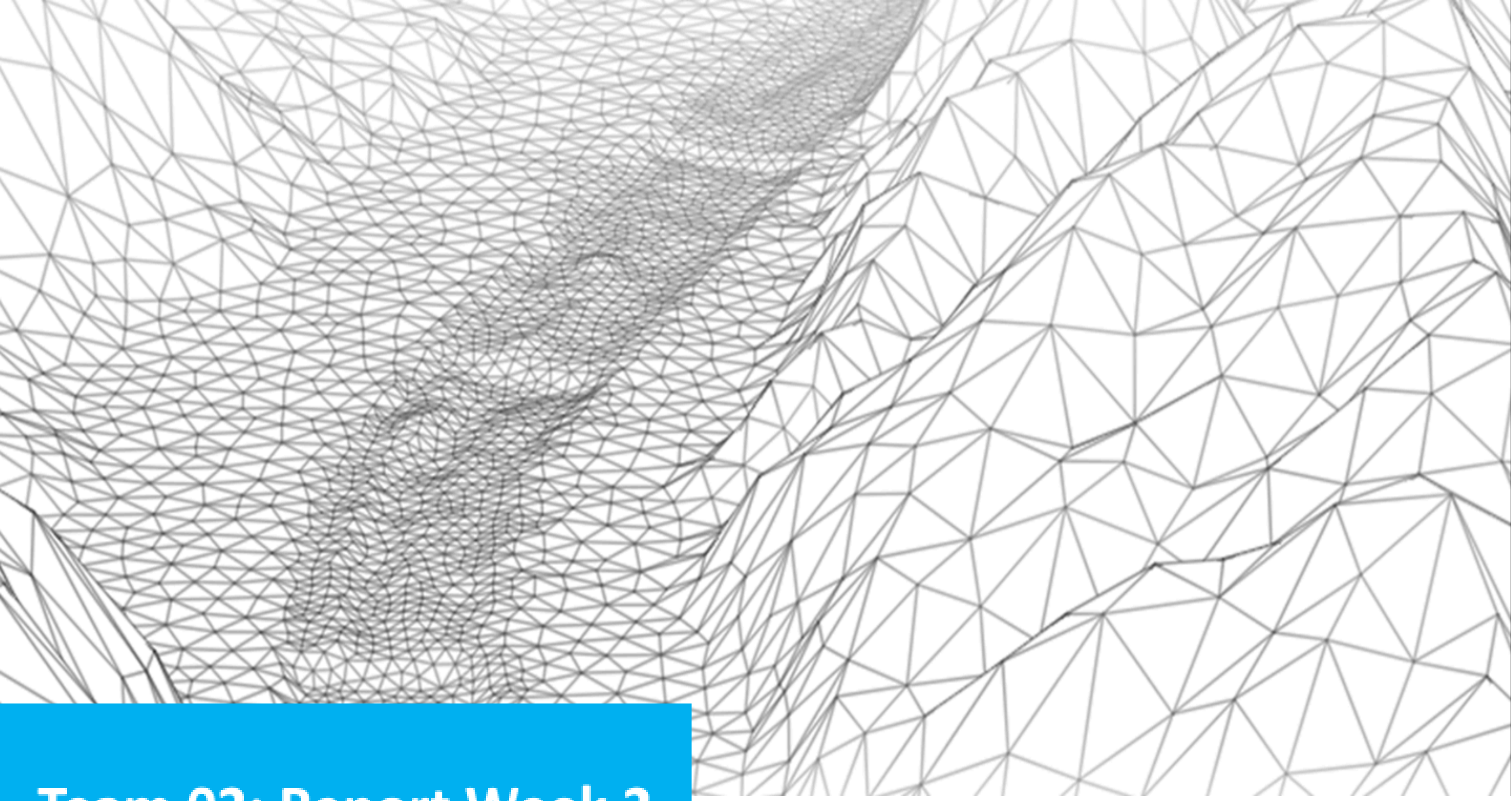

Team 02: Report Week 2

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 Var Catchment (Country France)

Team 2 - Report Week 2: Climate Change Impacts on Flash Floods

A.B. and C.D, Team XX
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Introduction

Climate change has become one of the most pressing and complex challenges facing our society today. It brings about a range of major environmental disruptions that impact various aspects of our daily lives, including food security, public health, biodiversity, and the economy. The impact of climate change is particularly felt in regions susceptible to extreme weather events, such as the Var region in France, and more specifically in Saint-Martin-Vésubie.

Extreme weather events, like storms Aline and Alex, have dramatically demonstrated the devastating consequences of climate change on coastal and mountainous regions. These events can lead to flash floods, landslides, damage to critical infrastructure, and significant human and economic losses. They underscore the urgency of adapting our practices and infrastructure to the new climate realities.

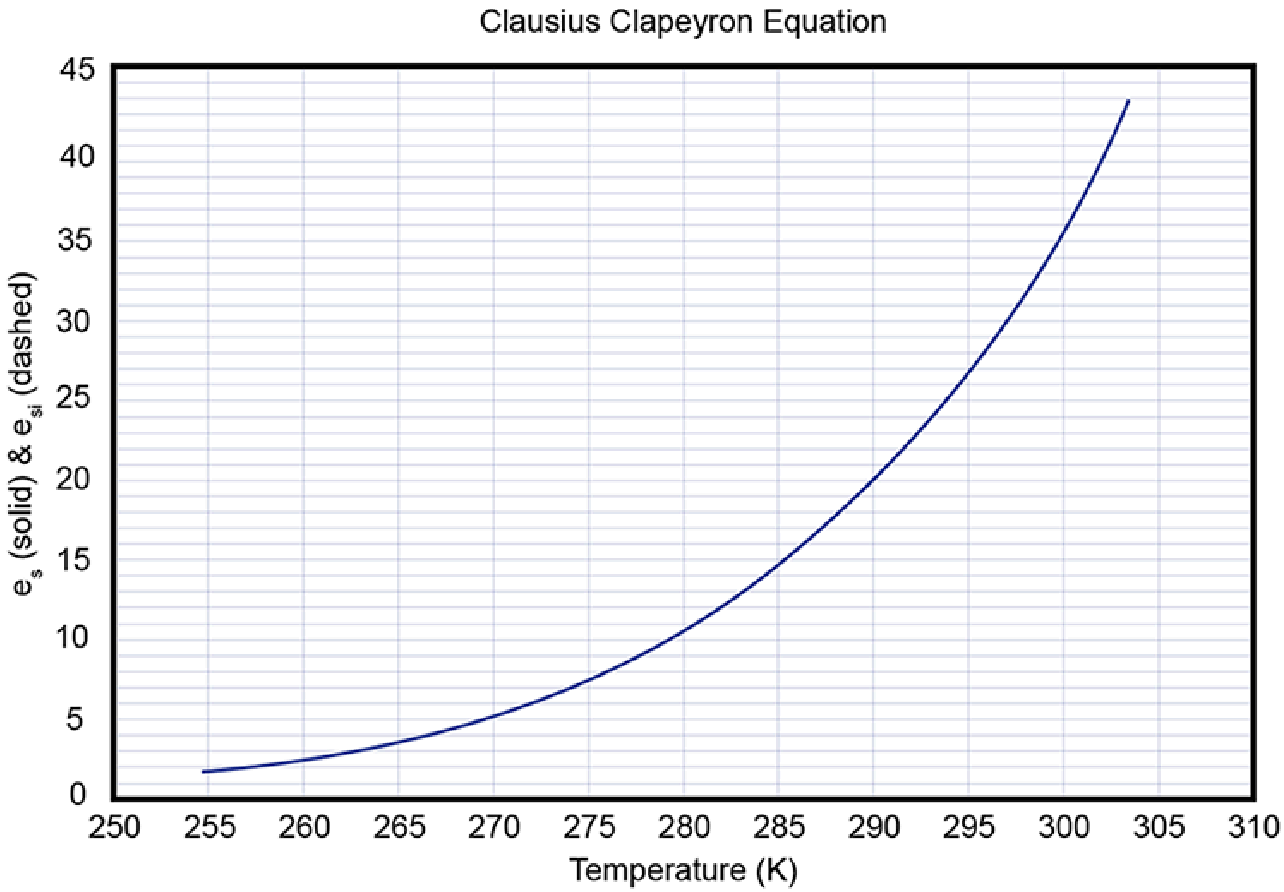
In this context, the establishment of essential infrastructure such as wastewater treatment plants (WWTP) is of paramount importance. WWTPs play a crucial role in managing and preserving water resources by treating wastewater to meet environmental standards and reducing pollution risks. However, their effectiveness and reliability can be greatly influenced by climate change.

