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Team 05: Week 2

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WP2: Uncertainty in Advanced Hydrological and Hydraulic Modelling
WP3: Climate Change Impacts on Flash Floods
WP4: Accidental Water Pollution
Case Study Var and Vésubie (France)

Team 05: Report 2st Week Phase:
Modelling and Analysis of the Vésubie sub-catchment

List of Authors: Henry Rong, Théo Salinas, Félix Tarralle, Lucas Lizin, Anaïs Lespine, Arvy Fachrully, Yanjia Zhou, Laura Romero Gómez, Muhammad Wayassirli Amri, Boucier Maximilien

Supervisor: Dr Jelena Batica (Université Côte d'Azur)

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SUMMARY

1 Introduction

Water quality management in river systems is a significant challenge, especially in regions impacted by industrial, urban, and agricultural activities. The Var and Vésubie river catchments in France face environmental pressures due to their proximity to industrial zones, transport infrastructure, and urban developments. Accidental water pollution poses risks to ecological integrity, public health, and socio-economic stability. This report examines hydrodynamic modeling, legal and regulatory analysis, risk assessment, and mitigation strategies to propose sustainable water management solutions. A key component of this study is water quality modeling using HEC-RAS and Telemac to simulate pollutant transport and dispersion. These models help predict contamination pathways under different flow conditions, supporting decision-making for pollution control and emergency response. The integration of spatial and temporal data allows for precise hazard mapping, identifying high-risk areas and informing intervention strategies.

The legal and regulatory framework is analyzed at European, national, regional, and local levels. Policies such as the Water Framework Directive and the Urban Wastewater Treatment Directive establish guidelines for water protection, while national and regional policies impose additional constraints on industrial discharges and urban wastewater management. Identifying gaps in compliance and enforcement helps improve governance and technical measures.

Risk assessment methodologies evaluate the vulnerability of the catchment to accidental pollution and flooding. The study incorporates hazard mapping, real-time monitoring, and early warning systems to improve response capabilities. Automated sensor networks enhance water quality surveillance, while public awareness initiatives strengthen community resilience. Mitigation strategies include nature-based solutions such as constructed wetlands, riparian buffer zones, and biofiltration systems, which use natural processes to filter pollutants and enhance ecosystem resilience. However, in highly urbanized or industrial zones, these approaches must be combined with engineered flood control and wastewater treatment infrastructure. A hybrid approach integrates both solutions for effective water resource management.

This report provides a scientific and engineering-based assessment of pollution risks in the Var catchment. The recommendations aim to improve water resilience, regulatory enforcement, and sustainable hydrological infrastructure. These findings support policymakers, environmental agencies, and engineering professionals in implementing long-term strategies to safeguard water quality and promote ecological sustainability.

1.1 Point source pollution sources

The Seveso Directive plays a critical role in preventing industrial accidents and ensuring public safety. By enforcing stringent regulations and transparency obligations, it helps mitigate the risks associated with hazardous industrial activities. A strict and consistent implementation of the directive remains essential to prevent future disasters and uphold high safety standards across European industries.

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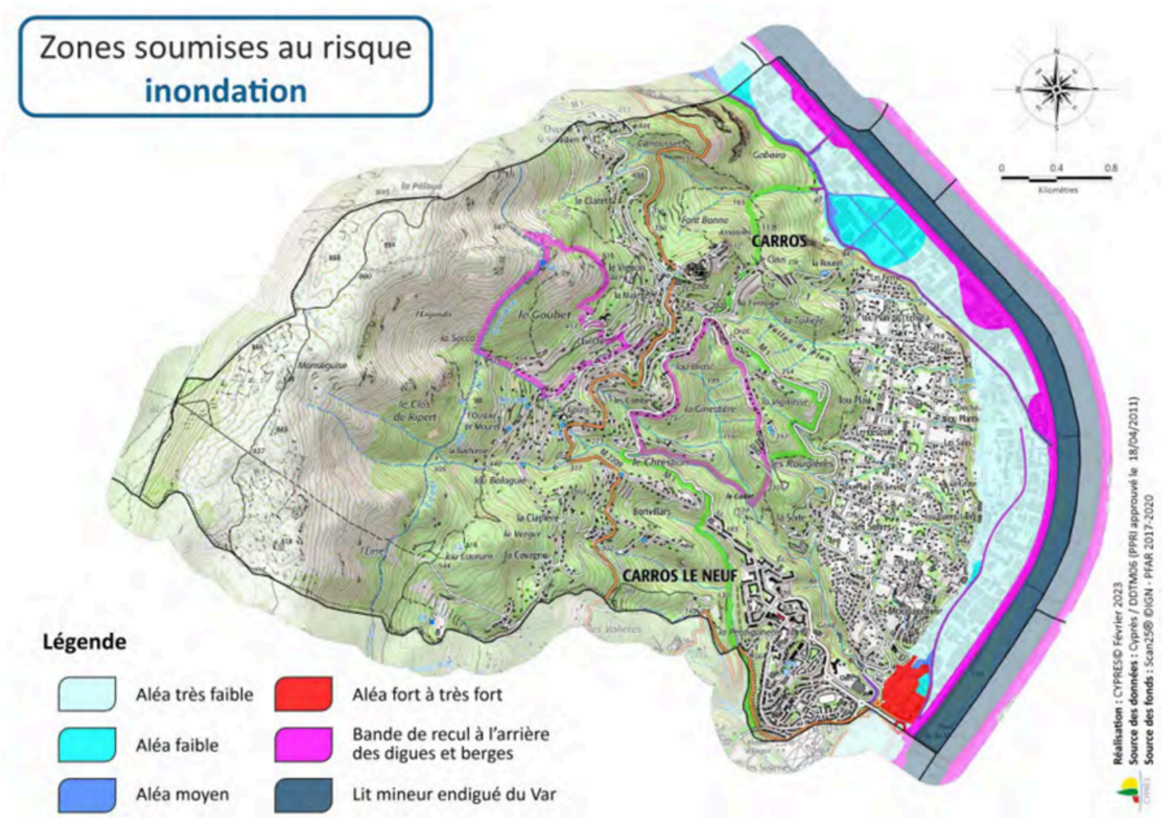

Figure 1 : Areas at risk of flooding (alea tres faible = very low hazard; alea faible = low hazard; alea moyen = average hazard; alea fort a tres fort = strong to very strong hazard; bande de recul a l'arriere des digues et berges = setback strip behind dikes and banks; minor bed dykes of the var).

In our case, we can see that a SEVESO low threshold facility is in the same area as a flood hazard. In particular, the company stores flammable fluids. The hazard is low, but the stakes are high, so the risk is high.

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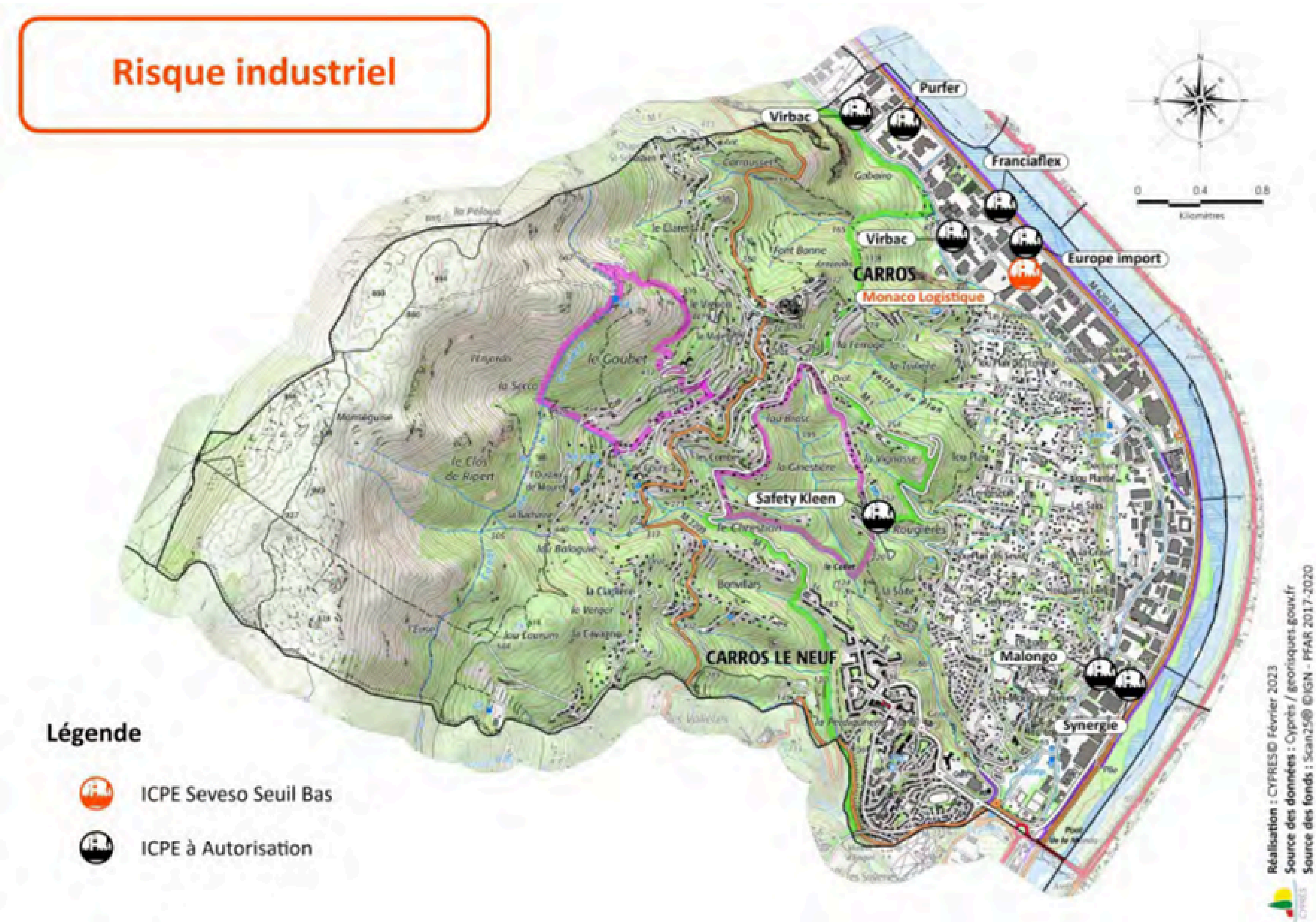

