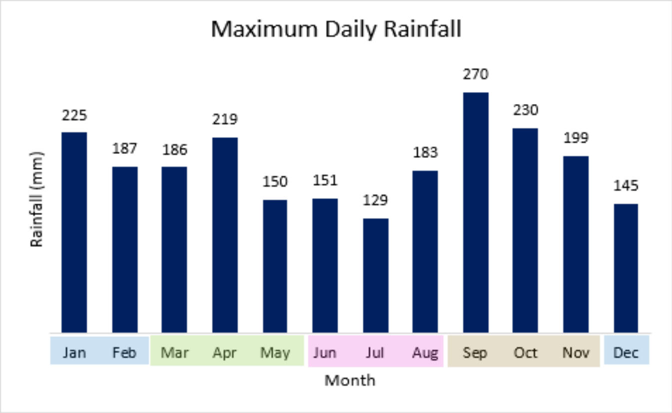


Figure 4: Average and Maximum Daily Rainfall for each month across all stations.

The temperature varies considerably across the catchment. Two stations are selected to depict this behaviour, 0259 and 0275, located in the highest elevation and in the basin's flatter area, respectively (see Figure 3). A clear contrast can be observed as illustrated in Figure 6. The most significant difference can be noted for the month of January with a difference of 20°C between the maximum daily temperatures registered at these stations. The monthly maximum and minimum temperatures registered for each month are shown in Figure 5, with temperatures reaching 45°C during summer. Nevertheless the records also show temperatures over 30°C across the whole year, which is of special interest for this study due to the effect temperature has in evapotranspiration processes considered in a long term simulation.

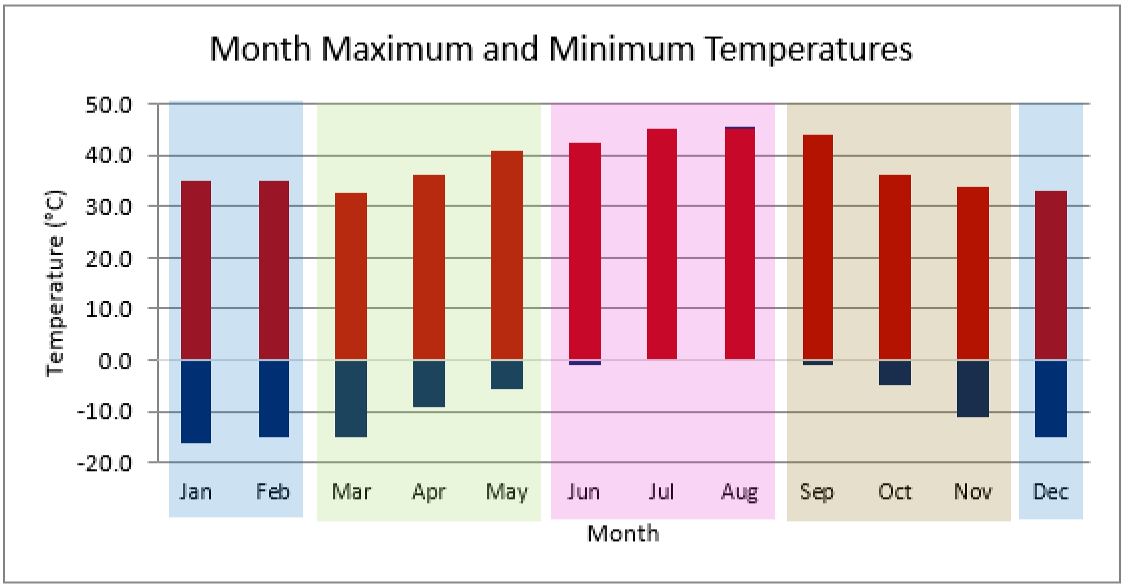


Figure 5: Maximum and Minimum Temperatures registered for each month across all stations.

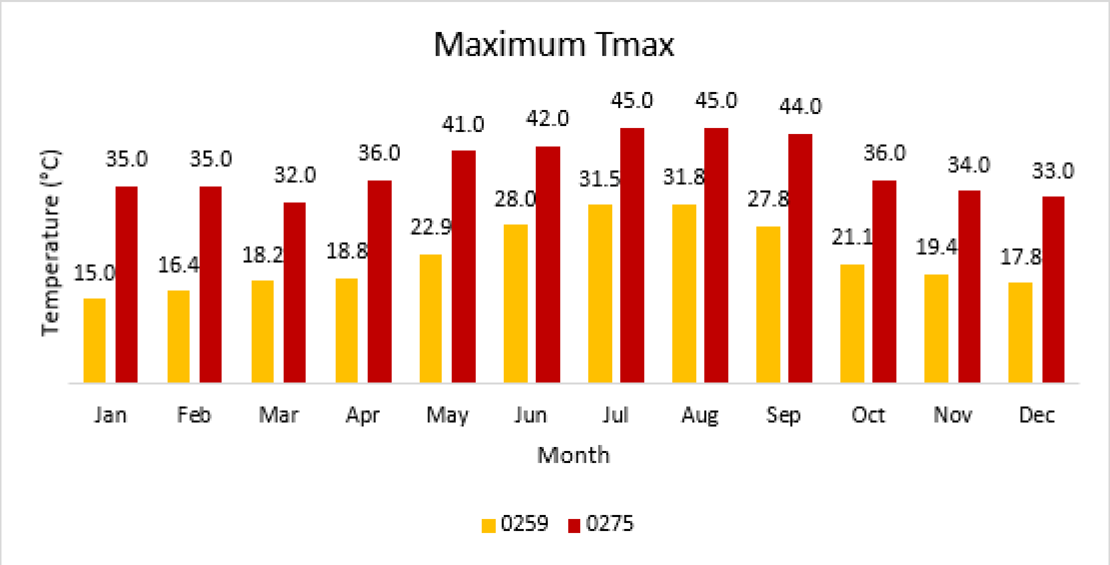


Figure 6: Maximum and Minimum Temperatures registered at stations 0259 and 0275.

2.3 Collecting auxiliary information

During the first week and the online phase, we made a conscious decision to refrain from pursuing additional or supplementary data collection. This choice was motivated by the intricacies associated with managing highly accurate data spanning multiple years, a task demanding substantial computational resources. Furthermore, provided the model is appropriately calibrated, it should be proficient in generating the required values without relying on excessively detailed data. Our methodology involves running the model with less precise data to facilitate calibration and validation processes. Additionally, the inherent challenge of acquiring precise data for our study area played a significant role in influencing this decision, as obtaining such data could potentially modify the quality and reliability of the obtained results.

2.4 Rainfall spatial distribution: building hydrological model

Once the gauge stations to build the model have been defined, the Thiessen polygon method is used to establish the area covered by each station for each subcatchment, distributing spatially the rainfall records available. These areas are presented below in Figure 7.

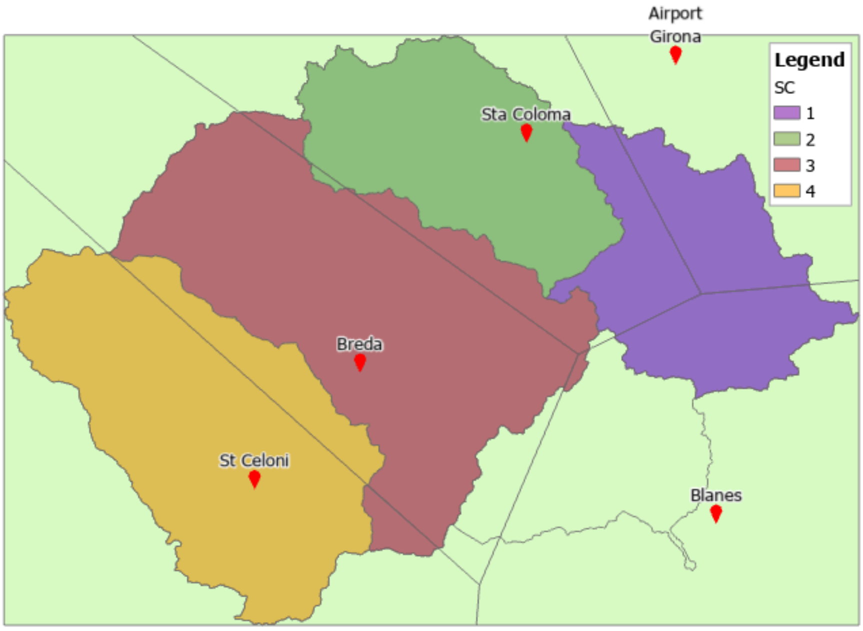


Figure 7: Thiessen Polygons for the gauge stations.

2.5 Definition of infiltration method and parameters

The Soil Moisture Accounting (SMA) loss method, included in HEC-HMS software, was selected as the loss method for the hydrologic model.

2.6 Definition of evapotranspiration method and parameters

The parameters

HMS offers a choice of different methods, and we chose the Priestley Taylor method for its simple and less data-intensive implementation, adapted to the climatic conditions of the study region. Although less complex, it offers acceptable results, particularly when absolute accuracy is not paramount. This method aligns with our hydraulic modeling objectives by offering a pragmatic and efficient solution.

In the Priestley-Taylor method, the Dryness Coefficient (Kd) is often between 0 and 1.
Low values of Kd (close to 0) indicate wet conditions, where evaporation is limited by factors other than net radiation, such as water availability.
High values of Kd (close to 1) indicate dry conditions, where evaporation is mainly limited by the net radiation available.

Sub-catchment	α (Dryness coefficient)
4	0.7672
3	0.7673
2	0.7708
1	0.7558

Table 1: Dryness coefficient for each subcatchments.

The results, with an average of 0.765, seem consistent given the location of catchment.

2.7 Definition of baseflow method and parameters

HMS offers a choice of different methods, and we choose a constant method because it is simple and computationally efficient. After analysing the Excel data, we obtain the following averages for flow between 1984 and 2008.

Month	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Mean	5.63	5.13	3.59	3.55	3.50	1.58	0.33	0.32	0.63	2.69	2.78	6.09

Table 2: Flow in m3/s for each month (baseflow)

We chose the Constant Monthly Base Flow method in the HMS hydrological model because we have monthly average data over a 30-year period. This approach uses these monthly averages to consistently estimate baseflow, providing a robust and simplified method for representing baseflow in our hydrological model. It is particularly suitable where detailed baseflow data is not available, but average monthly values are available over an extended period.

2.8 Hydrological Model Setup

HEC-HMS is a power tool for hydrological watershed modelling due to its comprehensive simulation capabilities, spatially distributed modelling support, integration with GIS data, and robust verification tools. In order to build the HEC-HMS model, the first step is to import the terrain data into the basin model. With QGIS, it is possible to extract the elevation from the DTM of la Tordera catchment and import it to HEC-HMS.

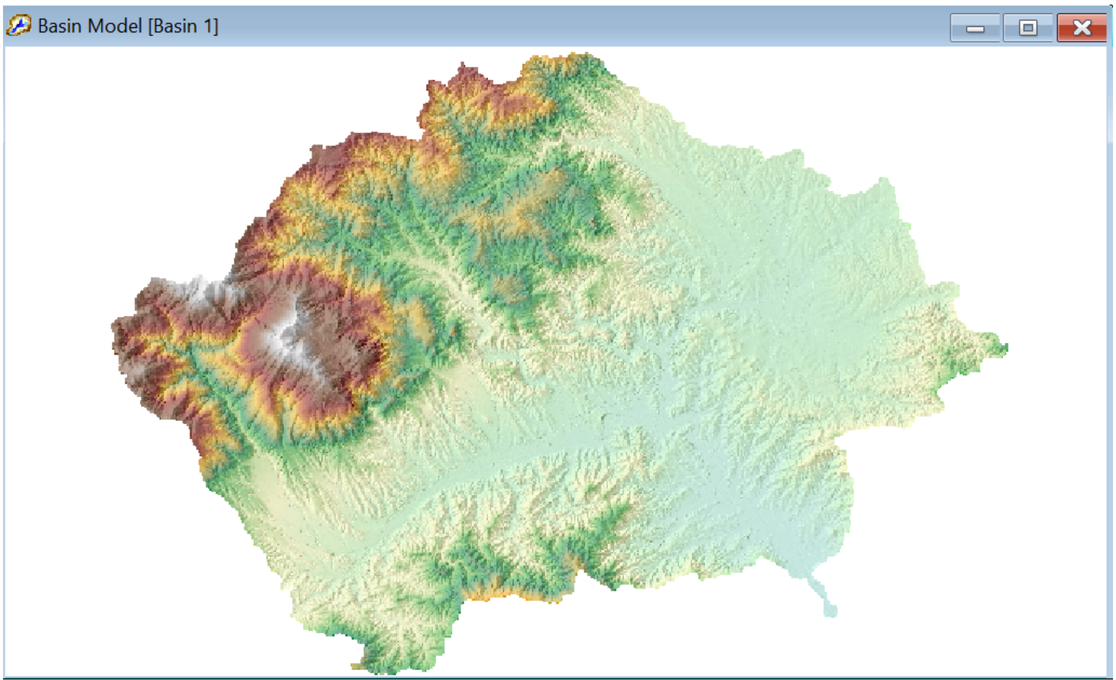


Figure 8: Terrain data of the basin model on HEC-RAS.