It is imperative to understand the potential impacts of climate change on water resources in the Var region, as well as on critical infrastructure like WWTPs, in order to take preventive measures and adapt our water management practices accordingly. This requires in-depth analysis of past and future climate trends, as well as precise hydrological and hydraulic modelling to assess risks and identify the most appropriate solutions to ensure the region's resilience to future climate challenges.

1. Discussion about climate change impact on water modeling

The elevated levels of carbon dioxide in the atmosphere contribute to an increase in atmospheric temperatures. As temperatures rise, the atmosphere retains more humidity, resulting in a greater quantity of water vapor held within it.

The influence of climate change on water resources involves various physical laws such as the partial pressure law of Dalton and the Clausius-Clapeyron relationship. As temperatures rise, the atmosphere's capacity to hold water vapor increases, leading to heightened atmospheric moisture content and a higher potential for precipitation events. However, the distribution of precipitation may not be uniform, exacerbating droughts in some regions while causing intense rainfall or flooding in others. Changes in temperature also affect relative humidity, altering evaporation rates and influencing the balance between surface water and atmospheric moisture.



Absolute humidity fonction of temperature.

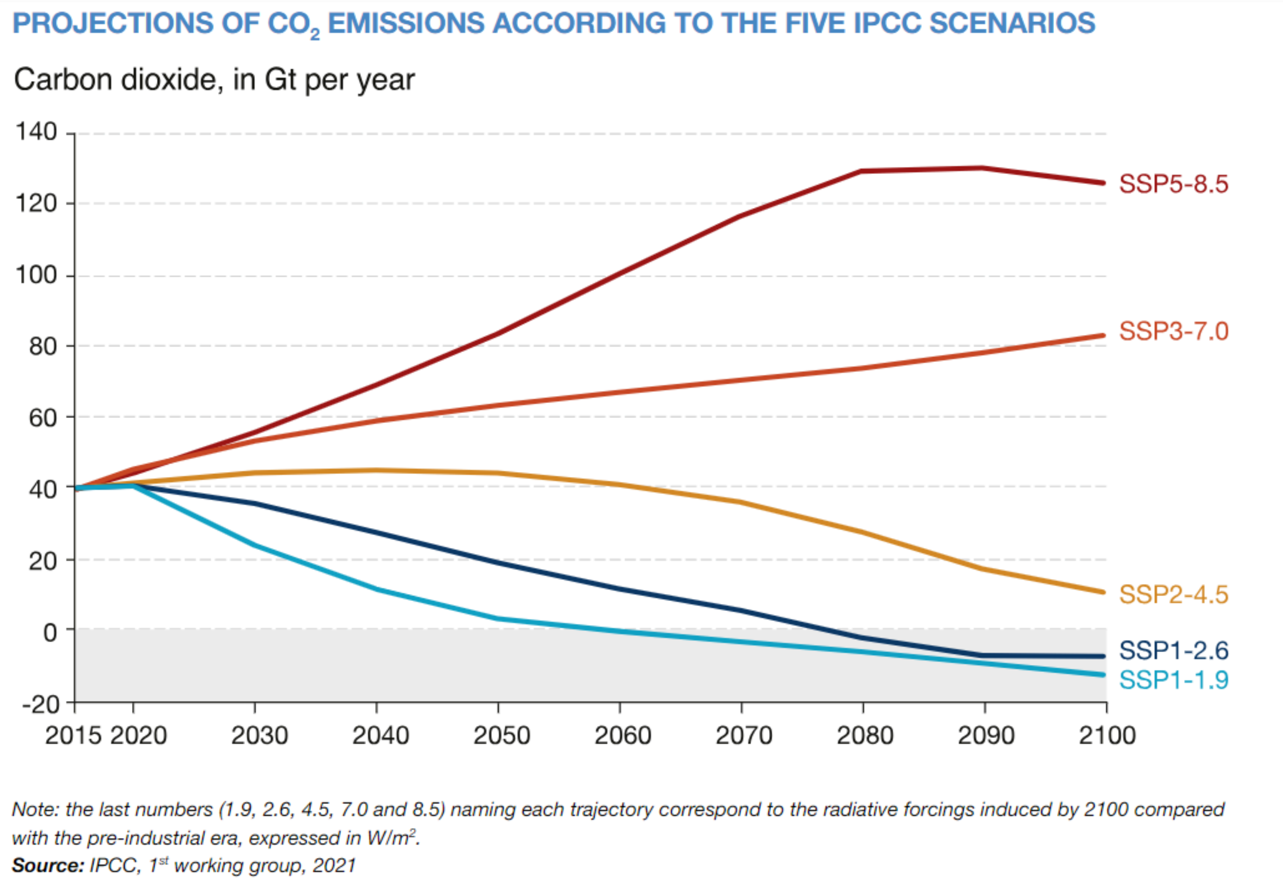
Climate change significantly impacts water modeling by altering precipitation patterns, leading to increased frequency of extreme weather events and prolonged periods of drought. Rising temperatures increase the atmosphere's moisture-holding capacity, intensifying rainfall during storms and potentially causing flash floods that overwhelm drainage systems. Conversely, prolonged dry spells exacerbate drought conditions, affecting water availability for agriculture, industry, and urban consumption. These shifts challenge traditional water management strategies, necessitating more sophisticated modeling techniques to predict and mitigate climate change impacts. Integrating climate projections into water models is crucial for effective planning and adaptation measures to ensure water security.

These interconnected processes underscore the complexity of climate change impacts on water dynamics, highlighting the importance of comprehensive adaptation and mitigation strategies.

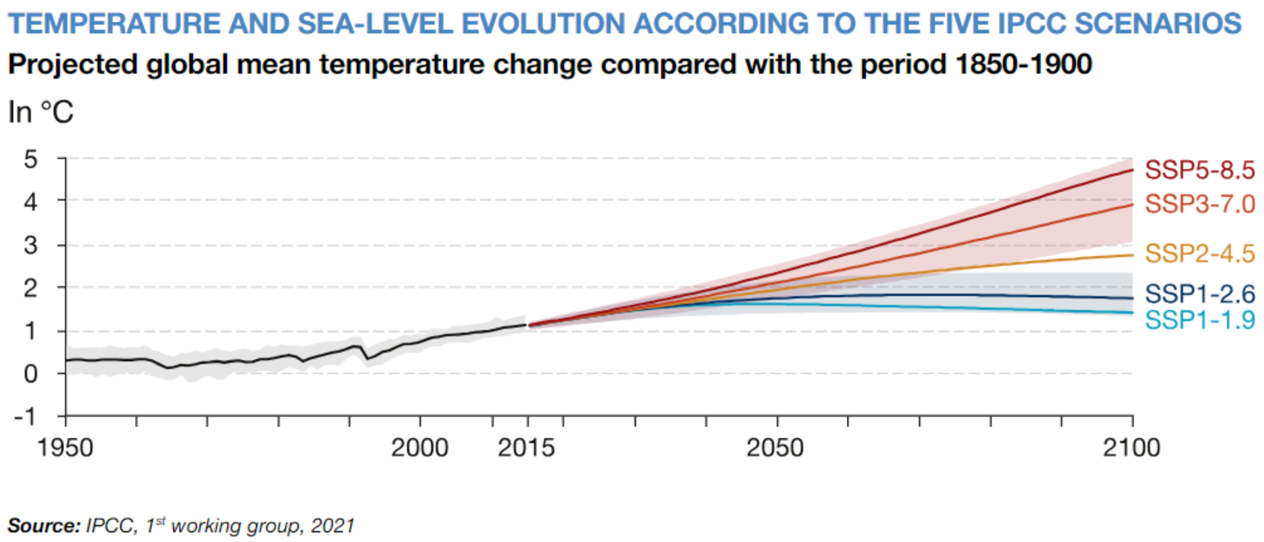
Sites like Climate.Copernicus.eu gives us access to data such as precipitations, sea levels, temperatures, runoffs…