Figure 2 : Areas at industrial risk. (Seuil Bas = at risk; a Autorisation = has authorisation)

1.2 History

Zavattero et al. 2018 modeled the situation of accidental flood pollution in the same modeling domain. It focused on two pollutants: cadmium from a painting factory and a nonconservative pollutant (COD) from a pharmaceutical factory. The study looked at the potential for contamination of aquifer pumping stations downstream.

The ammonium, nitrite, and nitrate ions are highly soluble in water and are mainly dispersed in the aqueous phase. A study on the determination of nitrates and nitrites in natural waters highlights their solubility and mobility in aquatic systems.

The silver ion can be associated with suspended particles and sediments, reducing its mobility in the water column. This behaviour is similar to that of other heavy metals which tend to accumulate in sediments due to their low solubility under.

Aluminum in its ionic form tends to precipitate and accumulate in sediments due to its low solubility in water at neutral pH. Studies on heavy metal pollution indicate that aluminum is mainly associated with suspended particles and sediments in water bodies.

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On the other hand, phosphates can form insoluble compounds with cations such as calcium, iron, and aluminum, leading to their precipitation and accumulation in sediments. Research on chemical pollutants in water indicates that phosphates readily adsorb to sediment particles, reducing their mobility in the water column.

The following table summarizes information on the means of transport of each of the pollutants present in the study area.

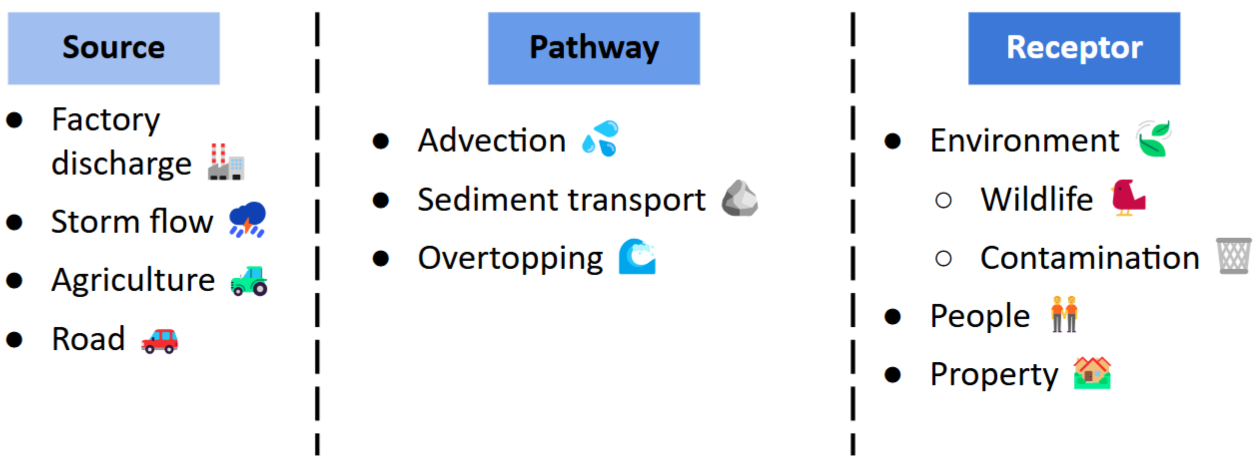
Table 1 : Type of dispersion of pollutants in the study area.

Chemical	Common name	Transport means
NH_4^+	Ammonium ion	Water
NO_2^-	Nitrite ion	Water
NO_3^-	Nitrate ion	Water
Ag^{2+}	Silver ion	Sediments
Al^{2+}	Aluminium ion	Sediments
PO_4^{3-}	Phosphate ion	Sediments

The dispersion of these pollutants in the environment depends on several factors, including pH, temperature, the presence of other ions and the hydrodynamic conditions of the water body.

2 Source-Pathway-Receptor model

The source-pathway-receptor (SPR) model is a proven methodology for representing the stages of water pollution.



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3 Legal setting regarding pollution

3.1 European level

- **Water Framework Directive (WFD) 2000/60/EC (October 23, 2000)**. It establishes objectives for achieving 'good ecological status' of water and imposes river basin management plans, as well as water quality monitoring.
- **Nitrates Directive 91/676/EEC (December 12, 1991)**. It regulates the use of agricultural fertilizers in order to prevent water pollution by nitrates (NO3-). To this end, it establishes vulnerable zones and specific action programs.
- **Urban Waste Water Treatment Directive (91/271/EEC)**. It regulates the collection, treatment and discharge of urban wastewater, protecting the environment from the negative effects of discharges.
- **Directive 98/83/EC** on the quality of water intended for human consumption. It defines the standards of water potability (pesticides, nitrates, heavy metals, etc.).
- **Habitats Directive (92/43/EEC)**. It guides the conservation of natural habitats and wild fauna and flora, establishing the Natura 2000 network to protect areas of Community importance.
- **REACH Regulation (EC) 1907/2006**. This is an EU regulation that regulates the safe production, marketing and use of chemicals, including those that may affect water quality.

3.2 France Level

- **Law on Water and Aquatic Environments (LEMA) No. 2006-1772 (December 30, 2006)**. This law aims at reforming water management in France by introducing taxes to limit pollution. It also strengthens water quality control mechanisms and creates the National Office for Water and Aquatic Environments (ONEMA) - now the French Biodiversity Office (OFB).
- **Environmental Code (Articles L210-1 to L219-18)**. They define water as a common heritage of the nation. On the other hand, it regulates industrial and agricultural wastewater discharges, establishing sanctions in case of pollution.
- **Classified Installations Legislation**, initially established by the Law of July 19, 1976. This regulation controls those activities that may be potentially polluting or hazardous, ensuring that they operate in a way that minimizes their environmental impact.
- **National Pesticide Reduction Plan (Ecophyto)**. It is a policy driven by the use of pesticides in agriculture. Although it has regional and local implementation, its scope is national, as it is overseen by the French Ministry of Agriculture and Food.
- **Water Law (Loi sur l'Eau) No. 92-3 of January 3, 1992**. establishes the principles for the management and protection of water resources in France, promoting a balanced and sustainable approach.
- **Regulation of Classified Installations for the Protection of the Environment (ICPE)**. Regulates industrial and agricultural activities that may present risks to the environment, including specific rules for the control of discharges and emissions.
- **The July 15, 2015 decree** sets limit values for wastewater discharges to protect aquatic environments. Key parameters include biochemical oxygen demand (BOD5) with limits of 25 mg/l for smaller stations and 15 mg/l for larger ones, suspended solids (SS) with limits of 35 mg/l and 20 mg/l respectively, as well as total nitrogen (15 mg/l) and total phosphorus (1 mg/l) for larger

stations. The pH of discharges must be between 6 and 9, and fecal coliforms must be below 1000 CFU/100 ml. These standards aim to protect water quality and aquatic ecosystems.

3.3 Region level

- **Master Plan for Water Development and Management (SDAGE) of the Rhone-Mediterranean basin**. Strategic plan defining objectives and actions to preserve and restore water quality in the region, addressing issues such as diffuse pollution and sustainable water resources management.
- **Water Management and Management Plans (SAGE)**. Planning instruments at sub-basin level detailing specific measures for water management, adapted to local specificities within the region.