Then, after preprocessing GIS basin (process sink and drainage), HEC-HMS identifies the stream within a 15 km² area. Thanks to the outlet indication, HEC-RAS delineates the sub-watersheds.

The representation of reality by the HEC-HMS model relies on precise calibration, accurate input data, and relevant model parameters. If well-calibrated with reliable data, the model has a higher likelihood of reflecting reality. However, models are simplifications, and inherent uncertainties exist. Validation with independent data is crucial to assess model performance. While the model is a useful tool, it should be viewed as an approximation rather than a perfect representation of reality.

2.9 Calibration and Validation periods

Considering the period of available discharge data for Can Simó Gauge, we used a section of data to calibrate and validate our model. The calibration period was between 1/11/1995 - 30/04/1997. This period was chosen to calibrate against as this was the longest period of available data without any gaps and included several peaks that could be calibrated against. The peaks are critical to the calibration period to ensure that the model accurately portrays these values, ensuring our future projection outputs are reliable. Additionally, the three validation periods included several large peaks, ensuring the calibrated parameters accurately modelled separate peaks from the calibration period. These three validation periods can be viewed in Table 3 with each period including a full dataset across the validation period. Once the model has been calibrated and passed the three validation periods within an acceptable tolerance, the model will be used to project future flow.

	From	To
Calibration	1-Nov-95	30-Apr-97
Validation 1	1-Apr-00	1-Apr-01
Validation 2	1-Mar-02	1-Jun-03
Validation 3	1-Jun-03	1-Jun-04

Table 3: Calibration and Validation Periods.

2.10 Model calibrated and validated

Methods selected for calibration:

During the calibration of the model, methods and parameters were adjusted in order to reproduce in the best possible way the registered data. In the next table, the selected methods and are shown:

Process	Method
Canopy	Simple canopy
Surface	Simple surface
Rainfall	Gage weights
Evapotranspiration	Specified ET
Loss	SMA
Baseflow	Linear Reservoir
Routing	Muskingum

Table 4: Processes and Methods selected for the Hydrological Model.

The information for the previous methods was provided to the model. Then, the SMA loss method parameters were adjusted to produce the best fit between observed and simulated data. The values shown in the next table gave the best fit for the baseflow on the long-term simulations for the calibration period (01/Nov/95 - 30/Apr/97).

Parameter	Units	Selected value
Canopy storage	mm	2
Surface storage	mm	7
Infiltración máxima	mm/h	5.5
Tension storage	mm	20
Soil depth	mm	SC1 323 SC2 95 SC3 467 SC4 35
Percolation	mm/hr	5
GW1 Storage	mm	200
GW1 deep Percolation	mm/hr	3
GW1 Coeff	hr	SC1 45 SC2 109 SC3 158 SC4 76

Table 5: Parameters' values.

In the previous table, the infiltration rate was the most sensitive parameter influencing the peak discharge simulated values. As the peak values are the most important results out of the simulations on this project, this parameter was tested with several values around an initial calibration value, specifically 3.2, 3.5, 3.6, 3.8 and 5.5 mm/hr.

To select the best value among the tested ones, two approaches were implemented to select the parameter that best fit the peak values. The first one consisted of using the simulated values for the historical period to fit a GEV distribution and to find the extreme values associated with several return periods, and assess the most similar value. The second approach was to calculate the average value of the punctual discharges surpassing a selected threshold (30m3/s) and compare the different results with the historical measured series.

Infiltration rate (mm/h)	Return period (T)				Mean value of peaks > 30 m3/s
	50	100	200	500	
3.2	378.79	472.30	581.92	756.60	83.2
3.5	318.27	397.15	489.74	637.53	78.1
3.6	309.67	387.93	480.14	627.94	76.2
3.8	293.12	372.16	466.91	621.92	72.6
5.5	167.92	251.38	375.92	639.52	53.3
Historical		210.7	225.75		54.5

Table 6: Discharge results for different return periods.

According to the results of the two approaches, the best infiltration rate and therefore the one selected for the model predictions is 5.5 mm/hr.

2.11 Analysis of the model's results

Considering the main purpose of this study is to address the occurrence of flash floods in the basin, the main goal was to achieve a model able to reproduce a good approximation of the registered peak flows while also capturing the baseflow behaviour.

The performance of the hydrological model is evaluated based on a qualitative (visual) and quantitative basis. In terms of the former, the calibration period results, presented in Figure 9, are satisfactory. On one hand, three out of four peak values that occurred during this period are overestimated, although captured by the model, while the remaining one is underestimated. Nevertheless, the baseflow during this period has been sufficiently reproduced by the model. As for the validation periods, the peaks are considerably underestimated, which can be seen in the results presented in Figures 10 to 12 for each validation period. Once again the baseflow results are sufficiently similar to the observed discharges at the gauge station.

The quantitative assessment is based on two performance criteria: the Nash-Sutcliffe Efficiency (NSE) and the Root Mean Squared Error (RMSE). It is important to bear in mind that values closer to 0 represent a better performance for the RMSE criterion, while for NSE this is the case for values closer to 1. A summary of the results is described in the table below. Contrary to what it was expected, the validation periods overperformed the calibration.

	From	To	NSE	RMSE
Calibration	1-Nov-95	30-Apr-97	-0.73	18.38
Validation 1	1-Apr-00	1-Apr-01	0.55	6.03
Validation 2	1-Mar-02	1-Jun-03	0.23	9.64
Validation 3	1-Jun-03	1-Jun-04	0.22	10.5

Table 7. Model's performance criteria.

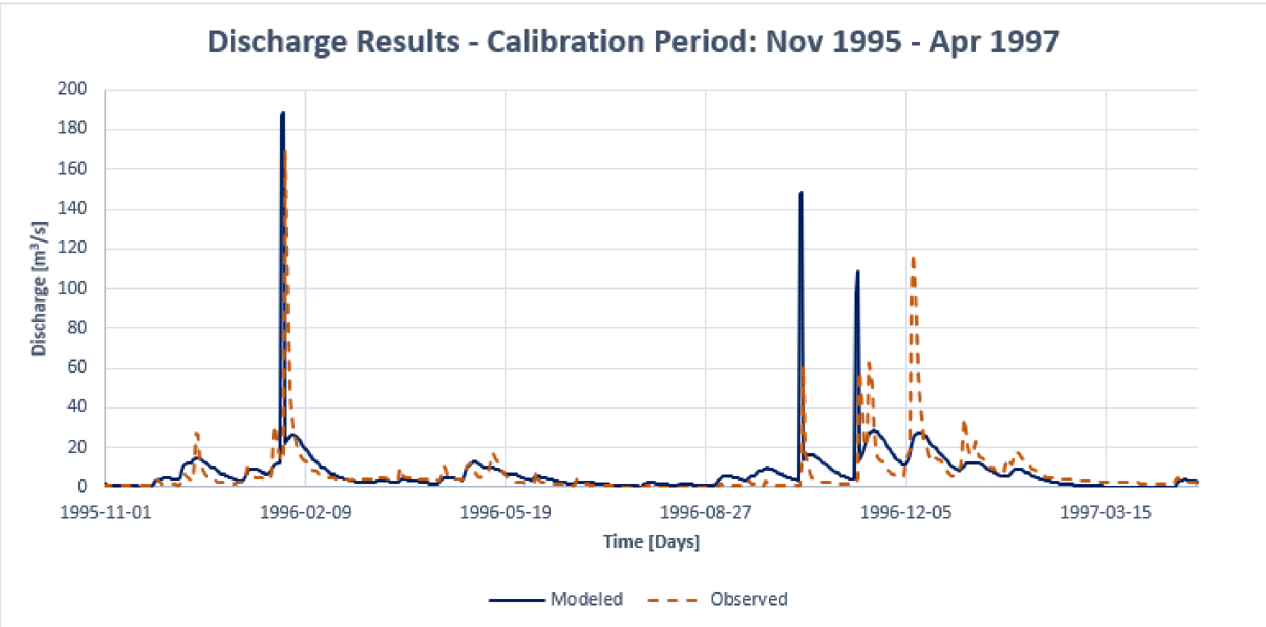


Figure 9. Discharge Results for the Calibration period.

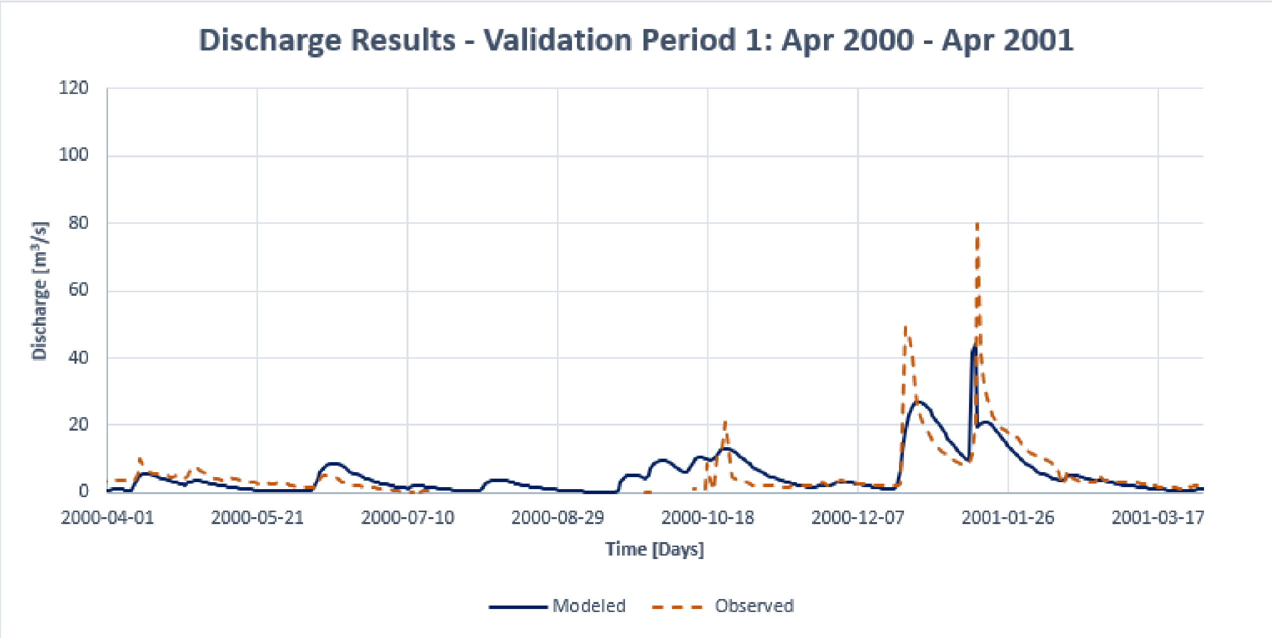


Figure 10. Discharge Results for the Validation period 1 from April 2000 to April 2001.