C3S is one of six thematic information services provided by the Copernicus Earth Observation Programme of the European Union. Copernicus is an operational programme building on existing research infrastructures and knowledge available in Europe and elsewhere. C3S relies on climate research carried out within the World Climate Research Programme (WCRP) and responds to user requirements defined by the Global Climate Observing System (GCOS). C3S provides an important resource to the Global Framework for Climate Services (GFCS).

Models created based on measured data and following scenarios coupling Shared Socioeconomic Pathways (SSP) and Representative Concentration Pathways (RCP) provide valuable insights into potential future outcomes under different socio-economic and climate conditions. By integrating observed data with projections derived from SSP and RCP scenarios, these models offer a comprehensive understanding of how various factors such as population growth, economic development, and greenhouse gas emissions influence climate change impacts. These models enable decision-makers to explore a range of possible futures and assess the effectiveness of different mitigation and adaptation strategies. By considering multiple scenarios, ranging from low to high emissions pathways, scientists and engineers can better anticipate and prepare for the uncertainties associated with climate change.



<u>PROJECTIONS OF CO2 EMISSIONS ACCORDING TO THE FIVE IPCC SCENARIOS.</u>



<u>TEMPERATURE AND SEA-LEVEL EVOLUTION ACCORDING TO THE FIVE IPCC SCENARIOS</u>

Climate change brings a lot of issues on flood estimation models and the imperative for enhanced methodologies in light of projected alterations in extreme weather patterns. Traditional statistical techniques may prove insufficient due to potential shifts in extreme value distributions. Consequently, there is a call for physically-based strategies integrating meteorological and hydrological data. These encompass analytical methods like intensity–duration–frequency (IDF) curves, though they may overlook spatial variations and interactions between flood-generating mechanisms.

Studies delve into the complexities of flood estimation modeling, particularly in the context of addressing the challenges posed by climate change-induced warming. It underscores the significance of understanding how changes in temperature patterns and precipitation regimes influence flood occurrences. Through examining various spatial resolutions and parameter estimation techniques, studies seek to elucidate the impacts of climate change on river flooding dynamics. Furthermore, it emphasizes the necessity of robust methodologies to navigate the uncertainties inherent in modeling flood events under changing climatic conditions. By analyzing synthetic precipitation data across different climate scenarios, the research sheds light on the intricate interplay between climatic variables and flood risk. Ultimately, the findings underscore the importance of adopting adaptive modeling approaches to effectively mitigate the evolving threats of climate-induced floods (Journal of Hydrology 303 (2005) 176–198).

2. Methodology and justifications of 3 scenarios

2.1. Justifications of the 3 scenarios

SSP1-2.6 is a scenario within the Shared Socioeconomic Pathways framework utilized in climate research to envision potential future socioeconomic trajectories and their effects on greenhouse gas emissions and climate change. In SSP1-2.6, the narrative revolves around sustainable development, strong global cooperation, and prioritization of environmental conservation. The "2.6" in SSP1-2.6 denotes a specific radiative forcing level targeted for the year 2100, where efforts are made to limit global warming to 2.6 Watts per square meter, aligning with the ambitious goals of the Paris Agreement. This scenario envisions low population growth, extensive investment in renewable energy technologies, implementation of eco-friendly policies, and concerted actions to mitigate climate change impacts. SSP1-2.6 represents a pathway towards a resilient and sustainable future, characterized by reduced greenhouse gas emissions and limited global warming compared to alternative scenarios. We chose this scenario because it was one of the most optimistic.

SSP5-8.5 is another scenario within the Shared Socioeconomic Pathways framework, offering a contrasting vision of the future characterized by high greenhouse gas emissions and limited climate mitigation efforts. In SSP5-8.5, socioeconomic development follows a trajectory of high population growth, rapid economic expansion driven by fossil fuel consumption, and limited environmental regulations. The "8.5" in SSP5-8.5 refers to the radiative forcing level targeted for the year 2100, reaching 8.5 Watts per square meter. This scenario depicts a world where global warming surpasses 8.5°C by the end of the century, far exceeding the goals set in the Paris Agreement and leading to severe and widespread impacts of climate change. SSP5-8.5 reflects a future where efforts to address climate change are inadequate, resulting in escalating temperatures, rising sea levels, extreme weather events, and significant ecological disruptions. It underscores the importance of urgent and robust actions to mitigate greenhouse gas emissions and adapt to the unavoidable consequences of climate change. It is the most pessimistic scenario.

SSP3-7 represents a scenario within the Shared Socioeconomic Pathways framework characterised by medium-to-high greenhouse gas emissions and intermediate climate mitigation efforts. In this scenario, global socioeconomic development follows a trajectory marked by moderate population growth, uneven economic progress across regions, and a mix of fossil fuel consumption and renewable energy adoption. The "7" in SSP3-7 refers to the radiative forcing level targeted for the year 2100, reaching 7 Watts per square meter. While not as extreme as SSP5-8.5, SSP3-7 still envisions a world where climate change impacts are significant, with global warming exceeding 7°C by the end of the century. This scenario suggests a future where some efforts to mitigate climate change are made, but they are insufficient to prevent substantial environmental changes, including rising sea levels, altered weather patterns, and ecosystem disturbances. SSP3-7 underscores the need for more ambitious climate action to avoid the most severe consequences of climate change and to build a more sustainable and resilient future. We consider that this is the most possible scenario for our study but we didn't do any modelisation as there was no model available associated with those data.

2.2. Justifications of the model

The CNRM-CM6-1-HR is a high-resolution climate model developed by the National Center for Meteorological Research in France. It represents an enhanced version of the CNRM-CM6-1 climate model, featuring finer spatial resolution to capture detailed spatial distributions of climate variables such as temperature, precipitation, and winds.

Key features of the CNRM-CM6-1-HR include:

- High Spatial Resolution: Utilises a finer spatial grid compared to standard versions, enabling more detailed representation of regional and local climate phenomena.

- Multi-Component Model: Integrates various components of the Earth's climate system, including the atmosphere, ocean, cryosphere (sea ice and glaciers), and land surfaces, to simulate interactions between different elements.
- Detailed Physical Processes: Represents detailed physical processes influencing climate, such as clouds, precipitation, atmospheric and oceanic circulation, and glacier dynamics, enhancing the model's ability to capture regional climate features and extremes.
- Research Applications: Used for a wide range of research applications, including assessing future climate projections, studying impacts of climate change on ecosystems and societies, analysing climate extremes, and modelling specific meteorological phenomena.