3.4 Department and prefecture level

1. Sanitary Regulation of the Alpes-Maritimes Department:
   This regulation, updated in September 2003, defines the conditions for sanitation and the quality of water intended for human consumption within the Alpes-Maritimes department. It sets strict criteria regarding the concentration of chemical and microbiological substances, in line with national and European recommendations, while also accounting for local water management issues. The regulation is monitored by the Regional Health Agency (ARS) PACA, which conducts regular checks to ensure compliance.

2. Alpes-Maritimes Air Quality Protection Plan (Objective 2025):
   Although this plan primarily focuses on air quality, it has indirect effects on water quality by reducing the emissions of pollutants that can end up in rivers and streams. For instance, reducing nitrogen and sulfur dioxide emissions—key air pollutants—helps limit water contamination. The Air Quality Protection Plan for the PACA region aims to cut these emissions by 30% by 2025, benefiting both air and water quality by decreasing pollutants like nitrates and nitrogen oxides.

The limit values for chemical and microbiological parameters in drinking water are set by the order of February 2, 1998, and apply throughout the Alpes-Maritimes. Here are some examples:

- **Lead:** The maximum allowable concentration for lead in drinking water is 10 µg/L. This ensures that water is safe for public health, even at low concentrations of lead, a toxic heavy metal.
- **Nitrates:** The maximum concentration for nitrates in drinking water is set at 50 mg/L. Nitrates typically come from intensive agriculture, and high concentrations can pose health risks, especially for infants.
- **Pesticides:** The limit values vary depending on the pesticide, but the goal is to ensure that water does not contain residues exceeding safety thresholds set by European regulations.

PFAS (Per- and Polyfluoroalkyl Substances) are increasingly being monitored in the Alpes-Maritimes due to their persistence in the environment and potential health risks. These substances, used in a variety of industrial products, are particularly concerning because they remain in the environment for a long time and can contaminate groundwater. Recent studies have detected their presence in surface waters in the PACA region, with some areas near industrial sites showing particularly high concentrations. Surveillance of PFAS in rivers and drinking water is a growing priority for local authorities and environmental agencies.

The limit values for these substances vary by country and regulation, but they are being continuously reassessed, especially within the EU and France.

Specific data on river water quality is also provided by the Rhône-Méditerranée-Course Water Agency, which follows the objectives of the SDAGE (Master Plan for the Development and Management of Water Resources) to improve water quality in the river basins of the Alpes-Maritimes.

3.5 City level

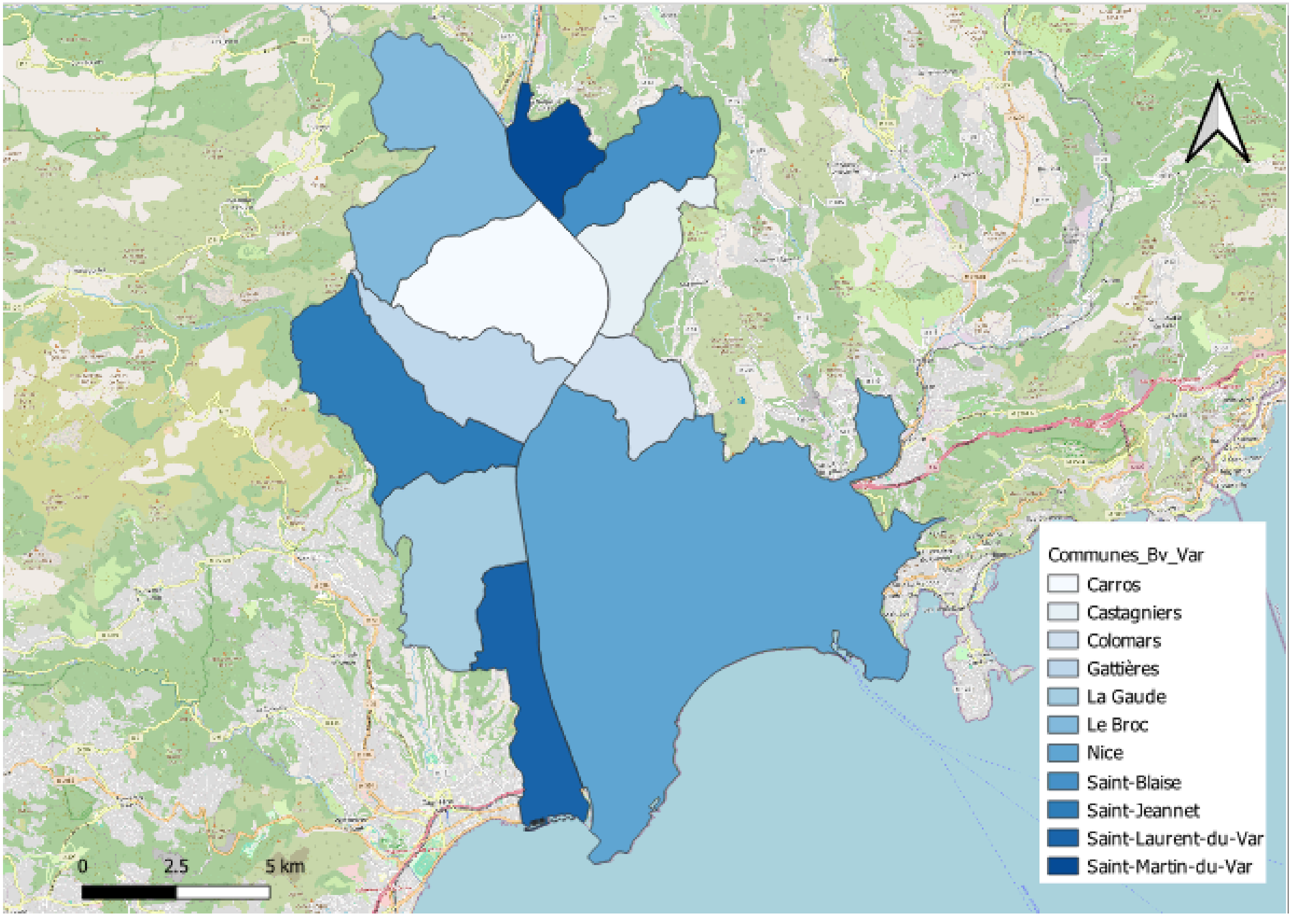

Figure 3 : Map of the different cities in the work zone from Saint-Martin du Var from the sea.