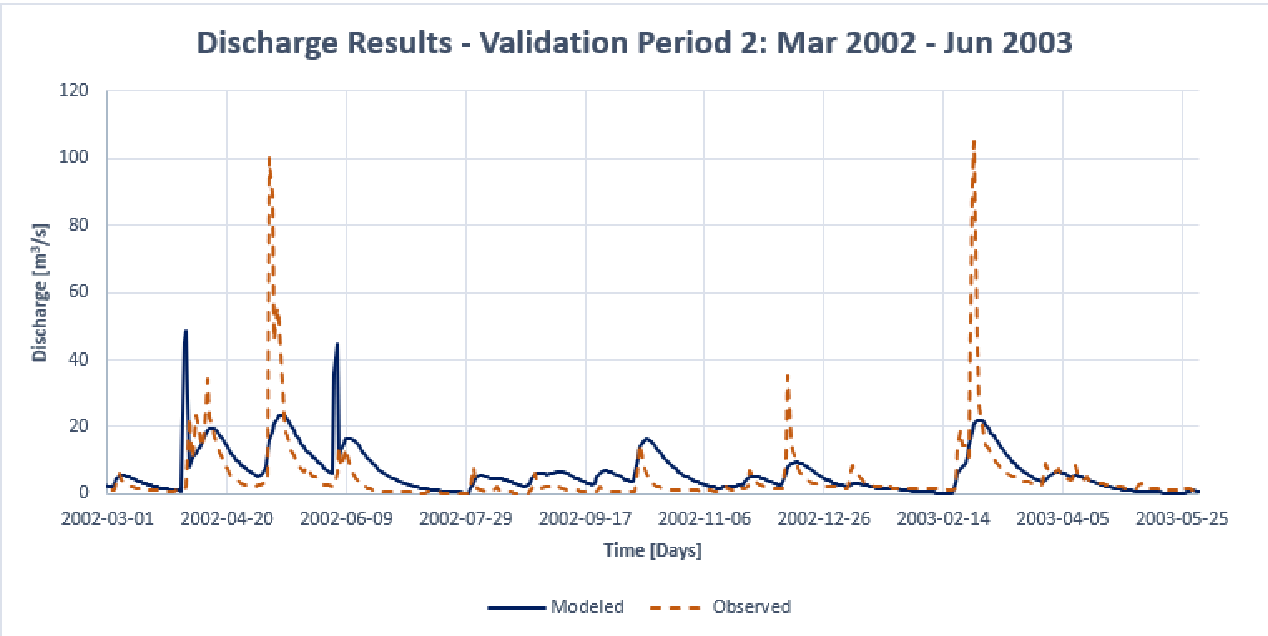


Figure 11. Discharge Results for the Validation period 2 from March 2002 to June 2003.

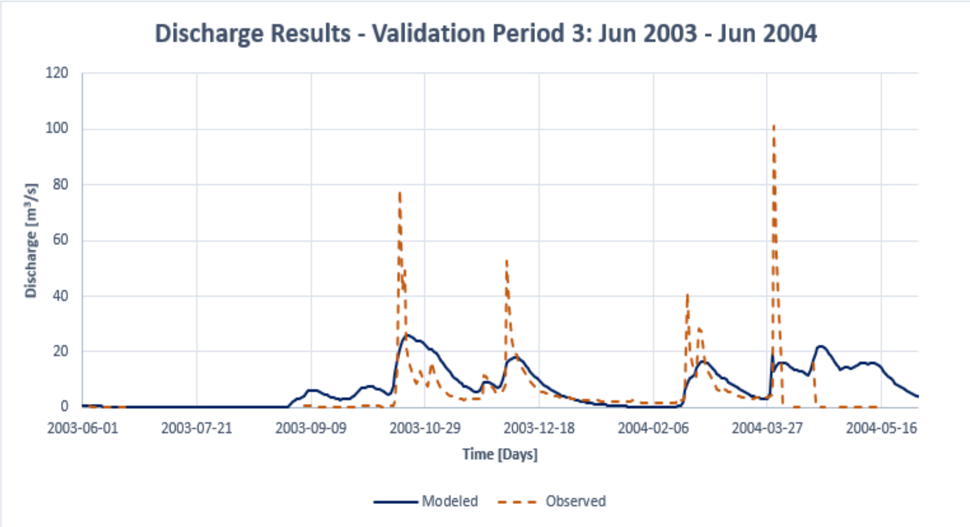


Figure 12. Discharge Results for the Validation period 1 from June 2003 to April 2004.

Rainfall analysis:

In this section, we focus on the statistical study of rainfall recorded at the measuring station downstream of the Tordera watershed.

We have a set of rainfall and flow data covering the period from January 1, 1984, to December 31, 2008.

The first step is to calculate average monthly rainfall for each year and for each station. Given the sheer volume of data to be processed, we need to use a VBA macro (Appendix).

The values are divided into 10 intervals between the minimum and maximum values. Cells are coloured according to the interval in which they lie. The higher the cell value, the darker the colour, and vice versa. As we would expect from a Mediterranean watershed, rainfall is higher on average in autumn and spring, but particularly so in September, October, and November.

What remains to be determined is the intensity of rainfall events, the parameter that interests us most in the study of flash floods.

These data confirm that rainfall is distributed between spring and fall. October is consistently the rainiest month, while July is the driest. Rainfall intensity varies enormously from month to month, making it difficult to generalise about the exceptional rainfall that can affect the watershed. It can also be noted that rainfall varies over the time series.

Precipitation appears to be decreasing over the years, but more data is needed to confirm or deny this trend. Flash flood events are characterised by intense storms that produce heavy rainfall in a short period of time. For each station, it is possible to find the 10 days with the heaviest precipitation, in order to obtain the values from which to model flash flood events.

Achieving good calibration for an HEC-HMS model involves a systematic and iterative process to align the simulated results with observed data. Here are key steps to achieve effective calibration:

-Collect Quality Data: Gather accurate and representative data for precipitation, temperature, and streamflow. High-quality input data are essential for reliable model calibration.

-Understand the Watershed: Have a thorough understanding of the watershed characteristics, including land use, soil types, and vegetation. This knowledge helps in setting up model parameters accurately.

-Initial Parameter Estimation: Start with reasonable initial estimates for model parameters. These can be based on literature, expert knowledge, or regional values.

-Calibration Period: Select a specific time period for calibration, ensuring it covers a range of hydrological conditions. It's common to use historical data for calibration.

-Manual Adjustments: Fine-tune parameters manually based on hydrological insights and patterns observed in the calibration process. This step may involve adjusting parameters like initial soil moisture, baseflow, and runoff coefficients.

-Sensitivity Analysis: Perform sensitivity analyses to understand the impact of each parameter on the model output. Focus calibration efforts on parameters with significant influence.

-Validation: After calibration, use a separate dataset (not used during calibration) to validate the model. This helps ensure that the calibrated parameters generalise well to different hydrological conditions.

-Iterative Process: Calibration is often an iterative process. Refine the model, re-run simulations, and compare results until a satisfactory match between observed and simulated data is achieved.

2.12 Obtention and analysis of climate change scenarios for different GCM

For this investigation into the future impacts of climate change on the La Tordera catchment ten different climate change models have been explored. The use of these climate change models produces an estimated daily precipitation and temperature value for the next 100 years at ten climate change stations across the catchment. The outputs from the climate change model can then be inputted into the HMS model, allowing for comparison to current and past flows.

We accessed multiple climate change models (Access_CM2, BBC_CSM2_MR, CAN_ESM5, CMCC_ESM2, CNRM_ESM2, EC_Earth3, MPI_ESM1, MPI_ESM2, NOR_ESM2, and UK_ESM1) with key characteristics specific to each model, and we will need to select a model moving forward, considering various scenarios.

<u>Precipitation</u>

Figure 8 shows the 5-year average precipitation values for each of the climate change models across the Tordera catchment. The trends show that ssp126 has minimal change from the current climate however, ssp585 shows a dramatic reduction in precipitation from the current climate. The different climate change models show similar trends with peaks and troughs at similar points in the ssp126 scenario. On the other hand, the ssp585 scenario has more variation with model CMCC_ESM2 below the average and CAN_ESM2 above the average for the majority of time periods.

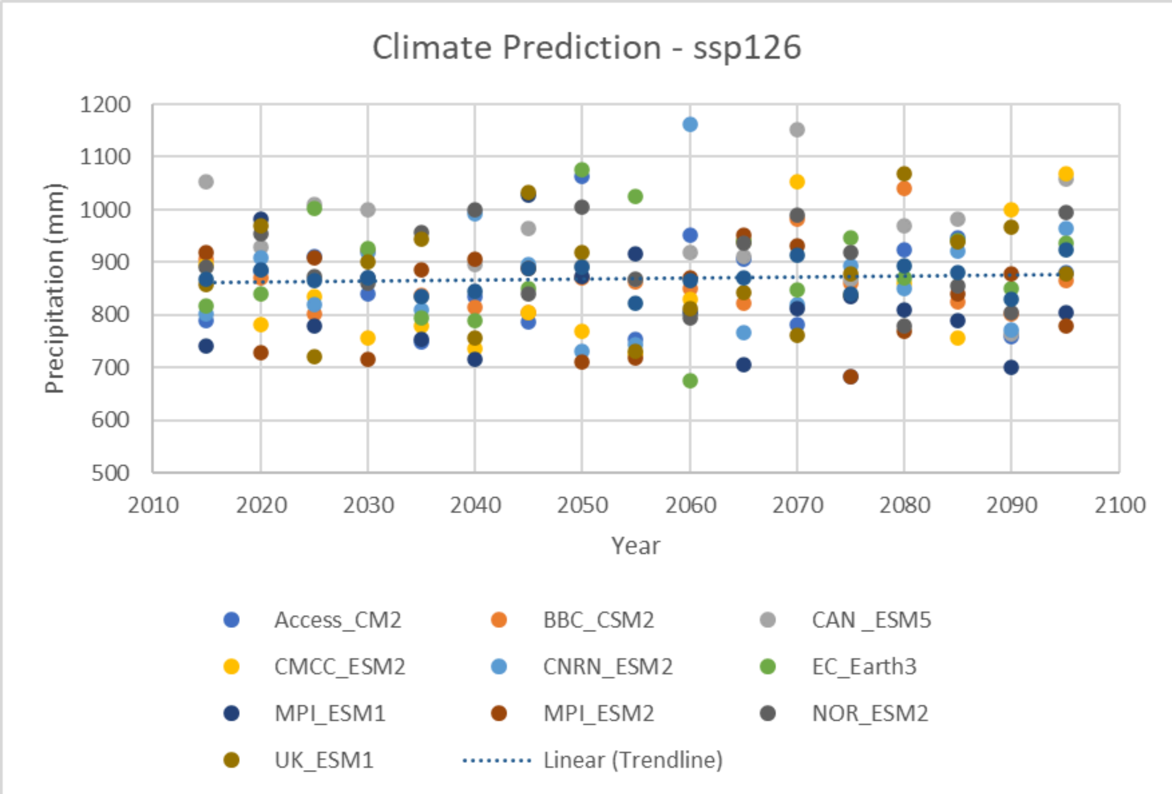


Figure 8: Climate projection for precipitation (ssp126)

<u>Temperature</u>

Figure 9 shows the temperature change between the current climate and 2100 for the ssp126 scenario. These Figures show that the average temperature is predicted to increase at both high and low temperatures in the majority of climate models investigated. The average temperature increase across the ten climate models is 1°C at the low and high temperatures.

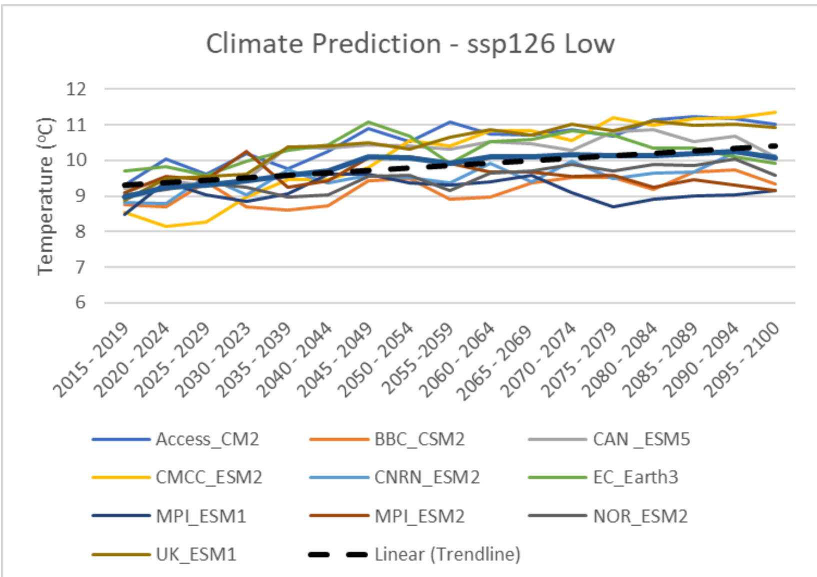


Figure 9: Climate projection for temperatures (ssp126 low)

3 Resume week one

3.1 Evapotranspiration

In estimating the evapotranspiration across the Tordera catchment's subcatchments, the Oudin method was employed due to its robustness and efficiency in handling diverse climatic conditions with minimal data inputs. This temperature-based approach calculates potential evapotranspiration (PET) by utilising readily available temperature data, alongside the latitude of the study area, to account for the energy available for evaporation. The simplicity of the Oudin formula, which integrates temperature thresholds and extraterrestrial radiation, makes it particularly advantageous for regions where comprehensive meteorological datasets might be scarce.