2.3. Methodology

To assess climate change and its potential impacts in the study area, a rigorous methodology was implemented, relying on the use of climate models and climate data analysis tools. The adopted approach consists of the following steps:

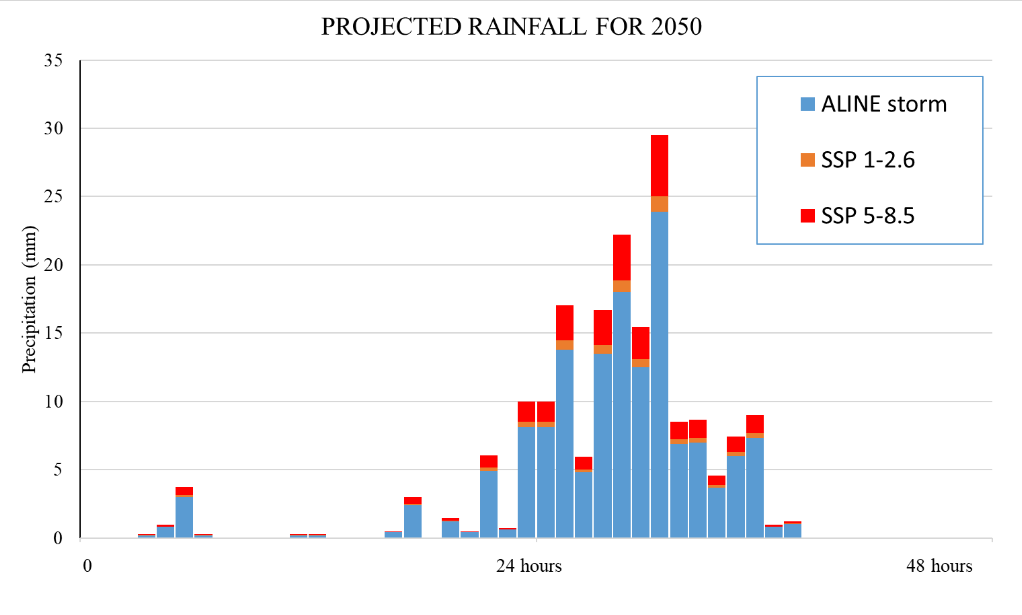
1. **Selection of Climate Models**: Well-established and widely-used climate models were chosen to perform simulations of current and future climatic conditions. Among these, the CNRM-CM6-1-HR model,introduced above, was selected for its high spatial resolution and ability to capture regional details of climatic phenomena.
2. **Configuration of Climate Scenarios**: Climate scenarios representing different greenhouse gas emission trajectories were selected to simulate future climatic conditions. Specifically, the Shared Socioeconomic Pathways SSP 1-2.6 and 1-8.5 scenarios were chosen to represent low and high greenhouse gas emission scenarios, respectively. These scenarios, defined by reports from the Coupled Model Intercomparison Project Phase 6 (CMIP6), allow for the assessment of a range of future climatic conditions based on different emission levels.
3. **Configuration of Simulation Parameters**: Specific parameters of the climate model, such as spatial resolution, temporal period, and included climatic variables, were configured according to the study's requirements. Simulations were conducted for past, present, and future periods to analyze climatic trends over different time scales. The "Maximum of 1-day precipitation" variable was selected as one of the key indicators to assess extreme precipitation events.

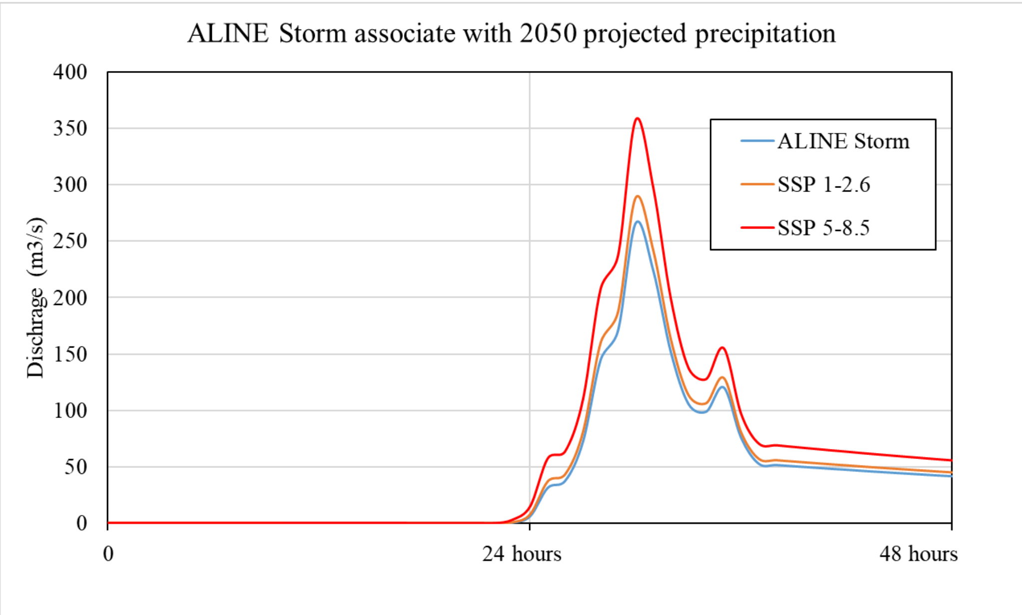
4. Hydrological results

4.1 HEC-HMS

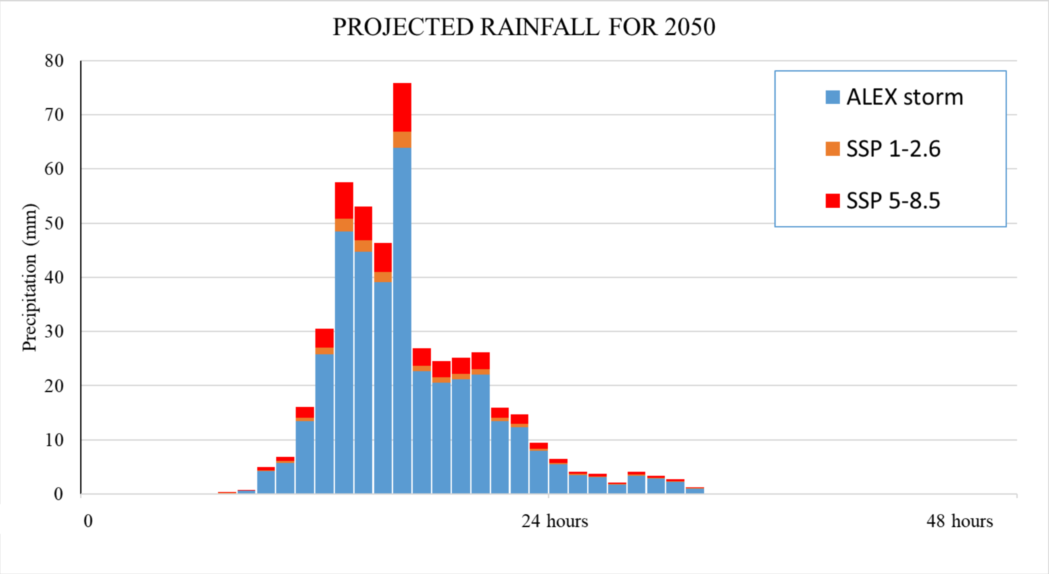
The hydrological results obtained through the use of the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) offer a comprehensive understanding of the potential impacts of climate change on rainfall intensity and subsequent hydrological responses. By incorporating climate change projections, specifically an increase in rainfall intensity by 4.78% for the SSP 1-2.6 scenario and 18.73% for the SSP 5-8.5 scenario, the study addresses the crucial aspect of how extreme weather events may evolve in the future. Focusing on two significant storm events, ALINE and ALEX, this analysis provides a detailed examination of how climate change-induced alterations in rainfall intensity may exacerbate the intensity and frequency of these storms by 2050. Through the application of these modified rainfall patterns within the HEC-HMS framework, the model offers insights into potential hydrological outcomes.