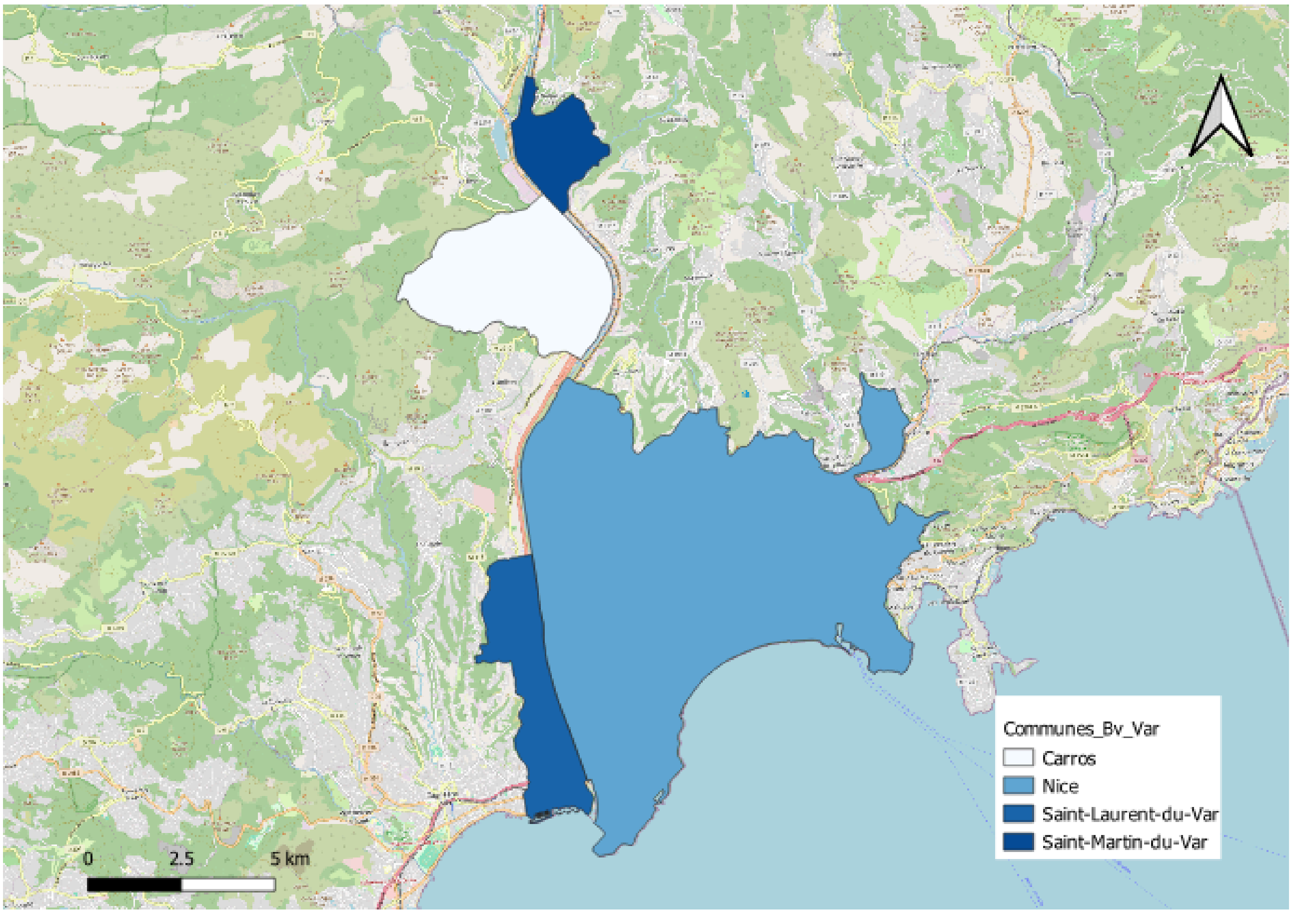

Figure 4 : Map of the different cities in reference from local reglementation.

3.5.1 Nice

- **Local Metropolitan Urban Planning Plan (PLUm)**. The Nice Côte d'Azur Metropolis adopted the PLUm on October 25, 2019, establishing guidelines for land use and urban development in the 49 communes that comprise it, including Nice. This plan addresses the management of water resources, flood zones and environmental protection.
- **Municipal Ordinances on Water Management and Sanitation**. The municipality of Nice has implemented specific regulations for stormwater and wastewater management, with the aim of protecting local water resources, including the Var River.

3.5.2 Carros

- **Local Urban Plan (PLU)**. Carros has its own PLU, which defines land use and urban planning regulations, considering the proximity to the Var River and establishing measures for the protection of flood zones and sustainable water management.
- **Municipal Ordinances on Sanitation**. The municipality has adopted regulations for wastewater treatment and disposal, ensuring the preservation of water quality in the vicinity of the Var River.

3.5.3 Saint Laurent du Var

- **Local Urban Planning Plan (PLU)**. This document establishes urban development and land use guidelines in Saint-Laurent-du-Var, including provisions for water resource management and the protection of sensitive areas near the Var River.
- **Municipal Ordinances on Water Management**. The municipality has implemented specific regulations for stormwater and wastewater management to prevent pollution and protect local water resources.

3.5.4 Saint Martin du Var

- **Local Metropolitan Urban Planning Plan (PLUm)**. Like Nice, Saint-Martin-du-Var is part of the Nice Côte d'Azur Metropolis and is subject to the PLUm adopted in 2019. This plan includes regulations on land use, water management and flood zone protection.
- **Risk Prevention Plans (RPP)**. Saint-Martin-du-Var is subject to RPPs that identify areas at risk of flooding and establish preventive measures to minimize the impact of potential natural disasters.

In conclusion, water quality in the catchment is subject to strict regulations, but the presence of emerging pollutants, like PFAS, and challenges related to agricultural and industrial activities remain significant issues for the department.

4 Quality Table

4.1 Parameters (unit)

In France, rivers are evaluated under a statutory classification system. A prefectural decree defines five categories for each physicochemical parameter, ranging from “Very Good” to “Very Bad.” If all parameters are rated “Good” or “Very Good,” no intervention is required for the river.

4.1.1 Oxygen Balance

Table 2 : Data for the oxygen balance.

Parameter	Very Good	Good	Average	Bad	Very Bad
Dissolved Oxygen (mg O2/l)	≥ 8	[6 ; 8 [	[4 ; 6 [	[3 ; 4 [	< 3
Dissolved O2 Saturation Rate (%)	≥ 90	[70 ; 90 [	[50 ; 70 [	[30 ; 50 [	< 30
BOD5 (mg O2/l)	≤ 3	] 3 ; 6]	] 6 ; 10]	] 10 ; 25]	> 25
Dissolved Organic Carbon (mg C/l)	≤ 5	] 5 ; 7]	] 7 ; 10]	] 10 ; 15]	> 15

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4.1.2 Temperature

Table 3 : Data for the temperature from two important parameter..

Parameter	Very Good	Good	Average	Bad	Very Bad
Salmonid Waters	≤ 20	] 20 ; 21.5]	] 21.5 ; 25]	] 25 ; 28]	> 28
Cyprinid Waters	≤ 24	] 24 ; 25.5]	] 25.5 ; 27]	] 27 ; 28]	> 28

4.1.3 Nutrients

Table 4 : Data for the different important nutrients parameters..

Parameter	Very Good	Good	Average	Bad	Very Bad
$PO4^{3-}$ (mg $PO4^{3-}$/l)	≤ 0.1	] 0.1 ; 0.5]	] 0.5 ; 1]	] 1 ; 2]	> 2
Total Phosphorus (mg P/l)	≤ 0.05	] 0.05 ; 0.2]	] 0.2 ; 0.5]	] 0.5 ; 1]	> 1
$NH4^{+}$ (mg $NH4^{+}$/l)	≤ 0.1	] 0.1 ; 0.5]	] 0.5 ; 2]	] 2 ; 5]	> 5
$NO2^{-}$ (mg $NO2^{-}$/l)	≤ 0.1	] 0.1 ; 0.3]	] 0.3 ; 0.5]	] 0.5 ; 1]	> 1
$NO3^{-}$ (mg $NO3^{-}$/l)	≤ 10	] 10 ; 50]	*	*	*

4.1.4 Acidification

Table 5 : Data for the a physical parameters..

Parameter	Very Good		Good	Average	Bad	Very Bad
Minimum pH	≥ 6.5		[6.5 ; 6 [	[6 ; 5.5 [	[5.5 ; 4.5 [	< 4.5
Maximum pH	≤ 8.2		] 8.2 ; 9]	] 9 ; 9.5]	] 9.5 ; 10]	> 10

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5 Pollution

For our study, the potential pollution from the Monaco logistic industry located next to the Var.

Figure 5: Localisation about the factory could cause accidental water pollution.

This company stocks a large number of hazardous materials, which are listed in the table below:

Table 6 : Stocks a large number of hazardous materials.

N° category	Designation	Quantity (tons)	Status
4510	Dangerous products for the aquatic environment category acute 1 or chronic 1	330 T	A SH
4511	Dangerous products for the aquatic environment category chronic 2	600 T	A SH
4130-1	Acute toxicity category 3 inhalation Solid	20 T	D
4140-2a	Toxic products category 3 oral Liquid	11 T	A
4733	Specific carcinogens	0.8 T	A SB

Specific instructions are imposed, and staff are trained to react in the event of a risk of pollution through leakage from these storage areas. Despite these measures, in the event of very high floods and damage to the infrastructure, the chemicals may end up in the river. In addition, other sources of pollution are possible, such as pollution from road cleaning. Rainwater and wastewater are treated differently depending on their use. Their treatment is listed below.

Table 7 : Different types of water pollution.

Nature of Effluents	Treatment Before Discharge	Receiving Natural Environment or Collective Treatment Station	Connection Conditions
Domestic wastewater	None	Municipal wastewater treatment plant of Saint Laurent du Var	Agreement
Rainwater from roads and roofs	Hydrocarbon separator	Industrial zone collector network	
Rainwater from roads and roofs	Hydrocarbon separator	Industrial zone collector network	
Firefighting water	/	No discharge: firefighting water will be stored in basins and then pumped and treated by specialized channels	/

The maximum authorized runoff rate of rainwater into the natural environment is **30 l/s/ha**, with a total authorized runoff rate of **52.86 L/s**.

6 HEC-RAS modelisation

6.1 Methodology

6.2 Result

7 Telemac modelisation

7.1 Methodology

The equations used by TELEMAC-2D modelling are the Barré-Saint-Venant equations.

Surface flows : This equation represents the conservation of mass in surface flows (such as rivers or coastal waters)

$$\frac{\partial h}{\partial t} + \nabla \cdot (h\mathbf{U}) = 0$$

where:

- h is the water surface height,
- U is the velocity vector of the fluid,
- $\nabla \cdot (hU)$ represents the mass flux of the water

To establish a model on TELEMAC-2D, we used a 25m DTM and a 5m DTM for comparison. Initially, we worked on the model using the 25m DTM. The nearest buildings were included in the mesh, with mesh sizes ranging from 100m to 15m for the major bed of the Var (25m DTM) and from 25m to 5m (5m DTM).