The application of the Oudin method within the Tordera catchment's analysis involved a detailed examination of the area's climate patterns, focusing on temperature variations to ascertain the PET across the five subcatchments. By correlating the daily mean temperature data with the specific geographic and solar parameters of each subcatchment, the study was able to generate accurate estimations of evapotranspiration rates. This methodology not only facilitated an in-depth understanding of water loss through evapotranspiration but also provided a solid foundation for water resource management and planning in the region.

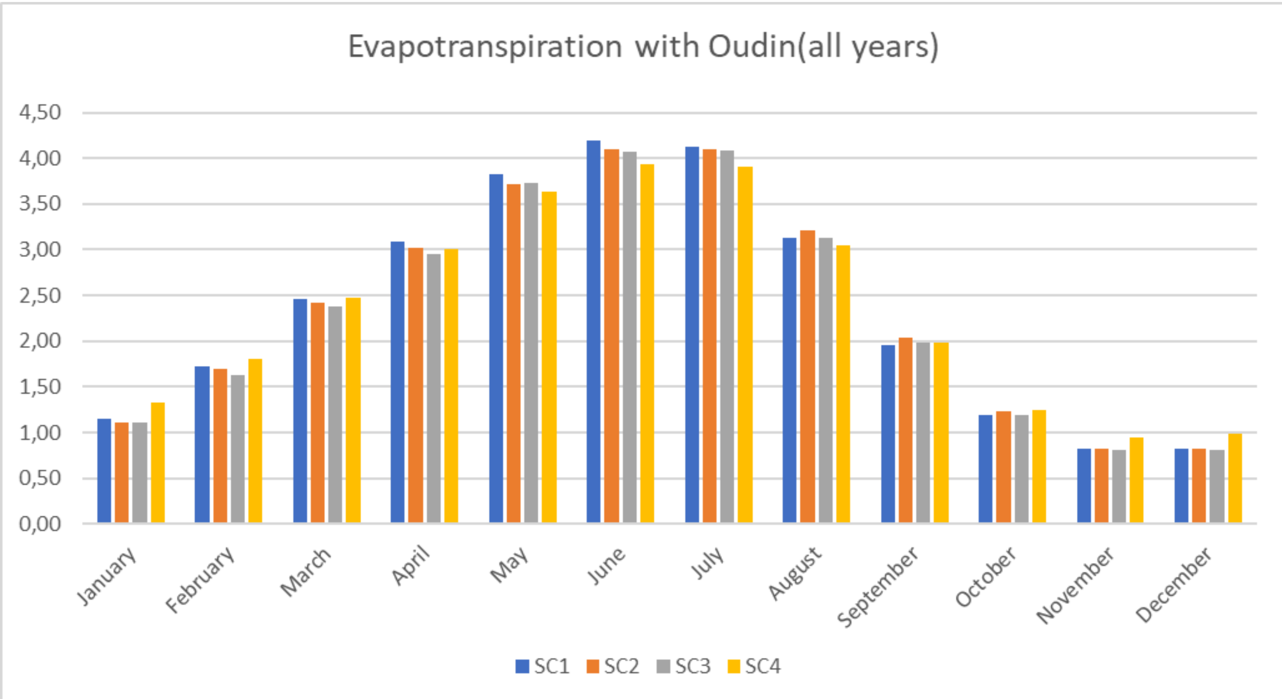


Figure 10: Evapotranspiration for Tordera (Oudin data)

3.2 Transformation

The transform method chosen to simulate the direct runoff in the model is the SCS Unit hydrograph, for which the lag time is needed and can be calculated in terms of the time of concentration. As for the peak rate factor the standard PRF 484 was selected for all the cases, meaning 37.5% of the total runoff occurs before the hydrograph's peak time.

The time of concentration is found based on the subcatchments' characteristics. The following equation was applied to determine this parameter, where: L = Longest flowpath in km and So = Longest flowpath slope in m/m.

$$t_c = 0.3 \left(\frac{L}{So^{0.25}} \right)^{0.75}$$

Subsequently, each subcatchments' lag time (in minutes) is calculated using the Temez Equation, which is specifically tailored for Spanish basins. Results are presented in Table 10.

$$t_{lag} = 0.35\, t_c$$

Subbasin	L [km]	Slope [m/m]	tc [h]	tlag [min]
1	19.60	0.00557	7.40	155.32
2	32.76	0.02525	8.19	171.95
3	36.71	0.04237	8.09	169.98
4	38.36	0.04158	8.39	176.28

Table 10. Subcatchments Time of Concentration and Lag time.

3.3 Infiltration : Soil Moisture Accounting (SMA) loss Method

The Soil Moisture Accounting (SMA) loss method, included in HEC-HMS software, was selected as the loss method for the hydrologic model. This method assumes the basin as a succession of storage layers. Therefore the infiltration water can move, first, through the soil profile and later through the groundwater layers.

The model is composed basically by the surface layer; the unsaturated zone of soil, namely *Soil profile* layer; and one or two Groundwater layers which are understood mainly as unconfined aquifers.

The process in the SMA model can be shortly described here. The water at the Surface level is available for infiltration towards the soil profile at the model infiltration rate. Consequently, the infiltrated water can percolate to deeper layers taking into account the maximum percolation rate and the storage available on them. Finally, the water on these groundwater layers will be routed back to the river as baseflow using a linear reservoirs scheme.

As a summary, the processes involved in the SMA model are shown in the next table.

	Inflow	**Outflow**
Canopy	Rainfall	Evaporation

Surface S.	from rain after canopy and in excess of infiltration	Infiltration, ET
Runoff	Rainfall when Surface S. is full	Runoff Hydrograph
Soil profile S.	Infiltration	Percolation to GW (upper) and ET (1st upper, 2nd tension storage) - ET rate reduced in tension storage (Adsorption). - Tension water doesn't drain by gravity
GW 1 | 2	Percolation from Soil profile when current soil S. > Tension S.	GW flow, percolation lower layers, Out of model (losses)

Table 4: SMA Model.

3.4 Climate change: Select a projection and different scenario

To validate a decision on a specific climate model a statistical analysis has been undertaken. This analysis will include the methods, Nash Sutcliffe efficiency, Root Square Mean, Bias, and Mean Absolute Error. To allow these methods to work effectively, 25 years of historical data will be compared to the first 25 years of each model in each climate scenario. The results from this investigation are not expected to produce scores which indicate a strong correlation between the model and the historical data, however, it will allow for a comparison between the models in relation to historical data from the catchment. This information, in addition to the desktop and visual analysis, will allow for a decision on the most accurate climate model for the La Tordera catchment.

Table 1 shows the results from the statistical tests that have been undertaken across the four models. The ideal score for the NSE test is 1, and the other three methods have an ideal score of 0. The results calculated indicate that the CMCC_ESM2 climate model outperforms the other three climate models in all methods and all scenarios. This result matches the results from the desktop study and the visual analysis, which also suggested that the Mediterranean model would be the best fit for the La Tordera catchment.

Model	Pathway	Bias	MAE	RMSE	NSE
CMCC_ESM2	ssp126	16.09	1.07	16.15	-1.35
	ssp245	8.61	1.05	8.64	-1.52
	ssp370	13.44	1.06	13.48	-1.26
	ssp585	6.55	1.04	6.57	-1.36
CNRN_ESM2	ssp126	21.91	1.08	21.98	-1.46
	ssp245	41.19	1.20	41.32	-1.83
	ssp370	19.68	1.09	19.74	-1.34
	ssp585	33.81	1.16	33.92	-1.71
EC_Earth3	ssp126	25.14	1.12	25.22	-1.65
	ssp245	33.62	1.15	33.73	-3.06
	ssp370	17.23	1.07	17.28	-2.32
	ssp585	34.49	1.18	34.59	-2.99
MPI_ESM2	ssp126	20.32	1.10	20.39	-2.34
	ssp245	30.56	1.14	30.66	-2.55
	ssp370	20.80	1.09	20.87	-2.54
	ssp585	23.48	1.13	23.55	-2.41

Table 4: Results from the Statistical Analysis of Climate Models

3.5 Routing method: Muskingum parameters

The Muskingum Method is a hydrological flow routing model that describes the transformation of discharge waves in a river bed using two equations. The first is the continuity equation (conservation of mass) and the second is the relationship between the storage, inflow and outflow of the reach (the flow storage equation). These equations are applied within a river section between two river cross-sections. This method is used to simulate the increase and decrease in channel storage during the passage of a flood wave. The initial parameters are determined using QGIS, and the model is then calibrated.

Estimation of initial values

Parameters that are required to utilize this method within HEC-HMS include the initial condition, K [hours], X, and the Number of Subreaches. The X values in the Muskingum parameter ranges between (0 to 0.5) and it represents wedge storage. X is a dimensionless coefficient with no physical significance. This parameter must lie between 0.0 (maximum attenuation) and 0.5 (no attenuation). For most river sections, an intermediate value is found by calibration. We take **X=0.35**, K is the time of travel between the inflow and outflow.

$$K = 0.18 \times \left(\frac{L}{S^{0.25}}\right)^{0.76}$$

We use this formula to calculate K, which we then enter into HMS. L is the length of the section in km and S is the slope of the section. We use QGIS to determine L and S. We need to calculate these parameters for 2 sections in the domain.

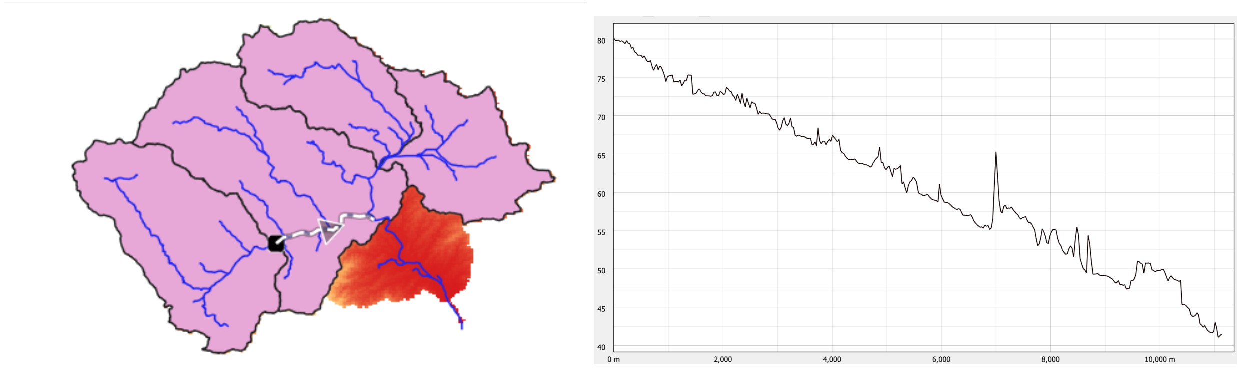


Figure 11: Reach number 1 and its elevation profile

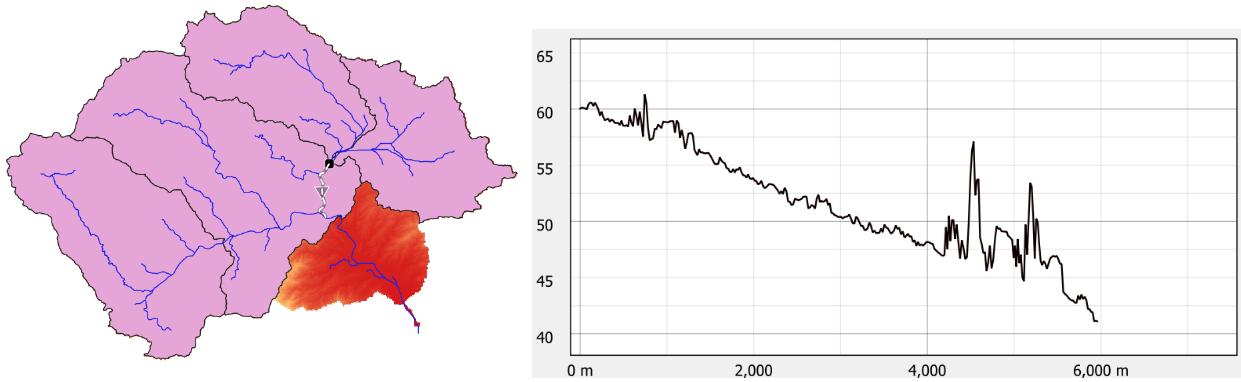


Figure 12: Reach number 2 and its elevation profile

We can therefore calculate the slope S with the elevation profile and measure the length L of each section to calculate the Muskingum parameter K.