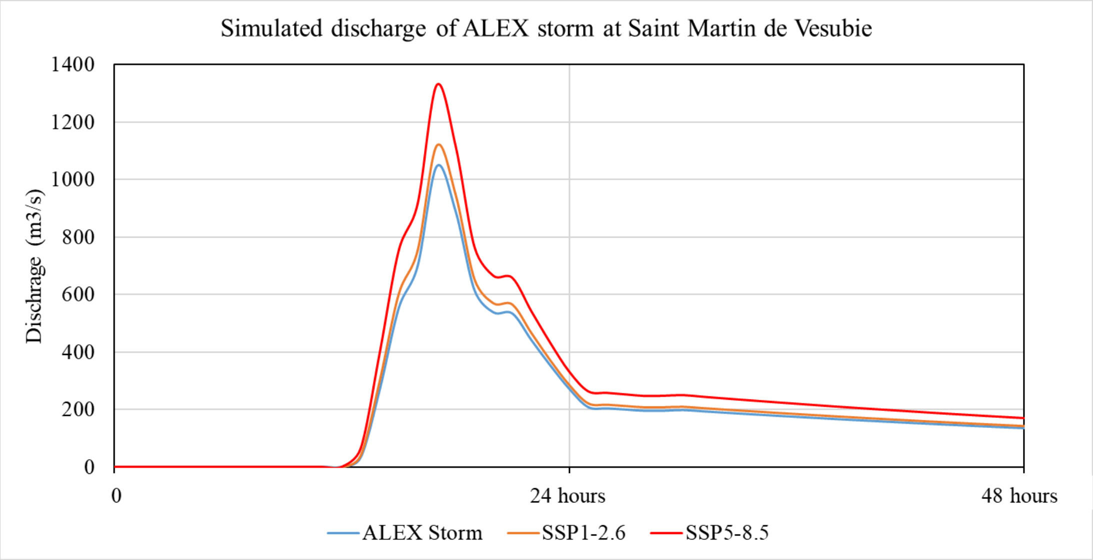
- ALINE storm





- ALEX storm

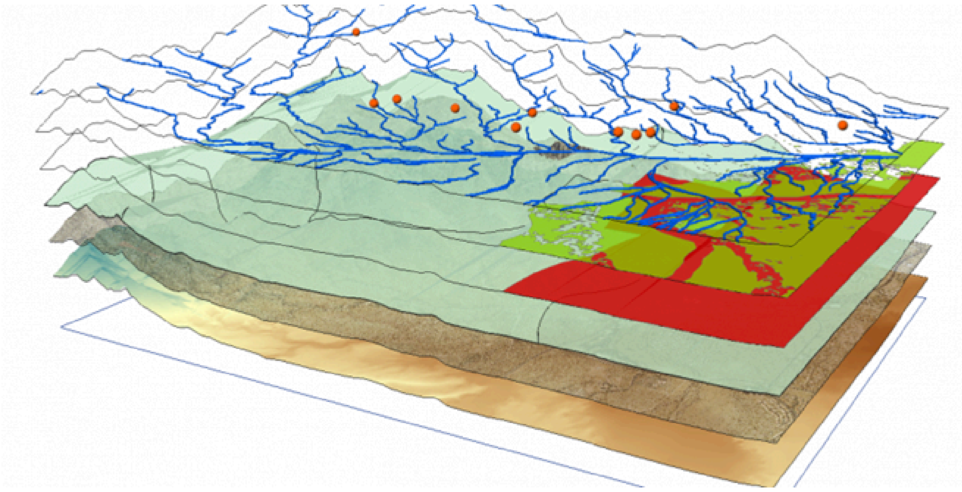

PROJECTED RAINFALL FOR 2050
Precipitation (mm)
80
70
60
50
40
30
20
10
0
0
24 hours
48 hours
ALEX storm
SSP 1-2.6
SSP 5-8.5


Simulated discharge of ALEX storm at Saint Martin de Vesubie
Discharge (m3/s)
1400
1200
1000
800
600
400
200
0
0
24 hours
48 hours
ALEX Storm
SSP1-2.6
SSP5-8.5

3.2 MIKE SHE

MIKE SHE is a hydrologic modeling software developed by DHI (DHI Water & Environment). MIKE SHE stands as an advanced and versatile hydrologic modeling framework, equipped with a comprehensive suite of pre- and post-processing tools. It provides a flexible blend of sophisticated and straightforward solution techniques for various hydrologic processes. Encompassing key elements of the hydrologic cycle, MIKE SHE incorporates process models for evapotranspiration, overland flow, unsaturated flow, groundwater flow, and channel flow, considering their intricate interactions.

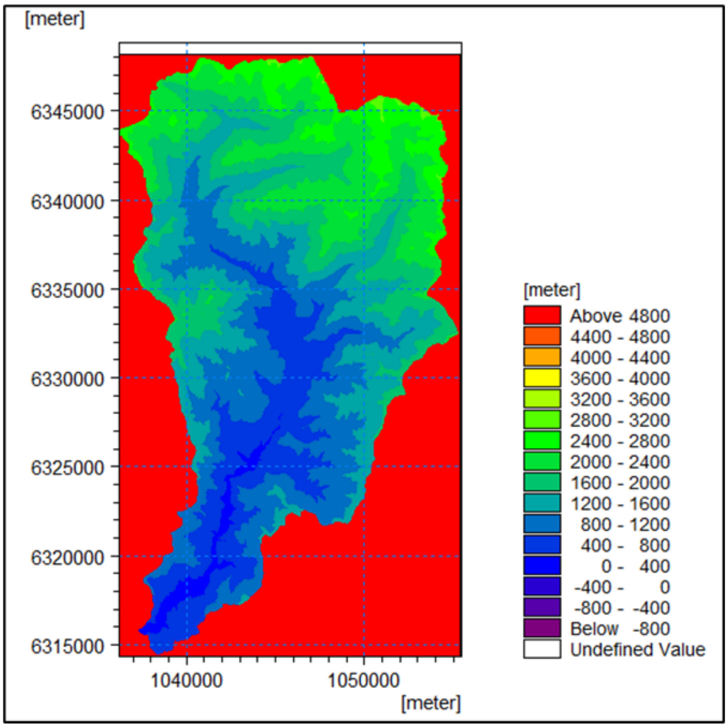
This framework accommodates the representation of each process at varying levels of spatial distribution and complexity, adapting to the specific goals of the modeling study, the availability of field data, and the preferences of the modeler. The user-friendly MIKE SHE interface facilitates an intuitive construction of the model description based on the user's conceptual understanding of the watershed. Model data, specified in diverse formats independent of the model domain and grid, includes native GIS formats. During runtime, spatial data seamlessly aligns with the numerical grid, simplifying the process of adjusting spatial discretization.



We tried to simplify the model by using the available data.

"The necessary input data for the MIKE SHE model depends on the specific application and characteristics of the studied area. However, for our case, the list of commonly used data types includes:

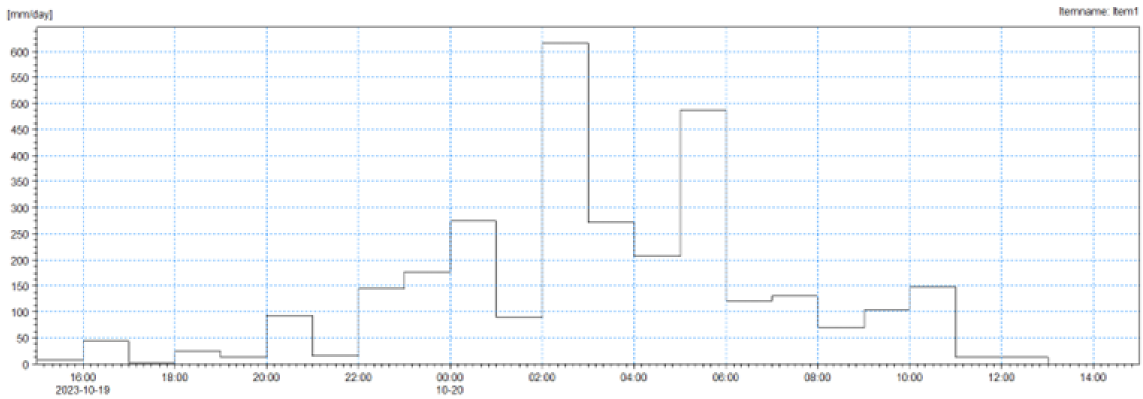
Topographic Data: This includes information about the elevation of the terrain, such as digital elevation models (DEM) with a resolution of 5 meters.