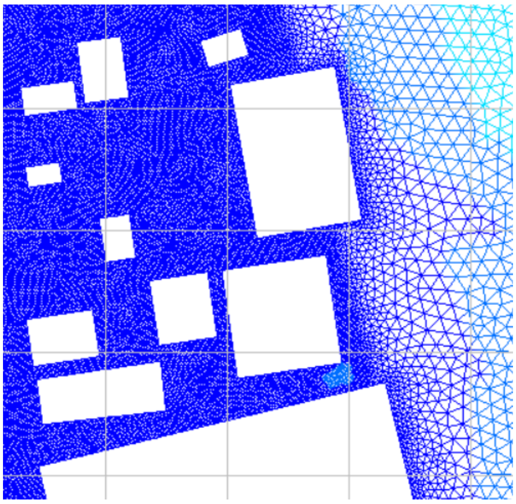

Figure 6 : Mesh with buildings

The CFL condition established earlier was used to determine a time step of 1s. With regard to the boundary conditions, a flow of 49.4m3/s was imposed upstream and a water height of 0m was imposed downstream.

Various floods were simulated, including the 2020 flood and the 1994 flood. In addition, the Monaco Logistique plant was chosen for the leakage of a pollutant. The pollutant was modelled on TELEMAC-2D using tracers with an imposed concentration. In order to model a pessimistic case, the concentration used was overestimated with a value of 500 mg/L.

7.2 Results

Firstly, the water level results for the mean flow of the Var and the 2020 flood using the 25m DTM and the 5m one.

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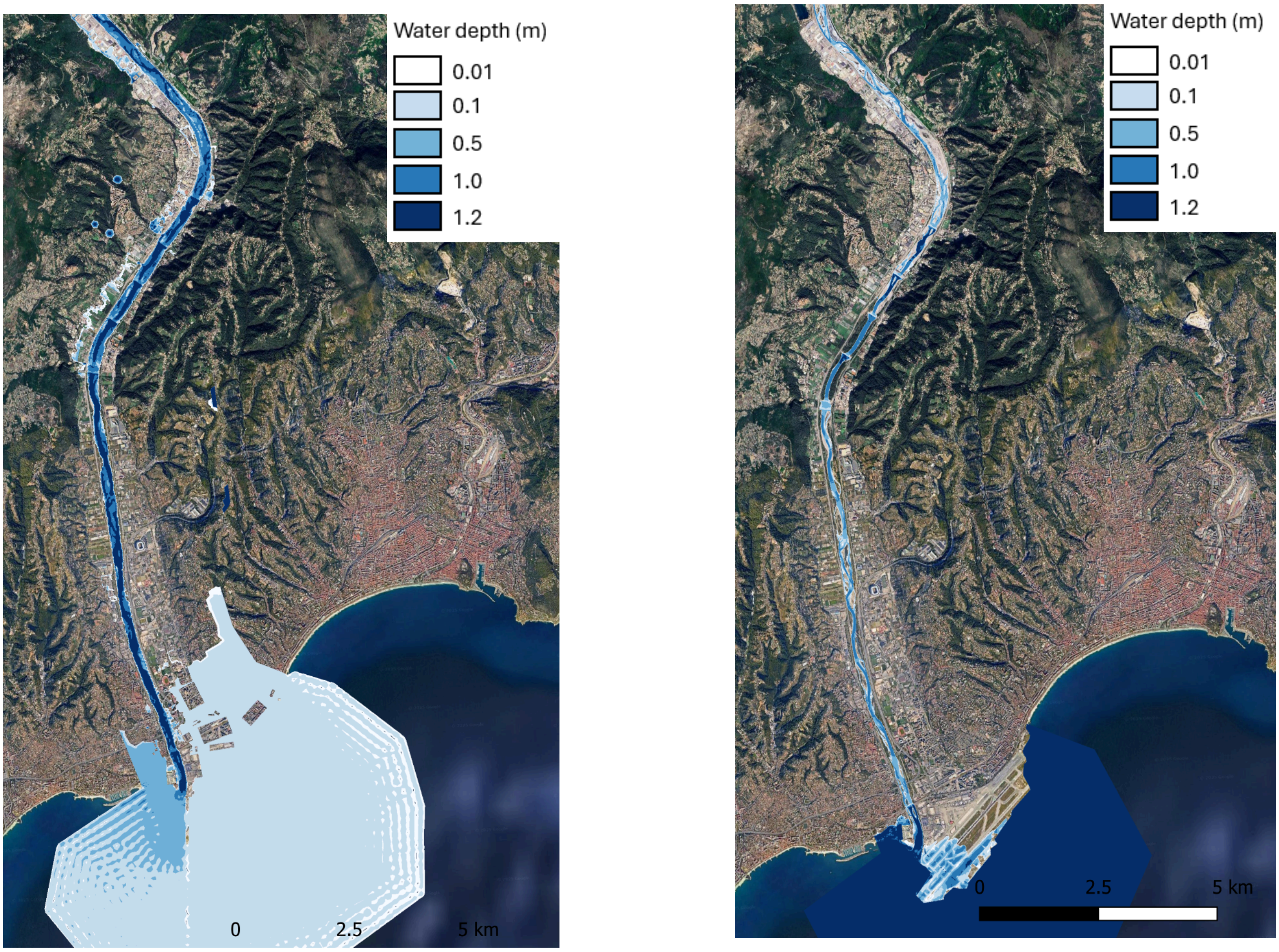


Figure 7 : steady case (25m DTM at the left and 5m DTM at the right)

As we can see, the steady case gives good results in both cases with slightly more accuracy using the 5m DTM. The big difference is observed downstream, where the sea seems to be more alienated with the 5m resolution DTM. The same boundary condition was used so this difference can be explained by the fact that we have to simulate for a longer time period for the 25m DTM to get correct results than for the 5m DTM, which has a finer time step.

For flood modelling, the peak flow can be observed below

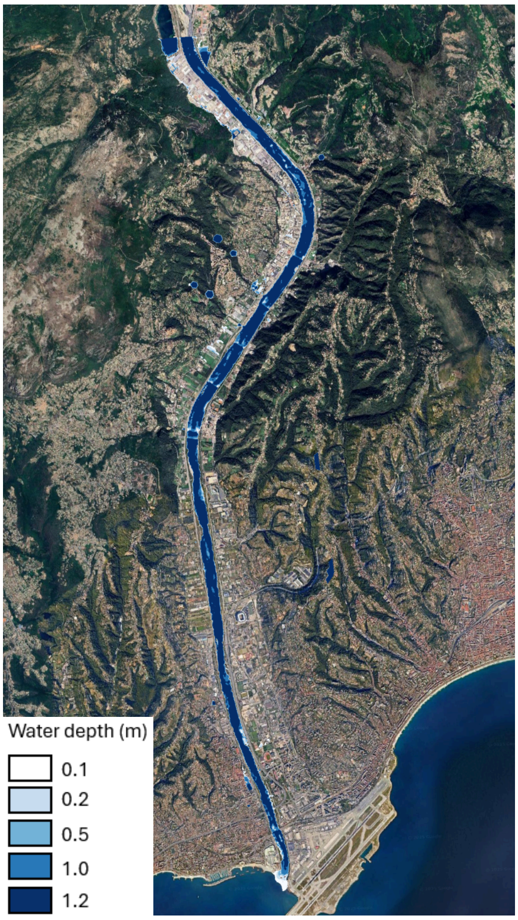


Figure 8 : Peak flood (25m DTM at the left and 5m DTM at the right)

The main differences were in mesh size and DTM resolution, resulting in different time steps and simulation times. These differences affect the accuracy of the model, but in our case do not have a major impact on the results (visually).