	Reach 1	**Reach 2**
L [km]	10.7	6.1
S [m/m]	0.0039	0.003
K [h]	3.13	2.15

Table 5: Parameter for Muskingum

3.6 Frequency analysis of the discharge: Historic

In flood frequency analysis, the primary emphasis lies in delineating the correlation between the appropriate probability distribution, the magnitude of floods, and their frequency. To achieve this, a chosen distribution is applied to a dataset of observed flood occurrences. This enables extrapolating the relationship between flood magnitude and frequency beyond the observed range of occurrences.

In order to carry out a frequency analysis of flow, only years with a complete record for the hydrological year (around October to May) were taken into account (flow peaks should be located between these months).

Ultimately, we can only retain 11 years of uninterrupted data. The sample size is insufficient to accurately reflect true discharge levels for each return period, especially for higher return periods that are more strongly influenced by the distribution.

Frequency analysis was carried out using 4 methods: normal, lognormal, Gumbel and GEV (using Gumbel).

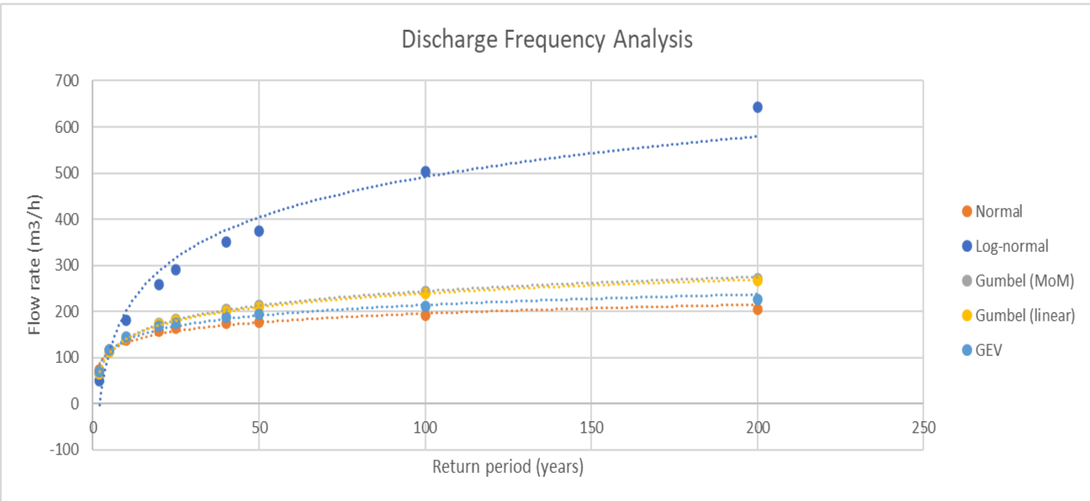


Figure 13: Historic Discharge Frequency Analysis

T (years)	normale	log_normale	Gumbel	GEV
2	73.116386	51.095962	64.23067	69.3
5	116.33497	116.929	112.04483	117.53
10	138.9195	180.22006	143.70196	144.74
20	157.55174	257.51637	174.06824	167.8
40	173.72021	351.00271	203.85338	187.85
100	192.50644	503.02919	242.82862	210.7
200	205.33856	643.19652	272.17549	225.75

Table 7: Analysis of Methods for Historic Discharge

The GEV, so Gumbel distribution, is often used to model extreme values or rare events. It is commonly used in reliability studies, hydrological studies and natural hazards, such as flash floods or extreme storms. The Gumbel distribution is often used to model the maximum or minimum of a data series, particularly when these extreme values are of primary interest. It is based on extreme value theory and can be more robust in modelling longer distribution tails than the normal distribution.

The Goodness-of-Fit test Kolmogorov–Smirnov was applied to check the adequacy of fitting of probability distributions to the observed data. To conduct the Kolmogorov–Smirnov test, the absolute difference between the empirical cumulative function of the data (non-exceedance data used for the P-P graph) and the cumulative density function of the distribution is calculated as $|F(x)ampirical - F(x)distribution|$ for each time step, in this case for each year.

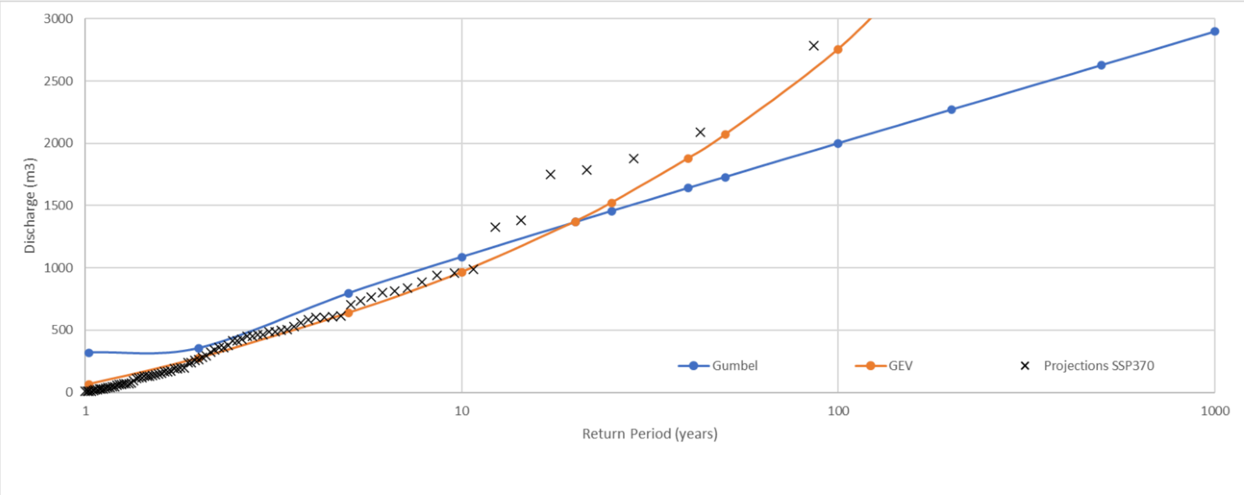
The highest of these values is then taken and referred to as the "K-S statistic," which is compared to a critical value from the Kolmogorov-Smirnov table for a given significance level "α" and degrees of freedom (number of data points). If the value from the table is lower than D, then the distribution is rejected. The test calculation was done in a Python script, and the results are shown in the following table.

Distribution	KS Statistic	P-value
Gumbel	0.1990	0.7065
GEV	0.1853	0.7808
Log-Pearson	0.5232	0.0024

Finally, selecting the best-fitting distribution involves choosing the candidate distribution that results in the smallest K-S test statistic or the highest p-value. This selection indicates which distribution best fits the observed maximum flood data. In this case, the GEV method is the distribution that best fits.

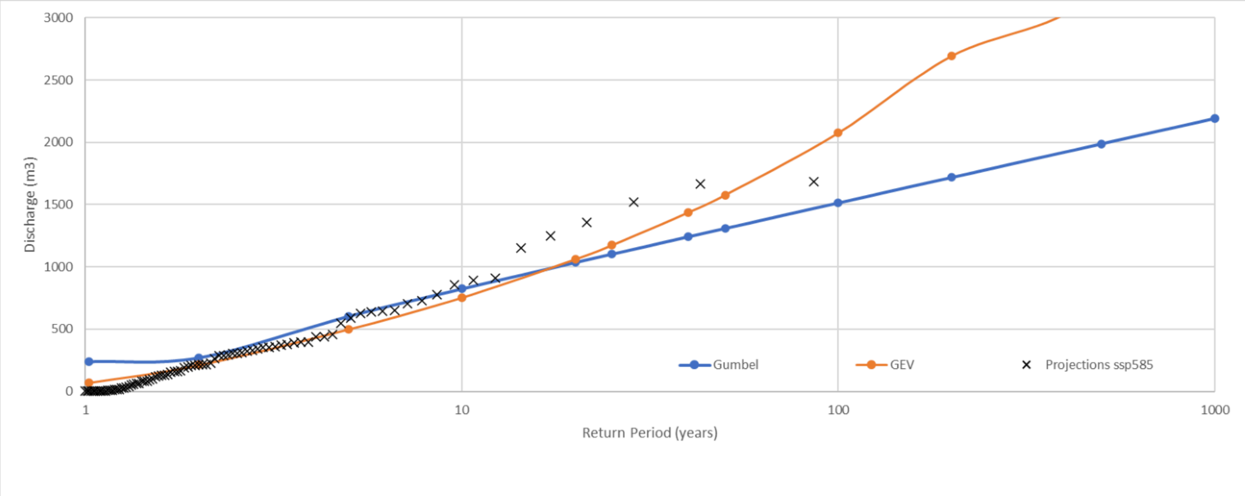
3.7 Frequency analysis of the discharge: Climate Change

Historical vs ssp370



SSP370		
Return Period	**Gumbel**	**GEV**
2	355.04	276.6
5	795.43	638
10	1087.01	966.8
20	1366.70	1372.5
25	1455.42	1523.5
40	1641.04	1880.3
50	1728.73	2067.9
100	2000.02	2755.4
200	2270.32	3624.1
500	2626.93	4408.7

Historial vs ssp585



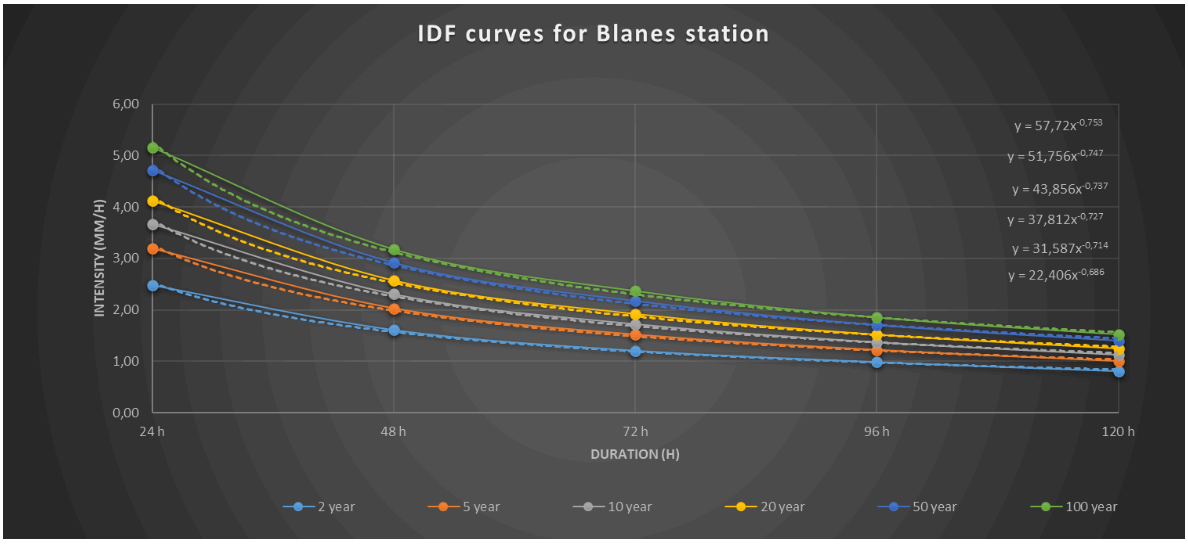
SSP 585		
Return Period	**Gumbel**	**GEV**
2	270.42	212.5
5	603.42	499.6
10	823.90	754.2
20	1035.38	1061.6
25	1102.47	1174.4
40	1242.82	1438.4
50	1309.13	1577.5
100	1514.26	2075.7
200	1718.65	2693.1
500	1988.30	3233.1