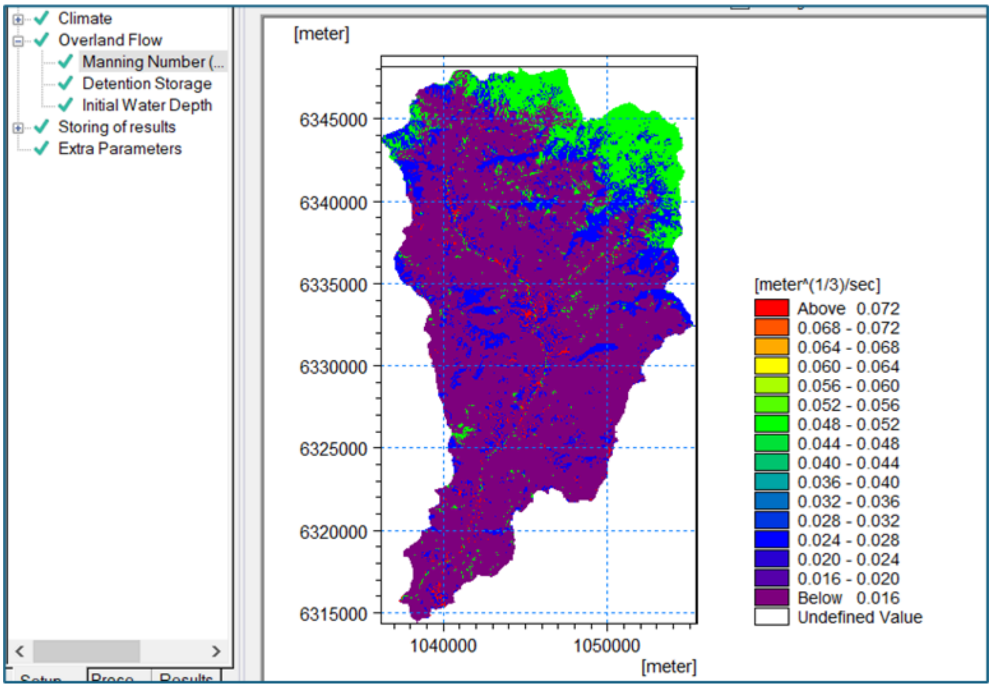
Importing the Vésubie catchment boundary and a Digital Terrain Model (DTM) with a 5-meter resolution into MIKE SHE involves using the dfs2 file format.

Climatic Data: ALINE storage rainfall data.

Import rainfall data from the Aline storm in dfs0 format.



Soil Occupation: Information about vegetation, including vegetation cover type, plant height, and density, is required to identify the Manning coefficient."

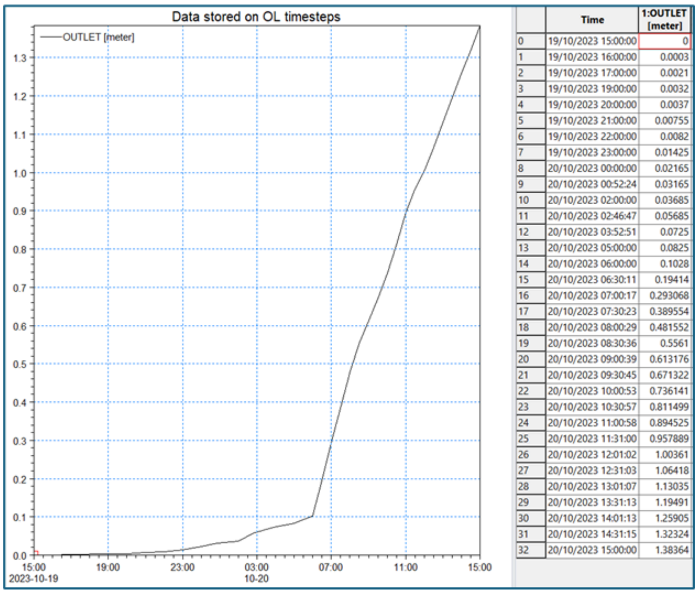


Define the Manning coefficient using land use type.

- Artificialized territories : 0.075
- Herbaceous : 0.05
- Forests and semi-natural environments : 0.025
- Tree :0.015

The results of the MIKE SHE model depend on the specific parameters you have defined in the context of your hydrological study. Here are some typical results you might obtain from simulations with MIKE SHE:

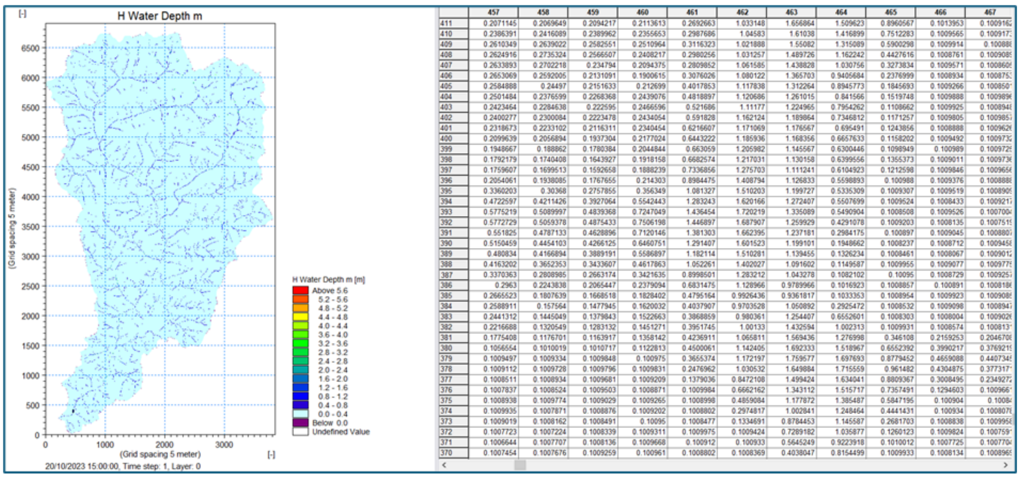
Flow Hydrograph: The model can generate flow hydrographs, showing the variation in water flow over time in simulated streams.



Flow Hydrograph in outlet (vésubie)

Spatial Distribution of Water Levels: could obtain maps representing the spatial distribution of water levels, allowing visualization of level variations at different points in the hydrological system.

Flood Maps: By simulating hydrological processes, the model can produce flood maps to identify areas prone to flooding during significant rainfall events.