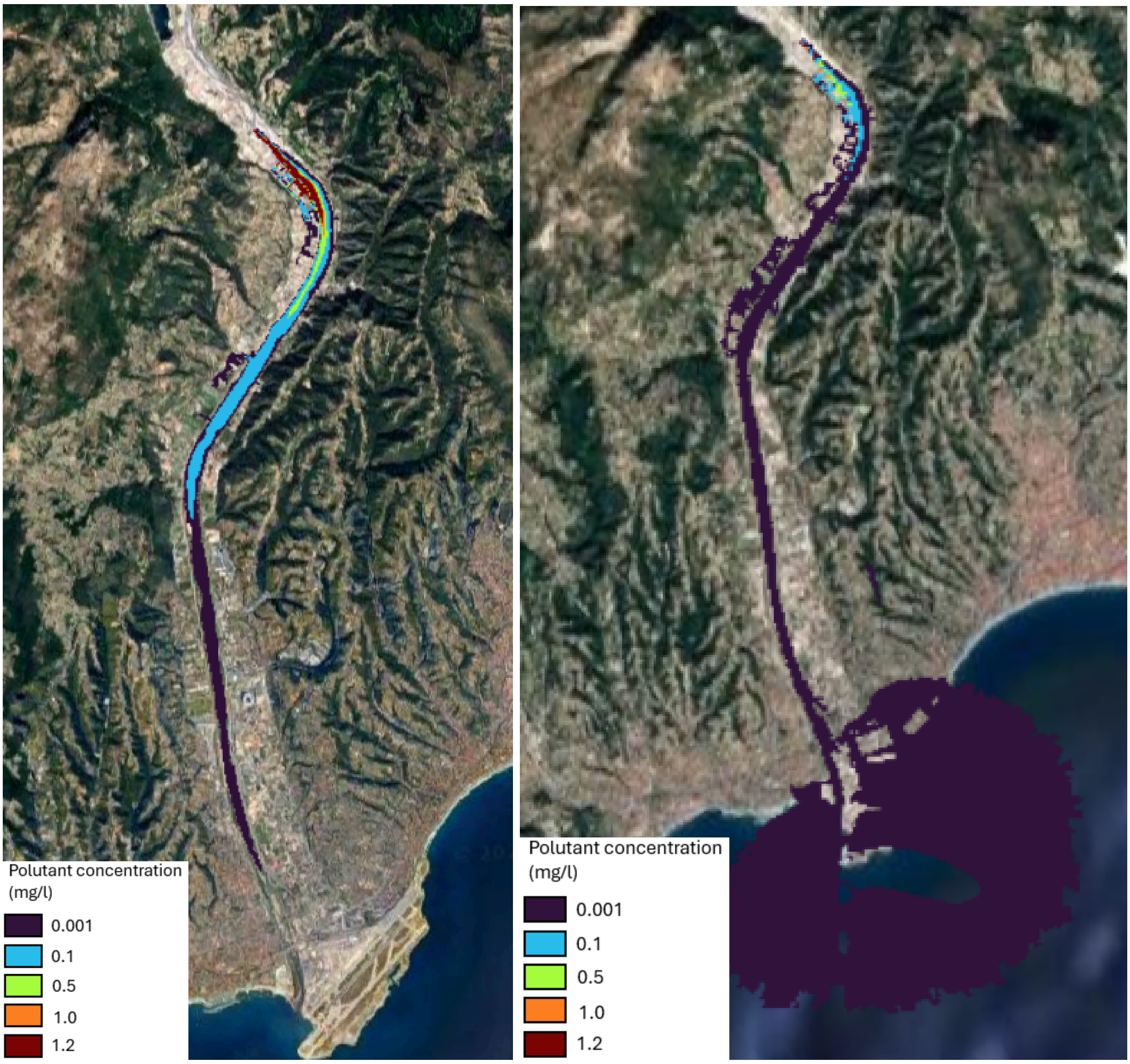
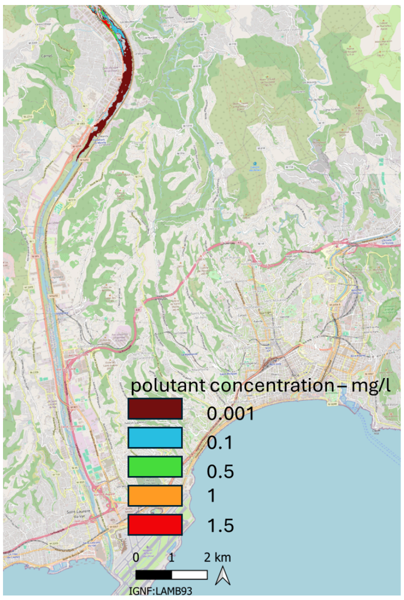


Figure 9 : spread of the pollutant with the 25m DTM at the peak flow (left) and at the end (right) during the 2020 flood



The pollutant spilled from the Monaco logistics warehouse into the Var. With an average flow, the pollutant spreads much less than in flood conditions. With a flood, the pollutant is discharged into the sea but not into the flood zone, at least for the 2020 flood. The pollutant spreads slightly along the banks but does not spread outside the industrial zone, it stays into the Var.

The major risk is for the sea and sea species. If a dangerous pollutant is spread from industries to the sea with an important concentration, it can cause damage to sea life.

In order to compare models, the 25m DTM was easier to put in place than the 5m one. Calculation was faster and results were great. The 5m DTM allows more accuracy for models that need it, but for the river Var, which has a large bed and not too many bends. It is not really necessary to be more precise than with the 25m DTM. It is important to consider the cost of mesh resolution on modelling and decide whether it is worth using more accurate data.

8 Spatial and temporal representation of the pollutant concentration

9 Zone of hazard and vulnerability of the case study area to water pollution

9.1 Natura 2000

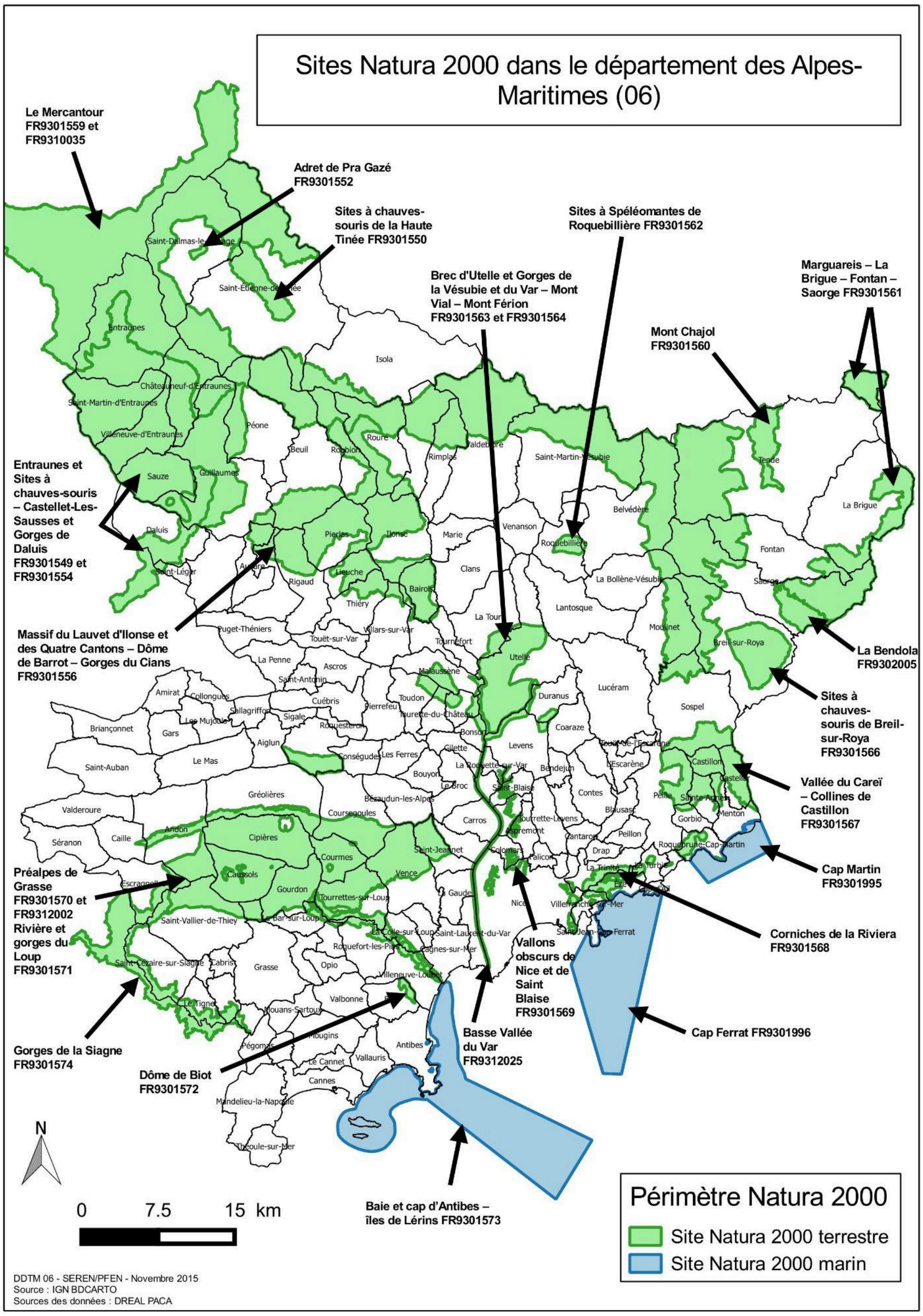


Figure 11 : Map of ‘Nature 2000’ classified sites in the Alpes-Maritimes department.

Natura 2000 is a European network of protected areas established under the Birds Directive and the Habitats Directive (INPN). This initiative aims to preserve biodiversity by protecting the most threatened species and natural habitats across the European Union. It is the largest coordinated network of protected sites in the world and comprises both terrestrial and marine areas.