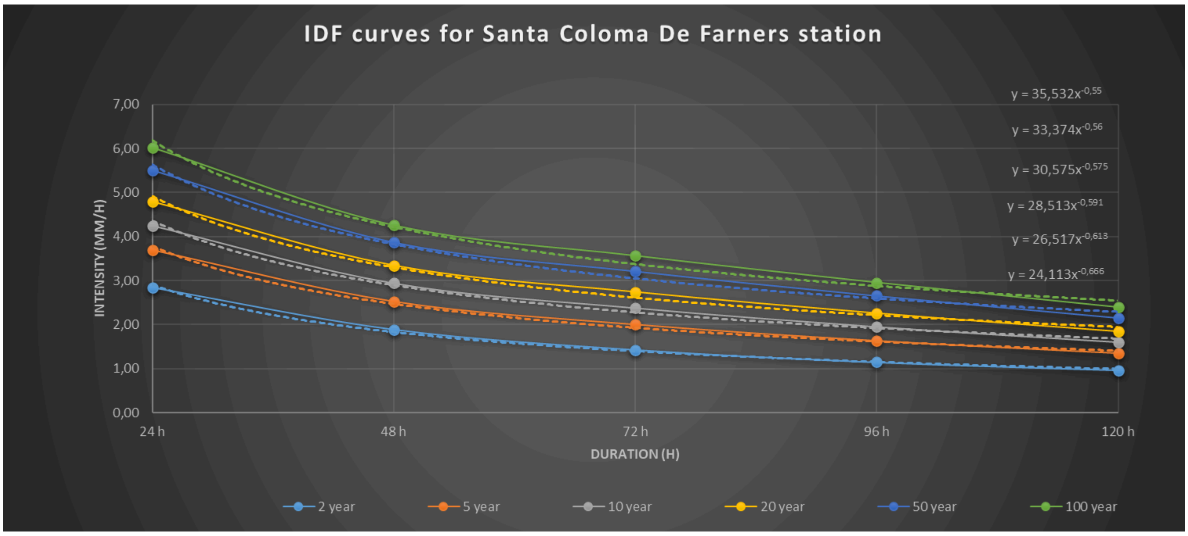
3.8 IDF Curve: Historic

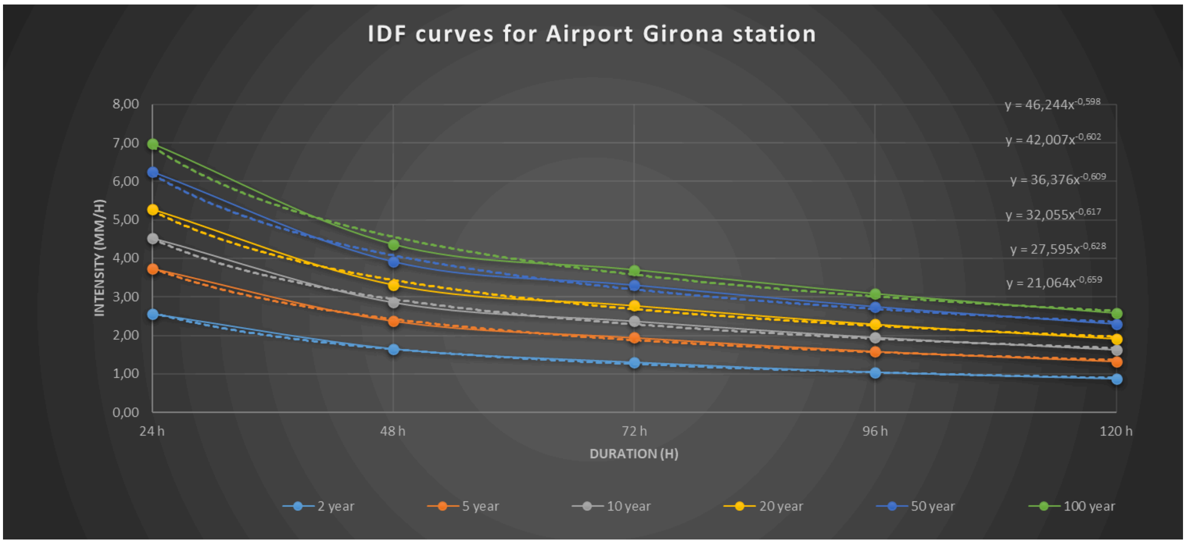
IDF curves, or Intensity-Duration-Frequency curves, are used in hydrology to characterise extreme rainfall events. They are of great importance in the design of hydraulic infrastructures and in the assessment of flood risks. However, their main use will be to gain a better understanding of the effects of climate change on the Tordera catchment in Catalonia (Spain).

In order to determine these IDF curves, we made use of available open-source data. The only rainfall data available for the region is daily rainfall data from 1984 to 2008 for 5 stations in the study area. Of these 5 stations, only 3 are actually located in the catchment studied. The last two are very close and can be used to distribute rainfall spatially.

To create the IDF curves for each station, we recovered the maximum intensity over 5 sliding days. Summing these 5 days and using this data to produce the curves.


IDF curves for Blanes station
INTENSITY (MM/H)
DURATION (H)
24 h
48 h
72 h
96 h
120 h
y = 57,72x-0,753
y = 51,756x-0,747
y = 43,856x-0,737
y = 37,812x-0,727
y = 31,587x-0,714
y = 22,406x-0,686
2 year
5 year
10 year
20 year
50 year
100 year


IDF curves for Santa Coloma De Farners station
INTENSITY (MM/H)
DURATION (H)
24 h
48 h
72 h
96 h
120 h
y = 35,532x-0,55
y = 33,374x-0,56
y = 30,575x-0,575
y = 28,513x-0,591
y = 26,517x-0,613
y = 24,113x-0,666
2 year
5 year
10 year
20 year
50 year
100 year


IDF curves for Airport Girona station
INTENSITY (MM/H)
DURATION (H)
24 h
48 h
72 h
96 h
120 h
y = 46,244x-0,598
y = 42,007x-0,602
y = 36,376x-0,609
y = 32,055x-0,617
y = 27,595x-0,628
y = 21,064x-0,659
2 year
5 year
10 year
20 year
50 year
100 year

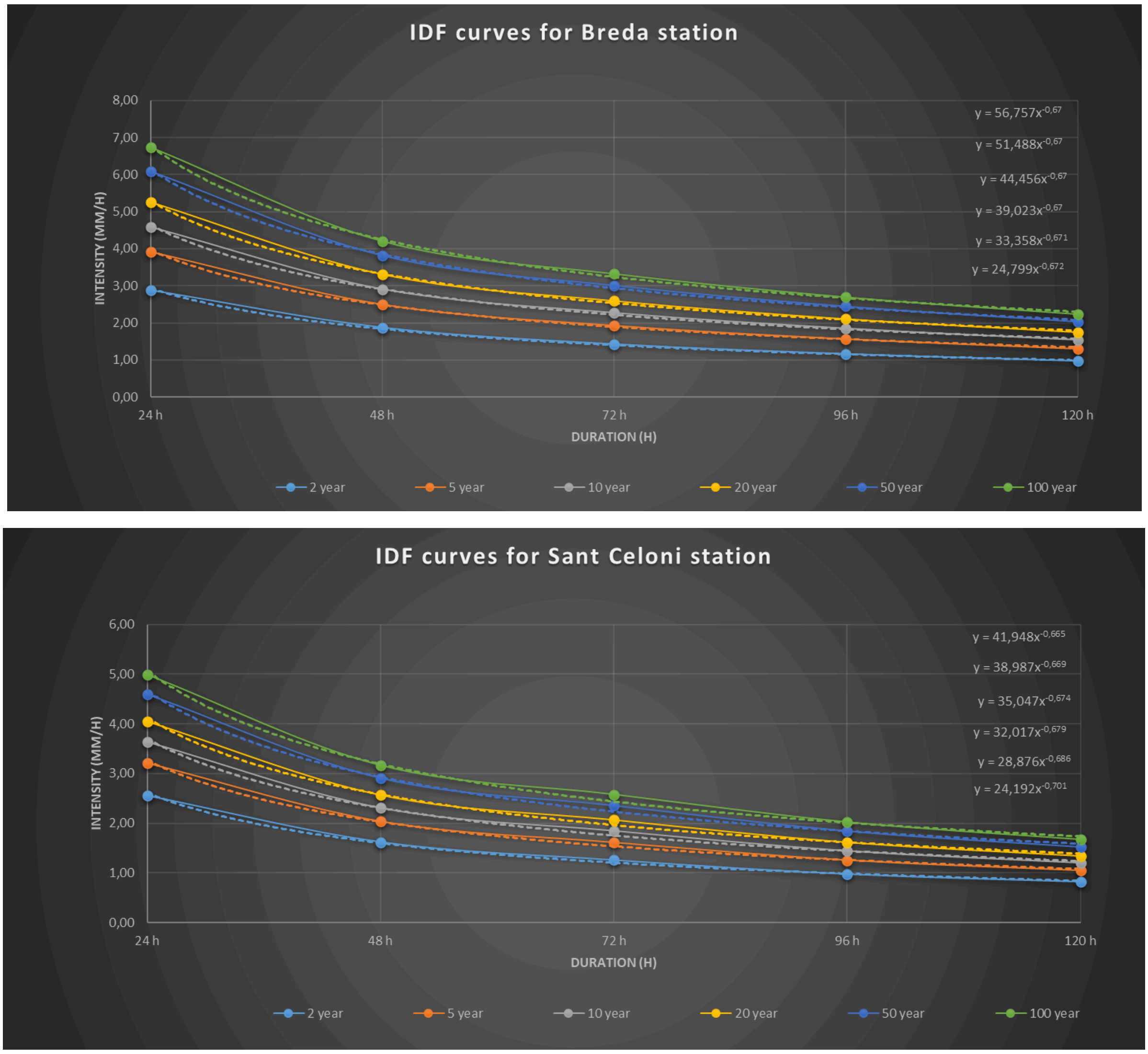


Figure 14: Historic IDF Curves for all Historic Stations

3.9 IDF Curve: Climate Change

To understand the impacts of climate change on the La Tordera catchment, Intensity-Duration-Frequency (IDF) curves have been created for a range of storm events. The IDF curves have also been investigated through the use of three different methods: Gumbel, Log Person and Log Normal. Each method has been used to create IDF curves at one rainfall gauge site for historical and projected flows. These graphs, with the help of a desktop study, will be used to decide on a single method to reproduce for the other five rainfall locations.

Figure 15 shows the result of the three methods displaying the results of a 100-year return period. The general results of all three methods produce similar outputs with the historical being the lowest and scenario 3 producing the highest intensity. The Log Person results have an overall drop of circa 15% in intensity compared to Log-Normal and Gumbel results. As discussed in section 4.7 in the frequency analysis of discharge data, the Gumbel distribution is often used to model the maximum or minimum of a data series, particularly when these extreme values are of primary interest. For this reason and from the visual analysis, the Gumbel distribution is the method used to calculate the IDF curves for all sites.