Flood Maps

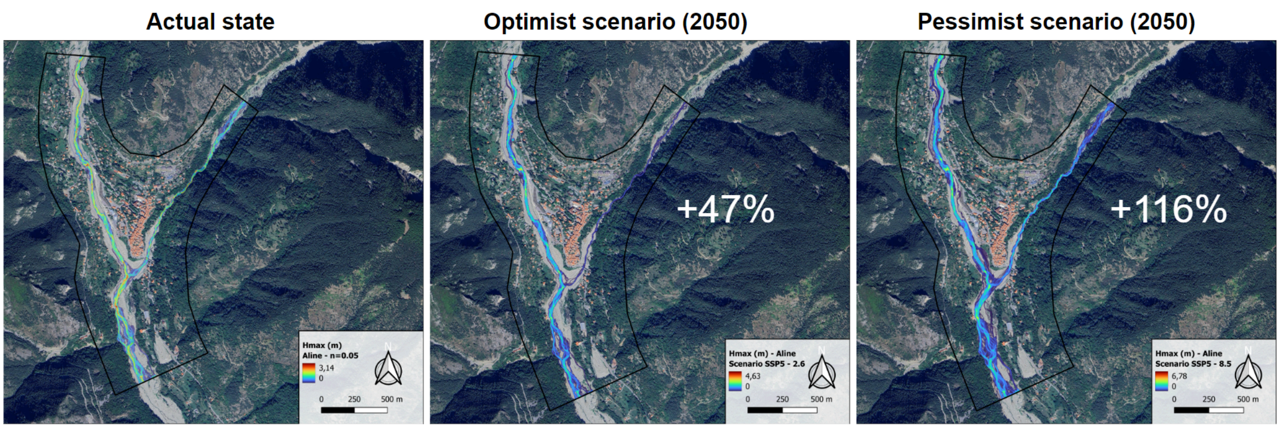
The water levels reach approximately 2 meters at the outlet, as indicated by the model. Calibration and correction are necessary to confirm the accuracy of the simulated flow and compare it with the observed flow. This process will help identify adjustments needed to the calibration parameters.
To determine flow rates at the river level, a 1D model with MIKE HYDRO is required.

MIKE SHE uses MIKE HYDRO river to simulate channel flow. MIKE HYDRO includes comprehensive facilities for modelling complex channel networks

However, in our case, since we do not have the MIKE HYDRO license, we were unable to obtain results at the river level.

Our model requires calibration and an extension of the simulation period, along with the incorporation of additional data such as evapotranspiration, saturated zones, soil types, and hydrogeological data to achieve a comprehensive MIKE SHE model. HydroEurope allows us to explore and become proficient with the MIKE SHE software, despite limitations related to the license and time constraints. While results may be influenced by these constraints, improvements can be made in other cases.

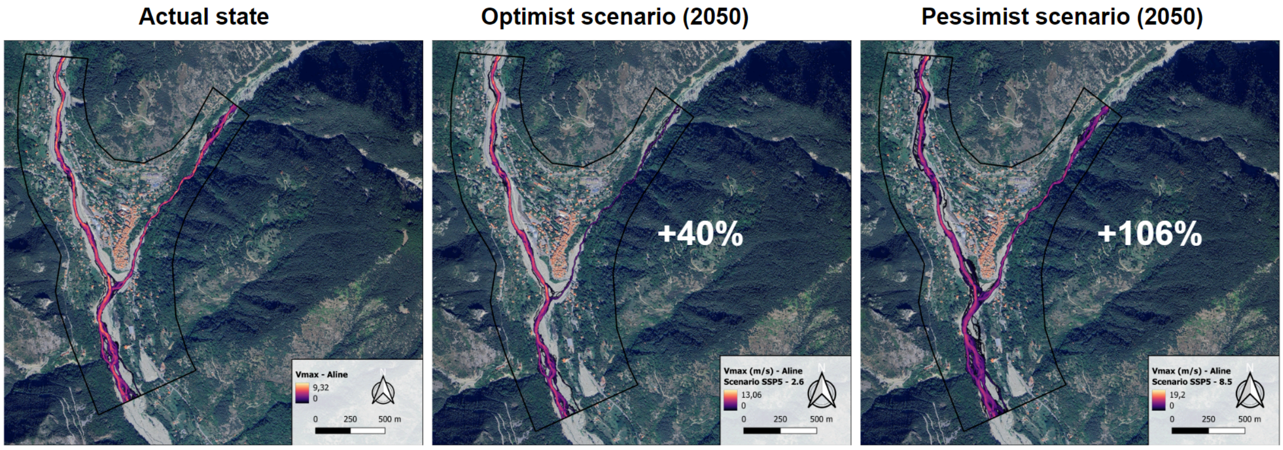
5. Hydraulic results



Our analysis of the different scenarios reveals differences in the potential impacts of flooding downstream of our study area, particularly with regard to projected increases in water level due to climate change.

In the current scenario, we observe relatively stable water levels within acceptable ranges downstream. However, when compared with the optimistic scenario for 2050, which predicts a 47% increase in maximum water level due to climate change, we anticipate moderate increases in flood risk. While the impact may be manageable with appropriate mitigation measures, such as improved drainage systems and flood defenses, it is crucial to note the potential challenges associated with rising water levels.

In contrast, the most pessimistic scenario for 2050, forecasting a 116% increase in water levels, presents a far more alarming picture. In this scenario, the risk of severe downstream flooding increases considerably, posing serious threats to infrastructure.



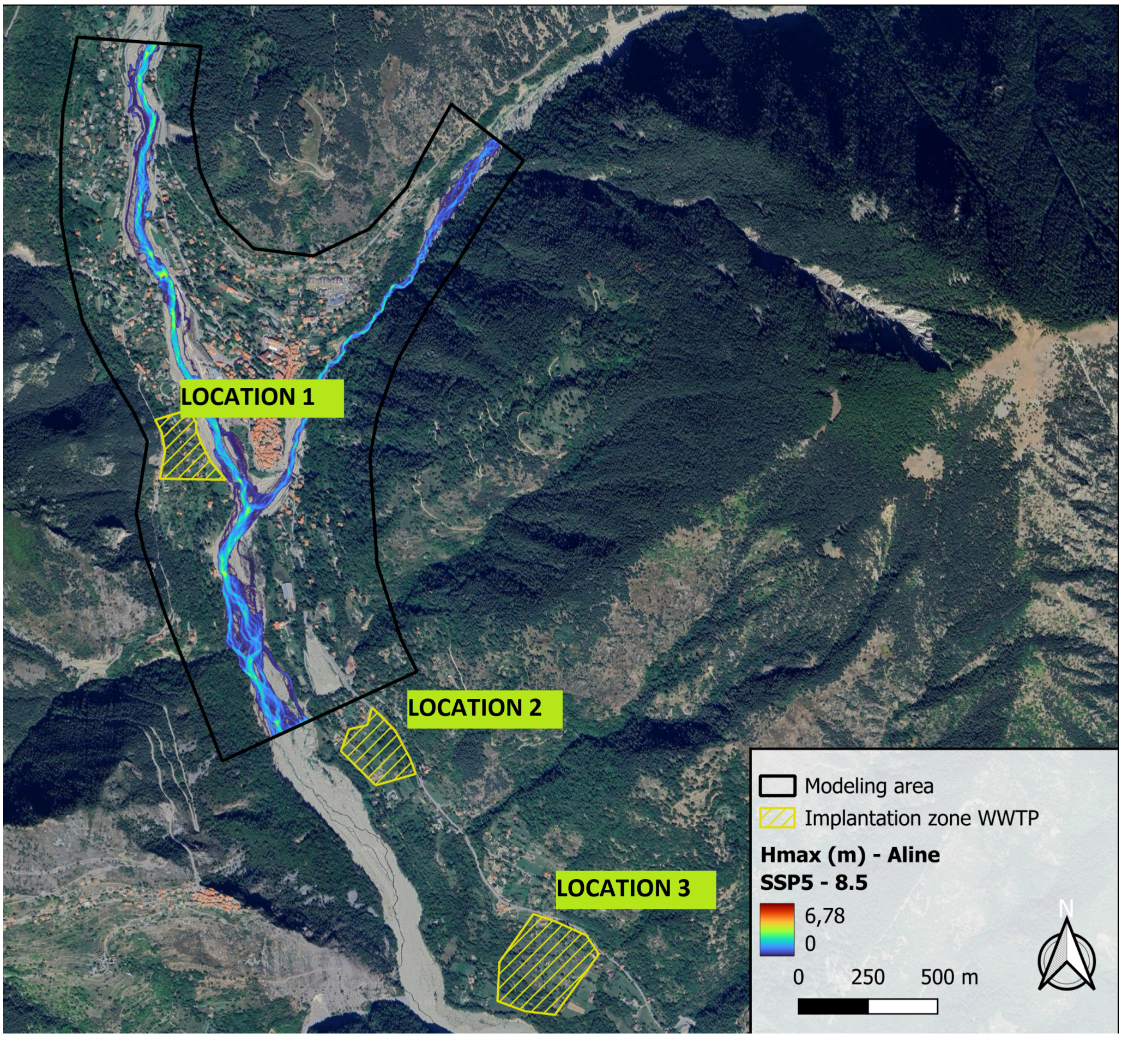
In the current scenario, we observe relatively stable and acceptable flow velocities in the study area. However, looking at the optimistic scenario for 2050, with a 40% increase in flow velocities due to climate change, we anticipate moderate increases in flow velocity risks.