The Lower Var Valley, that is, the southern part of the confluence is designated as a terrestrial Natura 2000 site. According to the “Alpes-Maritimes” website, the Lower Var Valley stands out as the most significant coastal wetland area on the French Riviera. Despite being heavily influenced by human developments, it is home to a variety of natural habitats that are rare in the region, including mudflats, gravel banks, and open waters. These characteristics make the site particularly attractive to birdlife, especially waterfowl. Thus, the lower Var Valley serves as an essential stopover for numerous migratory bird species, providing favourable conditions for rest and feeding after crossing the Mediterranean, as well as a gateway to the Alpine mountains. Each spring and autumn, the area is visited by several thousand birds. The area provides nesting sites for several waterbird species of high conservation value, such as the Sandwich Tern and the Little Bittern. It is also an important wintering site for certain waterfowl species, including the Mediterranean Gull. Nearly 200 bird species frequent the site, with around 50 of them classified as of community interest. Additionally, some species that do not nest in the area come to feed, particularly during the breeding season, such as the Peregrine Falcon (1-2 pairs) and the Eurasian Eagle-Owl (1-2 pairs).

The Lower Var Valley is recognized as the most significant coastal wetland area on the Côte d'Azur. Despite extensive human development in the region, the site encompasses a diverse array of rare natural habitats—including tidal flats, pebble banks, and open water areas—which makes it particularly attractive to birdlife, especially waterbirds. It serves as a crucial stopover for many migratory bird species that rely on the area for rest and feeding after crossing the Mediterranean, and it also acts as a gateway into the Alpine massif. Each spring and autumn, the skies above the Lower Var Valley are filled with thousands of birds. In addition, the area supports the nesting of several waterbird species of significant heritage value, such as the Pierregarin Tern and the Dwarf Blongios, and it provides an important wintering ground for species like the Black-headed Gull. Nearly 200 bird species frequent the site, with around 50 of these classified as being of community interest. Moreover, some species that do not breed within the area still rely on it as a feeding ground, particularly during their breeding periods; for instance, one to two pairs of Peregrine Falcons and one to two pairs of Eurasian eagle owls have been observed.

9.2 Aéroport Nice-Côte d’Azur

Nice Côte d’Azur Airport is located on the coastal plain, making it potentially vulnerable to flooding and water pollution risks. Partially built on reclaimed land, it is exposed to rising sea levels due to storms, heavy rainfall, and floods from the nearby Var River. During intense rain events, water accumulation and runoff can cause flooding on the runways and surrounding infrastructure, affecting airport operations and flight safety. Additionally, the tarmac and maintenance areas contain potentially polluting substances such as hydrocarbons and chemicals used for aircraft maintenance. In the event of submersion, these substances could spread into the environment, particularly into the Mediterranean Sea and nearby groundwater, worsening water pollution and impacting marine ecosystems.

Moreover, Mediterranean weather events, which are frequent in this region, can intensify these risks by causing heavy rainfall in short periods. The airport’s drainage system is designed to mitigate these impacts, but in extreme weather conditions, it may be insufficient. Furthermore, the proximity of the Var River increases the risk of flooding if the river overflows, potentially affecting runways and critical airport infrastructure. Water contamination could also occur if stormwater runoff carries pollutants from airport activities into the sea or nearby wetlands.

To address these challenges, preventive and adaptive measures have been implemented, including improved drainage infrastructure, hydrometeorological monitoring, and emergency protocols. However,

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with climate change and rising sea levels, these threats could become more severe in the coming years. Therefore, managing flood risks and water pollution remains a major concern for Nice Côte d'Azur Airport.

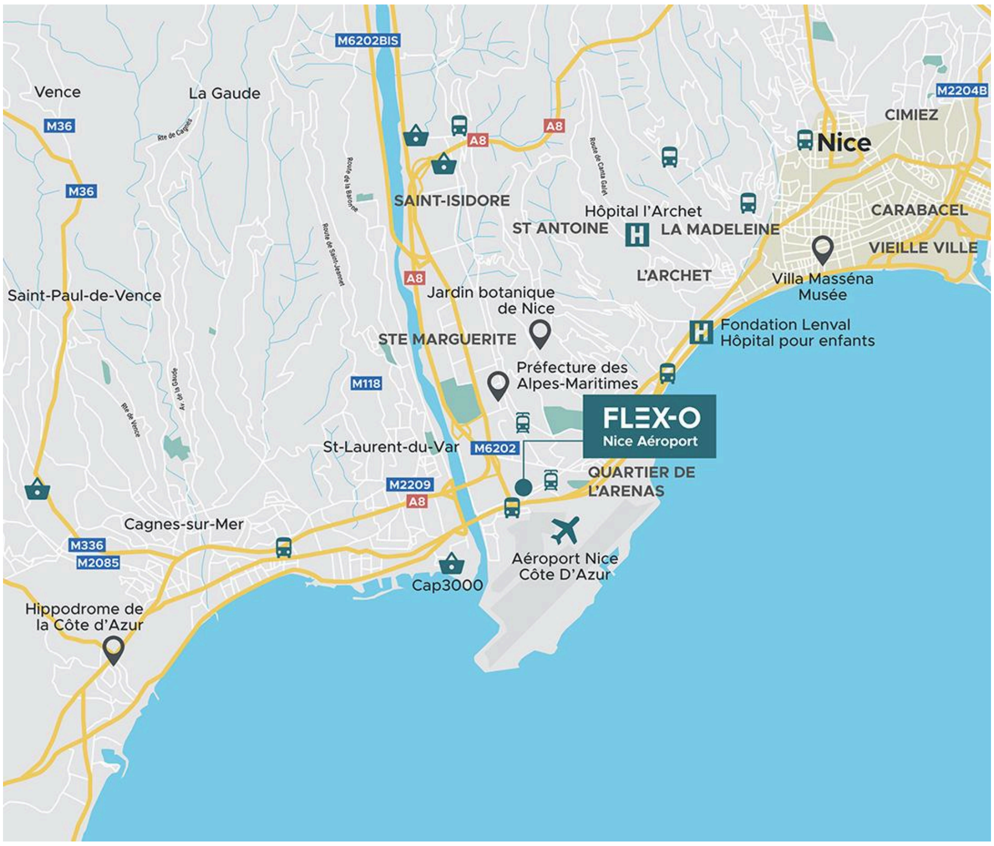

Figure 12 : Map of localisation of the airport next to the Var course.

9.3 Zone commerciale Cap3000

The Cap 3000 shopping center, located on the seafront in Saint-Laurent-du-Var, is exposed to flooding and water pollution risks. Situated near the mouth of the Var River, it is particularly vulnerable to river floods, heavy rainfall, and rising sea levels during storms. During intense rain events, water accumulation and runoff can lead to flooding, affecting shops, underground parking areas, and surrounding infrastructure. Additionally, sea level rise, worsened by marine submersion episodes, can exacerbate this phenomenon by making it more difficult to drain rainwater into the sea.

Water pollution is also a major concern. Runoff water from the shopping center and its parking lots may contain hydrocarbons, microplastics, and other pollutants from human activity. During heavy rainfall, these pollutants risk being carried into the Mediterranean Sea or nearby groundwater, affecting water quality and coastal ecosystems. The proximity to the Var River's mouth increases this risk, as the mixing of freshwater and seawater in this area facilitates the spread of contaminants.

To address these challenges, preventive measures have been implemented, such as improving drainage systems and installing rainwater retention facilities. However, with the increase in extreme weather events linked to climate change, the risk of flooding and pollution could intensify. Strengthening infrastructure

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and adaptation strategies is therefore essential to protect this commercial area and its natural environment.

Figure 13 : Map of localisation from some of bâtiments next to Var course

10 Risk Management for the Municipalities Between Carros and Saint-Laurent-du-Var / Nice

The municipalities along the Var River, between Carros and Saint-Laurent-du-Var, face significant environmental risks. Among these, flooding and water pollution are interdependent threats. During a flood, industrial and urban pollutants can be dispersed, contaminating water, soil, and surrounding ecosystems. This situation exacerbates environmental and public health impacts, necessitating a comprehensive risk management approach to protect residents and preserve biodiversity. The growing urbanization in these areas increases this vulnerability. The sealing of soils reduces rainwater absorption, encouraging sudden flooding.

Furthermore, the loss of wetlands and green spaces prevents the river from playing its natural role as a regulator. Proximity to industries and sensitive installations also aggravates the situation. In case of disaster, the risk of chemical contamination is high, potentially causing lasting damage to water resources and local wildlife. Due to these challenges, adopting a global risk management approach is essential. Prevention involves better urban planning, including restrictions on development in flood-prone areas and the development of appropriate infrastructure, such as retention basins or reinforced dikes. Additionally,

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preserving and restoring natural habitats should be a priority to strengthen the resilience of the area to flooding.