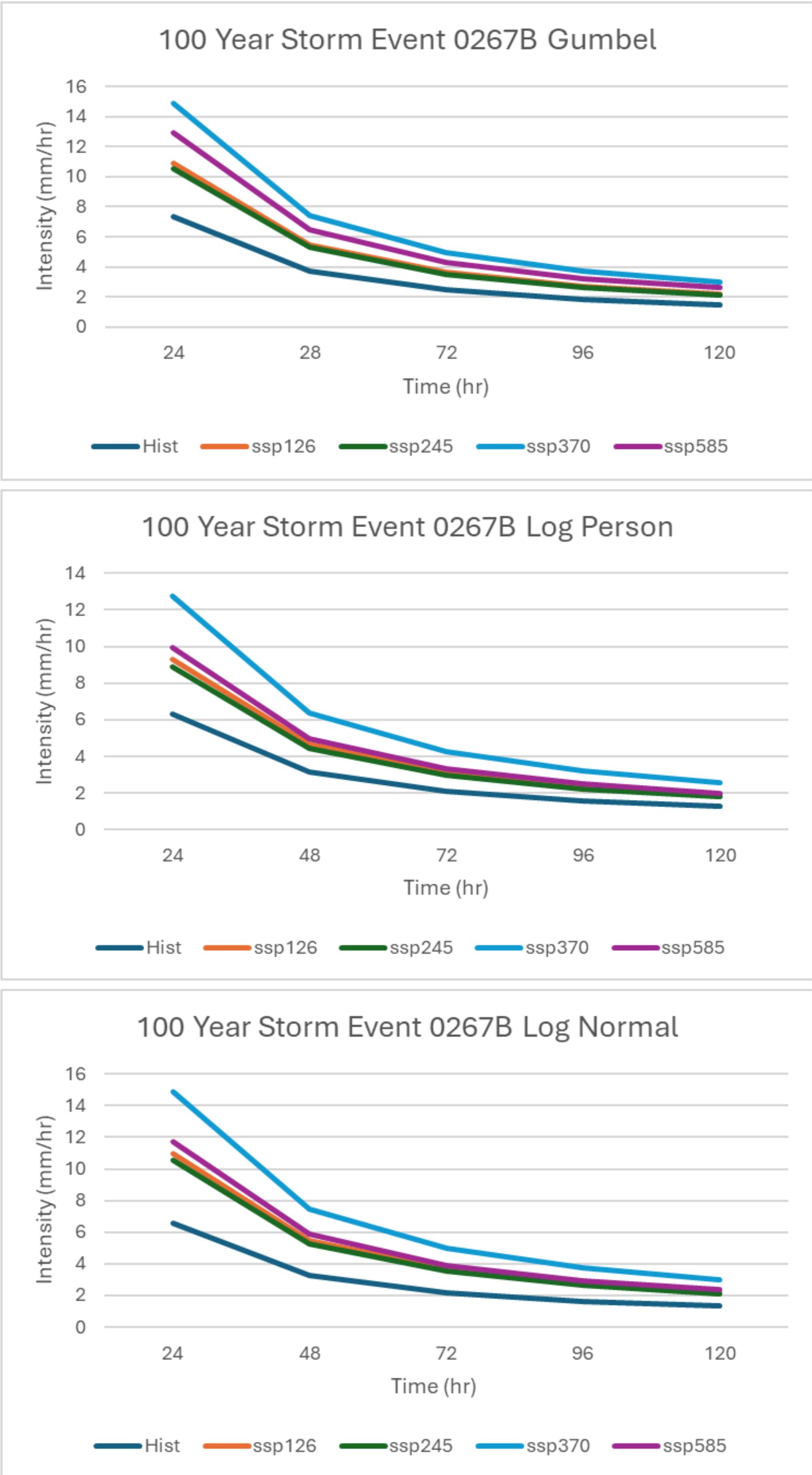
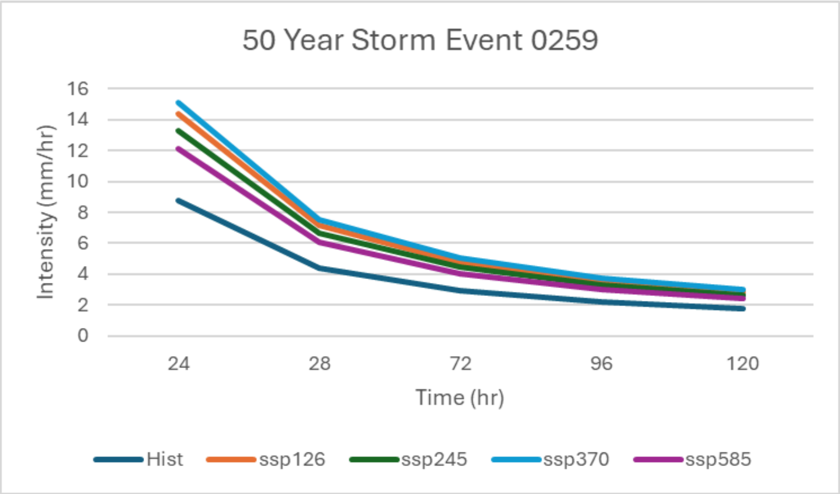


Figure 15: Comparison between IDF methods at station 0267B

Results

To understand the changes that climate change plays on the IDF curves an analysis of historical and climate change projects is required for all sites used in the model. The data used within the historical section of the investigation has a range of uncertainty due to the limited number of available data. This is different from the analysis of rainfall due to using different rainfall locations. These different locations have been chosen for this investigation to ensure that the comparison is not compromised by elevation change or local weather conditions. In some cases, the number of years available is limited to 20 years, leading to low confidence in the prediction of storm events over this threshold.

Figure 16 shows the results from stations 0259 and 0251B at a 50-year storm event shown as an IDF curve. These two results show that scenario 3, a 7oC temperature rise, produces the highest intensity for this chosen event. This is also the case in the majority of events across the catchment and a fact that will need to be considered when analysing the results of the hydraulic and hydrological models. Another observation found at the 0259 station found that the lowest intensity for a climate projection was from the most severe scenario, ssp585. Whilst this is not a trend in the other stations, ssp585 is consistently lower than initially thought.



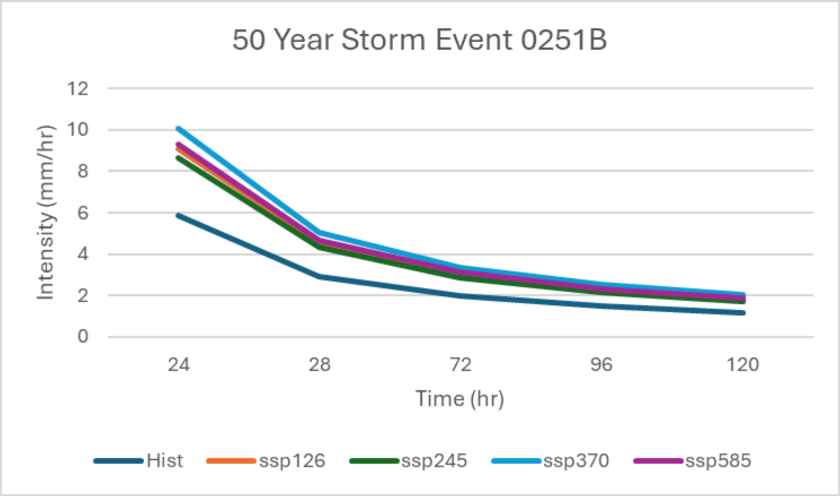


Figure 16: Results of IDF curve at a 50 year storm event at 0259 and 0251B

To understand how the intensity of storm events changes, Figure 17 shows the results of a range of storms at scenario 370 at 0263 station. This output follows the expected trend from this type of IDF curve with a 2-year event having an intensity of circa 4 mm/hr for a 24-hour event, reducing to 1 mm/hr for a 120-hour event. On the other scale, the 200-year storm event extends up to 14 mm/hr at a 24-hour event, this intensity has the potential to cause widespread flooding across the La Tordera catchment. When compared to the historical storm events found in Figure 14, the results found are much lower than the outputs in Figure 17. The climate change projections for ssp370 are circa double the intensity of the historical data that has been examined; whilst there may be geographic differences, this consistent increase from historical data shows a significant change in future storm events.

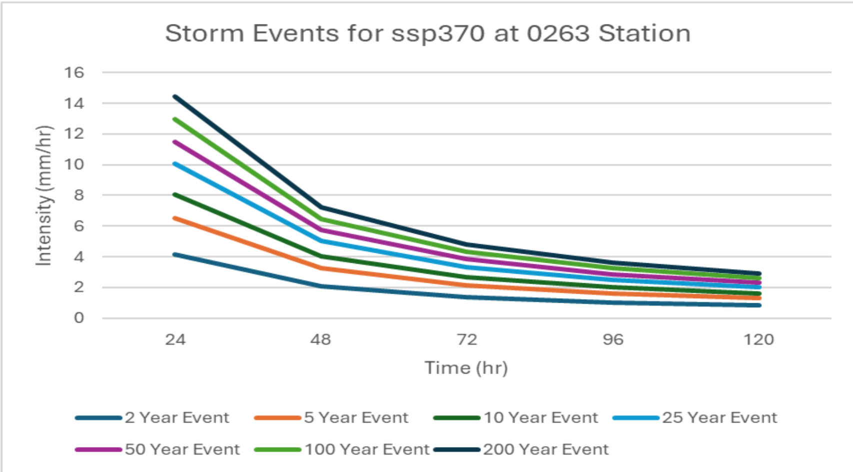


Figure 17: Different Storm Events at scenario 370 at Station 0263

4 Planning and distribution of work

4.1 Our plan

In this second week of the HydroEurope project and during the final phase of our study, we are concentrating on three key points. Firstly, we are focusing on constructing a hydraulic model using Telamac, aiming to deepen our understanding of the hydraulic characteristics of the region.

Simultaneously, our priority remains the completion of the hydrological model (HMS). We are fine-tuning the model to achieve results that closely mirror hydrological realities, addressing aspects such as evapotranspiration, infiltration, transformation, and accounting for climate change.

Concurrently, we are dedicating time to verifying potential errors identified in the first week, with particular attention to the IDF curve that raises questions. This step is crucial to ensure the reliability of results and to ensure that the model accurately reflects the hydrological dynamics of the region.

In summary, our targeted approach aims to strengthen the model's robustness for more accurate hydrological outcomes before advancing to advanced modelling stages.

4.2 Our planning

Task	Person

Work plan Schedule	All
Introduction and Report writing	All
Obtention and analysis HMS Model	Erika, Jorge
Build Telemac Model	Chloé, Constant, Maël, Lucas, Nicolas
Check IDF Curve	Dan
Analysis Telemac Model	Kevin, Nicolas, Marwane
Model calibrated and validated	Maël, Erika, Jorge, Constant
Obtention and analysis of climate change	Dan, Pamela
Conclusion	All

5 Construct hydraulic model

In this section, our aim is to build a hydraulic model of a predefined area of the Tordera basin. To do this, we'll be using various software packages: QGIS and ArcGis to define the boundaries of the area to be modelled, Bluekenue to create the mesh, define upstream and downstream boundary conditions and visualise our results, and Telemac to create the hydraulic simulation.

5.1 DTM

To create a hydraulic model, we first need to define the area we want to model. We have chosen to restrict the study area to the Tordera outlet, with a station upstream. We can then impose the results of the HMS simulation as input data, which will provide us with hydrographs. To delimit our domain, we use QGIS. To do this, we need to load the DTM covering our study area. Next, we need to delimit our study area. We've chosen to work on a small area around the Tordera outlet, so that the simulation on Telemac will be quicker.

Study area for the hydraulic model

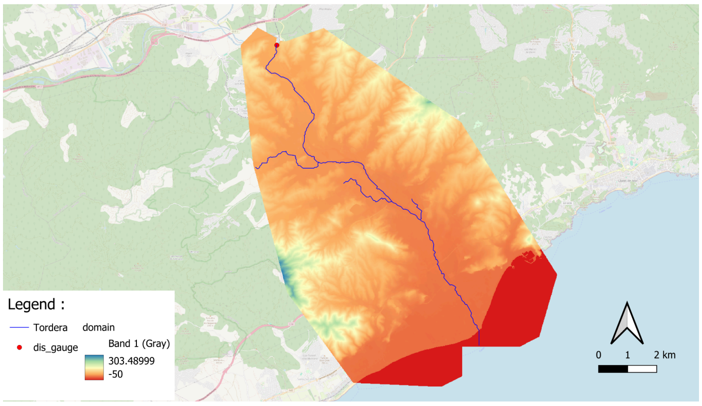


Figure XX. Delimiting the study area in QGIS

5.2 Bluekenue

Once our study area has been defined, we can create the mesh on Bluekenue. To do this, we've defined 3 zones where the accuracy of the mesh will vary according to the size of the zone. The first zone is the minor bed. For this zone, we chose a fairly precise grid every 50m. The second zone, intermediate, was defined according to the topography of the area. For this zone, the mesh spacing will be every 100m. And finally, for the furthest zone, we chose a mesh spacing of 200m, this zone being the furthest from the watercourse. Once the mesh is complete, we'll interpolate it to take into account the bathymetry of the domain.