By contrast, in the most pessimistic scenario for 2050, with a 106% increase in flow velocities, the risks associated with flow velocities become much more severe. In this situation, high flow velocities can lead to increased bank erosion, increased flood risk and deterioration of hydraulic infrastructure. These impacts could compromise the safety of riverside populations and require urgent adaptation measures.

Conclusion

Opening on Alex Storm results → show that this kind of very strong event might occur more and more in the future. And with this, climate change must be considered in the planning process for future developments. For this week, the different climate change scenarios were incorporated into the working hydrologic model. Then the outputs were used as input into the hydraulic model to see the extent of the flooding within the study area.

And to answer the case study objective for relocating the new wastewater treatment plant. For potential locations, 3 zones were selected.



To further evaluate these chosen locations, several factors were reviewed aside from the resulting flood map from the hydraulic modelling considering the worst-case scenario due to climate change.

A. Elevation

- For the operations of the treatment plant, elevation is important. So, the Location 1 initially proposed needs to be reconsidered because it is upstream on the river and far from the other urban settlements, even though it will not be affected by flooding based on the hydraulic results as shown in the flood map.

  Two (2) more locations were considered and evaluated as well. Location 2 is at the mid-downstream of the river with lower elevation from the 1st Location 1. Location 3 is 2 km far from the concentrated urban settlement upstream and has the lowest elevation among the proposed locations.

B. Accessibility

- this criteria is important in terms of the project implementation and mobilization as well as the operation. Based from Google Satellite Images, it is shown that there are visible roadways, mostly rough roads but are connected to the main roads in the area. Another aspect that was checked was the existing drainage and/or sewer lines, but data for these were difficult to find. So for the evaluation it was assumed that existing lines would be along the roads to account for sewage conveyance to the treatment plant.

C. Landuse

-This is another factor to be taken into account mainly due to the service connections from the source and also the stakeholders in the area. For this, data used were from the French Government websites

a. Urban Planning Geo Portal (https://www.geoportail-urbanisme.gouv.fr/)
b. Metropole Nice Cote D'Azur government website (https://cartes.nicecotedazur.org/portal/apps)

For zone selected for Location 1, urban and residential areas are assigned. Based on the flood map from the worst-case scenario due to climate change, the extent is not reaching that zone.

For the Location 2, it is towards the mid downstream and the land uses in that zone are also residential areas and areas considered for future urban development. No specific high-risk stakeholders were identified in the region based from the portal.

For Location 3, the land use assigned in that zone are areas allocated for needs in agricultural purposes, protected areas and some for future urban development.

D. Other Site Conditions

- For this, one of the aspects looked into was the soil conditions in the area. This is important in terms of structural stability for the wastewater treatment plant's structure. For all the 3 zones selected, the main soil type is Rendisol, based from the Soil Map portal of France (https://www.geoportail.gouv.fr/donnees/carte-des-sols). This type of soil is very prone to erosion.
- Also, for Location 1, there are some identified stakeholders nearby based on the urban planning portal. This is important to consider in the planning of this project for potential complaints and objections on the implementation and operations.

Evaluation criteria for the 3 proposed locations was summarized below.

Criteria:	Location 1	Location 2	Location 3
Elevation	946m	890m	835m
Accessibility	ok	ok	ok

Land Uses	Urban development, residential	Urban development, residential	For agricultural needs, Protected area, urban development
Other site conditions	1. Majority are Rendisol type		
	2. Nearby Stakeholders: -Gubernatis Palace -Chapel of the Holy Cross -Notre-Dame-de l'Assomption Church -Chapel of Mercy or Black Penitents		2. Very far from the existing urbanized area (about 2km)

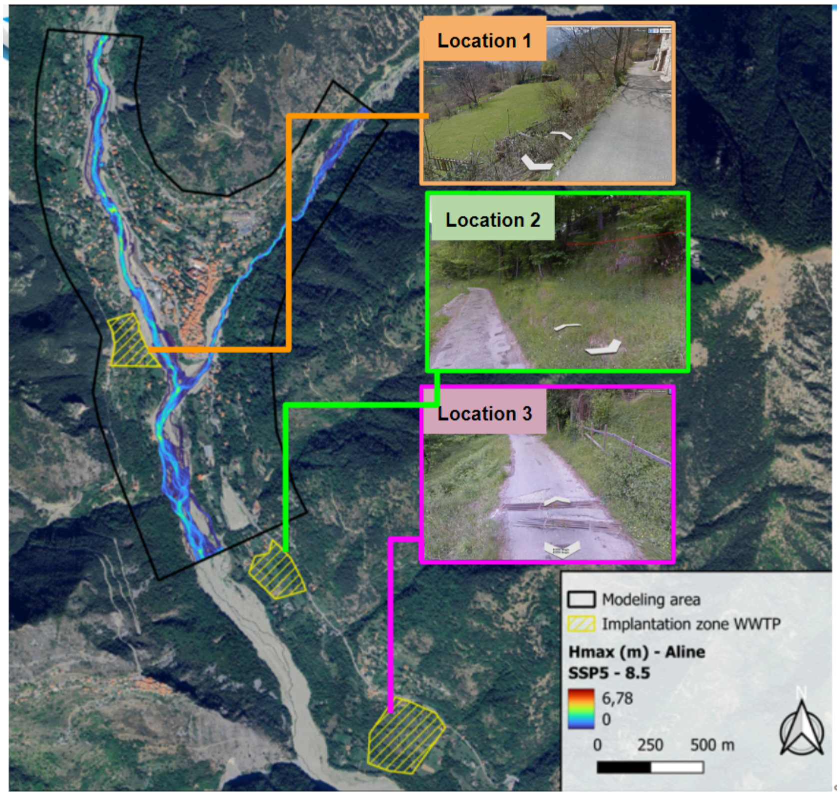
Table of Site Selection Criteria.

Recommendation:

For the final recommendation on the location for the new WWTP, Location 2 is recommended. The distance from the concentrated urban settlement on the upper part of the study area was the main point for recommending this location for implementation.

Prior to final implementation, further steps are recommended:

a. Perform modelling further downstream
   - since the selected location was outside of the model domain, it is recommended to verify again the results such as the flood extent map including the area for the proposed location for the new WWTP. Also, to incorporate further improvement in the models.
b. Complete site reconnaissance
   - prior to project implementation site visit to see actual site conditions relevant to mobilization such as utilities, existing structures and sub-structures.



(Google Satellite Images for the 3 proposed locations)

c. Conduct specific site investigation/studies.
   - Further investigation studies such as soil investigation to assess the soil bearing capacity for structural considerations and land survey to properly assess parameters such as elevation and invert level, property boundaries and limits are relevant data to be considered as well for project implementation. Also, other stakeholders should be identified and to then conduct the public consultation for them to be involved in the project planning.

d. Consider potential flooding impact in design
   - after conducting site specific studies and investigation, engineering design considerations can be incorporated. Engineering measures such as stronger structural strength consideration for the civil works, putting flood walls near or around the plant boundary or raising the elevation from ground level and enclosement to protect relevant equipment from big debris due to extreme flooding.

Reference:

1. https://atlas.climate.copernicus.eu/atlas
2. https://confluence.ecmwf.int/display/S2S/CNRM+Model (model reference)