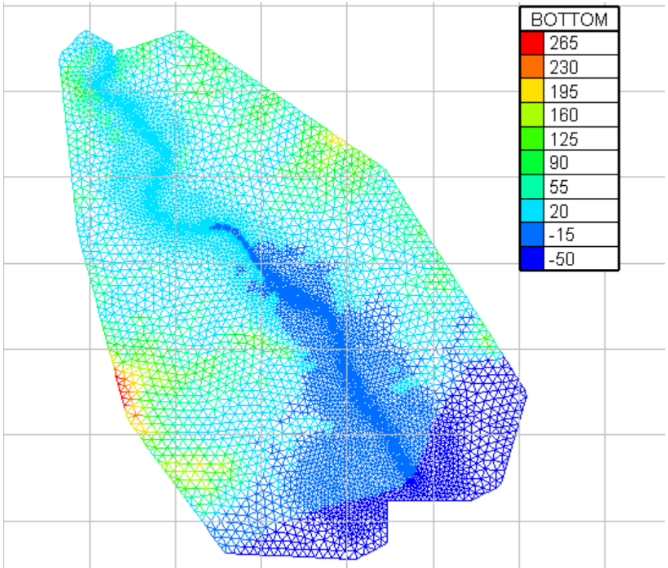
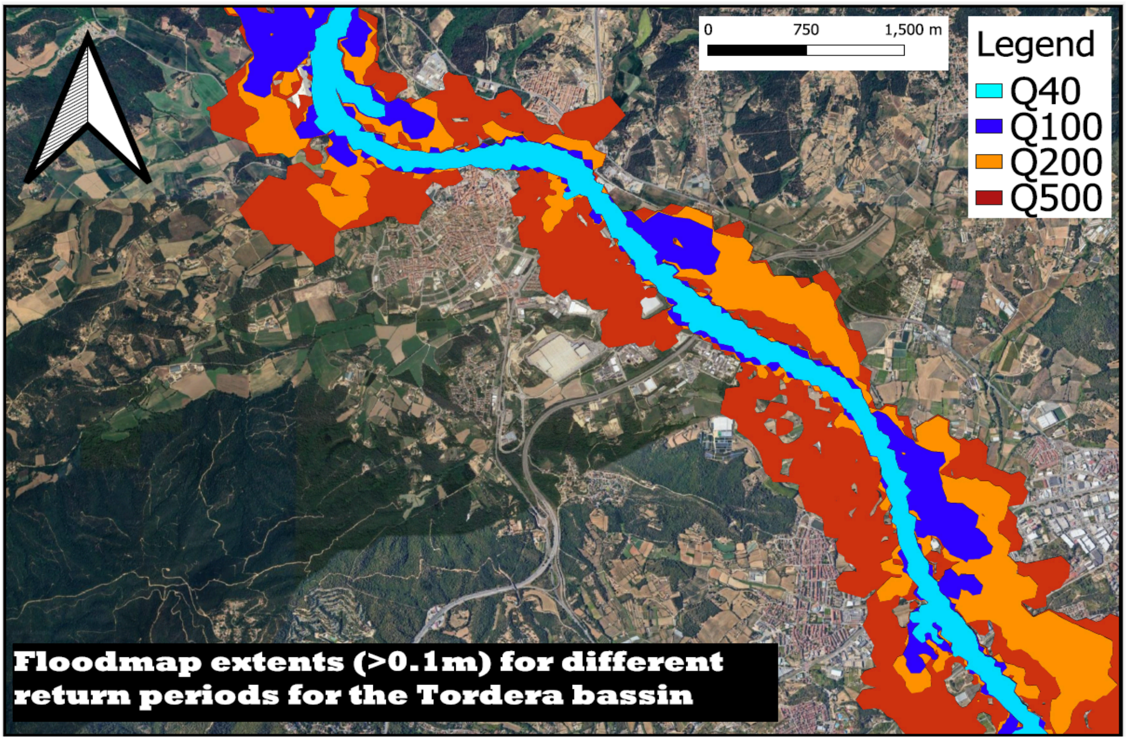


Figure XX. Visualisation of interpolated mesh with bathymetry on Bluekenue

The next step is to create a file to impose boundary conditions upstream and downstream of our domain. Upstream, we'll impose a hydrograph and flow, and downstream, a water level.

5.3 Telemac

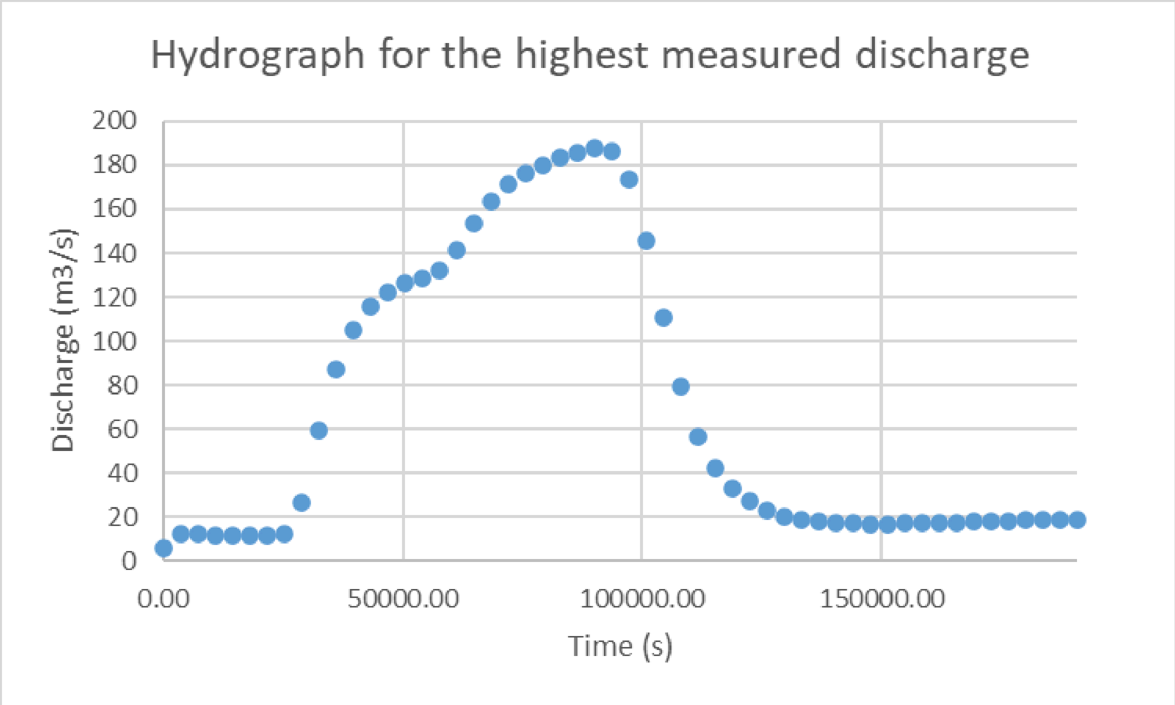
To create a hydraulic model, we have two options: to model the entire Tordera watershed with a coarse mesh for the upstream section, and with a finer mesh for the last few hundred meters, in order to obtain an accurate flood map. The input data would be a hyetograph of historical and forecast rainfall. However, such a model would be complex to implement, given the size of the mesh. Calibrating the model would be too time-consuming (we don't have access to an HPC). We chose to model only the downstream section of the Tordera, where the economic sectors and housing are located. The modeled area is 12 km long and 8.1 km wide. Upstream, we input various flood hydrographs, while downstream, the water level is set by the sea.



In order to model flood zones (flow height and velocity), we have chosen several maximum flow scenarios:

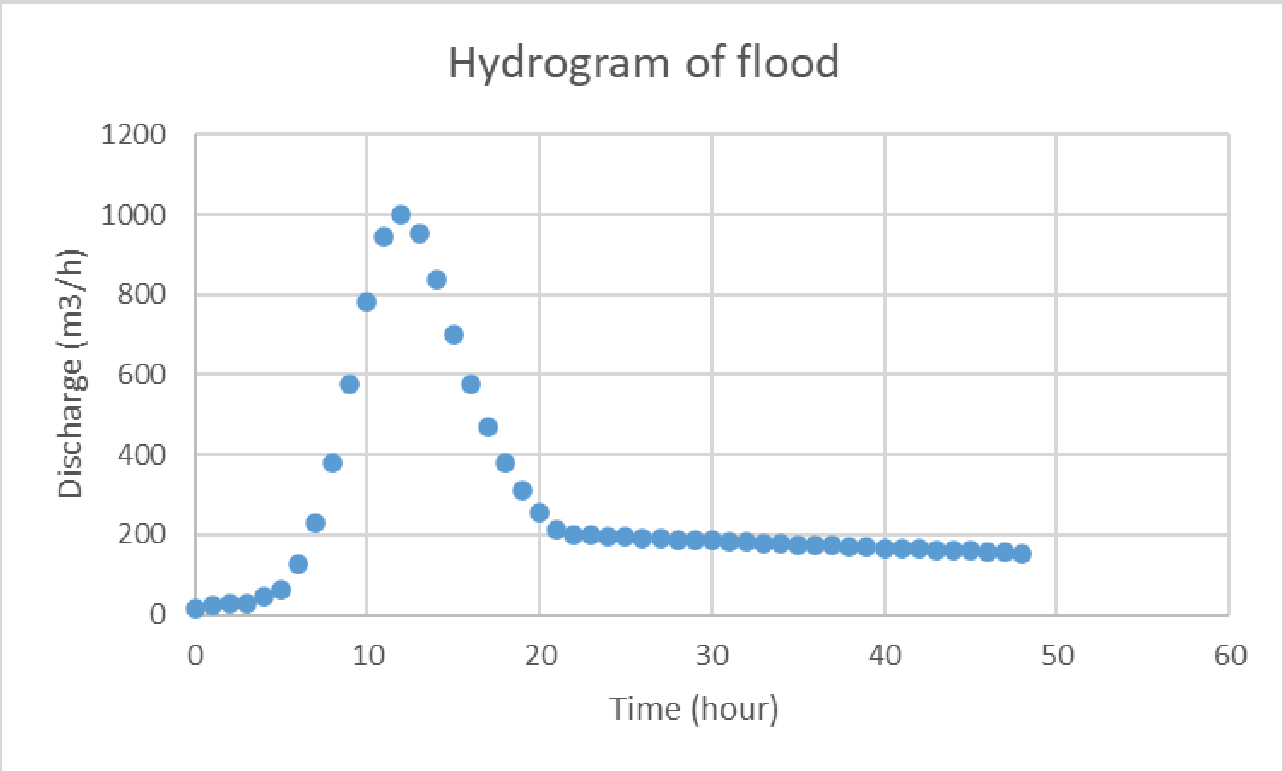
- Highest historical flood :

The highest historical flood was recorded on the night of January 28 to 29, 1996, reaching a peak of 170 m3/s. The calibrated and validated HMS model used gives a flood peak of 188 m3/s and hourly values. This gives the following flood hydrograph:



Mettre Telemac

Notre modèle Telemac nécessite un hydrogramme :



Conclusions

During this week's endeavours, our focus centred on refining the HEC-HMS model and advancing our understanding of the hydrological dynamics in the Tordera River Basin. The meticulous construction and calibration of the hydraulic model using Telamac represented a crucial step in capturing the intricacies of the region's water flow. Additionally, the completion of the hydrological model (HMS) allowed us to incorporate various factors such as evapotranspiration, infiltration, and climate change considerations, contributing to a more comprehensive representation of the watershed.

As we fine-tuned the model, our emphasis remained on achieving a robust and accurate representation of daily discharge. The incorporation of accurate precipitation data and a detailed understanding of the watershed's topography are instrumental in obtaining reliable estimates of daily discharge. This not only aids in predicting variations in flow over time but also enhances our ability to make informed decisions regarding water resource management.

It is noteworthy that our approach involves a systematic validation process, ensuring that the model's performance aligns with real-world conditions. This week's efforts, coupled with the validation carried out during the online phase, have further solidified the reliability of our model. Through the incorporation of different parameters and a continuous commitment to refinement, we have enhanced the model's capability to provide accurate estimates, contributing to a more robust understanding of the hydrological processes in the Tordera River Basin.