Monitoring and anticipating risks are also crucial. Modelling and forecasting tools can alert populations and local authorities in advance. The implementation of water quality monitoring systems is essential to detect any pollution and act accordingly quickly. Effective coordination between municipal services, industries, and emergency services is essential to ensure a rapid response in case of an environmental incident. Finally, crisis management should include emergency plans adapted to local specifics. These plans must include evacuation of populations, emergency services intervention, and deployment of decontamination resources in the event of contamination. Investment in innovative solutions to limit the impacts of disasters, such as green infrastructure or advanced decontamination techniques, is also necessary. Only an integrated and coordinated approach will reconcile economic development with environmental protection.

10.1 **Risk Assessment**

10.1.1 Flood Risk

The Var River is subject to violent floods, especially during heavy rainfall or Cevenol episodes, such as those following the Alex storm in 2020 and the Aline storm in 2023. These floods are exacerbated by several factors, both natural and anthropogenic. One of the main aggravating factors is the growing urbanization in the watershed. This urbanization has led to a reduction in natural water retention areas, increasing runoff and reducing rainwater infiltration. Impermeable areas such as roads, parking lots, and urban zones prevent water from penetrating the soil, contributing to faster surface flows and thus a higher risk of overflow.

The Var watershed, covering a total area of 2,812 km², is particularly vulnerable to these phenomena, even though our study focuses on a sub-basin of 119 km². Climate change also plays a key role in the intensification of Var floods. Rising temperatures and changes in rainfall patterns result in more intense and irregular precipitation, leading to sudden floods that are difficult to predict. This increased variability in weather conditions complicates risk management and infrastructure planning for drainage and protection. Meanwhile, the river's morphology and existing hydraulic structures, such as dikes and canals, although designed to protect infrastructure, can sometimes worsen flooding.

These structures alter the natural flow of the river and can cause blockages or overflow phenomena during significant floods. The consequences of Var floods are multiple and significant. They can cause considerable material damage, including the destruction of homes, infrastructure, and transport networks. Additionally, these floods disrupt economic activities and endanger the safety of riverside populations. Therefore, flood risk management must be strengthened through improved hydrological modelling and forecasting tools, the adaptation of protection infrastructure, and the development of more effective alert and crisis management strategies. Lastly, it is essential to consider sustainable and resilient management solutions, such as wetland restoration and riverbed renaturation, to limit runoff effects and enhance the watershed's ability to absorb heavy precipitation. These nature-based approaches, combined with advanced monitoring technologies, could greatly improve flood management and reduce long-term impacts.

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10.1.2 Pollution risk

Pollution in the Var River comes from various sources, increasing environmental and health risks for residents and biodiversity. Industrial activities represent a major threat, particularly in the industrial areas of Carros and Saint-Laurent-du-Var, where factories and warehouses handle potentially toxic substances. In cases of accidents or poor waste management, these pollutants can be released into the river, affecting water quality and disrupting aquatic ecosystems. Additionally, road and rail transport also contributes to pollution, especially due to the frequent passage of vehicles carrying hazardous products such as hydrocarbons or chemicals.

An accidental release of these substances could have catastrophic consequences for the river's flora and fauna. Furthermore, sewage and drainage systems represent another pollution factor. Malfunctions in wastewater treatment plants or a pipeline rupture can lead to direct discharge of pollutants into the river, worsening water contamination. Poor wastewater management can also foster the proliferation of pathogenic bacteria, endangering the health of both humans and animals. In the long term, the accumulation of pollutants in aquatic and terrestrial environments affects drinking water resources, endangers public health and deteriorates the quality of agricultural crops irrigated by the Var.

Continuous monitoring and rigorous pollution source management are essential to mitigate environmental and health impacts and ensure the protection of local populations and ecosystems.

10.2 Pollution Control and Management

10.2.1 Prevention Measures

To prevent pollution risks, several measures must be implemented to limit toxic releases and ensure the safety of aquatic environments. It is essential to install containment barriers around industrial sites to prevent the spread of hazardous substances in the event of accidental leaks. These barriers contain pollutants and prevent them from spreading into the river. Increased monitoring of sensitive installations is also necessary.

Regular inspections and environmental audits must be carried out to ensure industries comply with existing regulations. These checks help identify potential anomalies and take corrective actions swiftly. Raising awareness among businesses is another important lever. Informing industrialists about legal obligations and best practices for waste management and chemical discharges can encourage more responsible behaviors. Training programs on environmental accident prevention could also be implemented. Finally, conducting regular audits allows for evaluating the effectiveness of implemented measures and identifying areas for improvement. Constant monitoring is necessary to ensure optimal environmental risk management.

10.2.2 Monitoring and Alerting

An efficient monitoring system is crucial to detect pollution incidents promptly and trigger a swift response. Installing water quality sensors allows real-time monitoring of pollution levels in the river. These sensors can detect toxic substances and immediately signal any anomaly. Creating an environmental monitoring unit is also recommended. This unit would be responsible for analyzing collected data, coordinating prevention and alert actions, and proposing tailored solutions in case of confirmed pollution.

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Lastly, establishing an early warning system enables rapid communication of potential pollution risks to authorities and the public. Alerts could be sent via SMS, mobile apps, and display boards.

10.2.3 Emergency Interventions

In the event of confirmed pollution, prompt intervention is essential to limit environmental damage. Response services should be mobilized immediately to contain the pollution and prevent its spread. Specialized teams should be trained to act effectively in case of an accident. The use of floating barriers helps limit the spread of pollutants in the water. These devices are particularly effective for containing hydrocarbons and other floating substances. Finally, implementing appropriate decontamination procedures is necessary to restore water and soil quality. Specific techniques, such as pollutant absorption or biological treatment of contaminated waters, can be used to reduce the pollution's impact. A structured action plan and appropriate technical resources are therefore essential to ensure effective management of environmental risks related to the Var River.

10.3 Communication with the public

Communication is a vital element for effective crisis management, and several channels can be used to quickly and appropriately disseminate information. Among these channels, automated calling systems can instantly inform residents, while municipal websites provide regular updates. Social media platforms like Facebook and Twitter ensure real-time dissemination to a wide audience, and local media, such as radio and television, are crucial for reaching those without internet access.

Moreover, dedicated mobile apps allow real-time alerts and advice. The messages to be disseminated should include immediate alerts about the nature of the threat and affected areas, clear safety instructions on the actions to be taken (such as evacuation or confinement), regular updates on the situation's progress, and post-incident information to guide recovery efforts. At the same time, it is important to raise public awareness of flood and pollution risks through information campaigns such as workshops and seminars, as well as distributing educational brochures.

Educational programs in local schools should also include modules on risk management, and regular evacuation drills should be conducted to prepare the public for emergencies. Furthermore, collaborating with local industries is crucial to ensure environmental regulations are met and preventive plans are in place, while preparing documents such as the Departmental Major Risks File (DDRM) to inform about the region's specific risks. These actions must be regularly updated and adapted to the evolving risks and available technologies.

10.4 Flood and Pollution Emergency Plan

text needed for introduction because as I see, this is done with AI support. It is ok but make it with introduction, don’t just copy/paste.

10.4.1 Organization and Responsibilities

- ØMunicipalities: Coordination of interventions and communication.
- Emergency Services: Management of evacuations and security.
- Industrial Companies: Securing installations and managing leaks

- Environmental Agencies: Monitoring water quality.
- Citizens: Following instructions and participating in prevention efforts.

10.4.2 Alert Triggering

- Monitoring: Automatic sensors to measure river levels and pollution.
- Reporting: Incident reporting by municipal and industrial services.
- Alert Distribution: SMS, sirens, mobile apps, and display boards.

10.4.3 Immediate Measure

- Evacuation: Areas most exposed to floods and pollution.
- Floating Barriers: Limiting pollutant spread.
- Access Closure: Securing contaminated zones.
- Activation of Crisis Cells: Coordination of authorities and experts.

10.4.4 Communication and Awareness

- Evacuation: Areas most exposed to floods and pollution.
- Floating Barriers: Limiting pollutant spread.
- Access Closure: Securing contaminated zones.
- Activation of Crisis Cells: Coordination of authorities and experts.

10.4.5 Restoration Phase

- Cleaning and Decontamination: Interventions to reduce impacts.
- Rehabilitation of Infrastructure: Repair of essential infrastructure.
- Support for Victims: Material and psychological assistance.

10.4.6 Continuous Improvement of the Emergency Plan

- Post-Crisis Evaluation: Analysis of interventions and possible improvements.
- Regular Updates: Adaptation of the plan to new environmental data.
- Simulation Drills: Regular tests to ensure the effectiveness of the plan.

11 Climate Change

Climate Change Projections

According to climate studies, all European countries, will face a significant change of river flow as an impact of climate change for the next 100 years period

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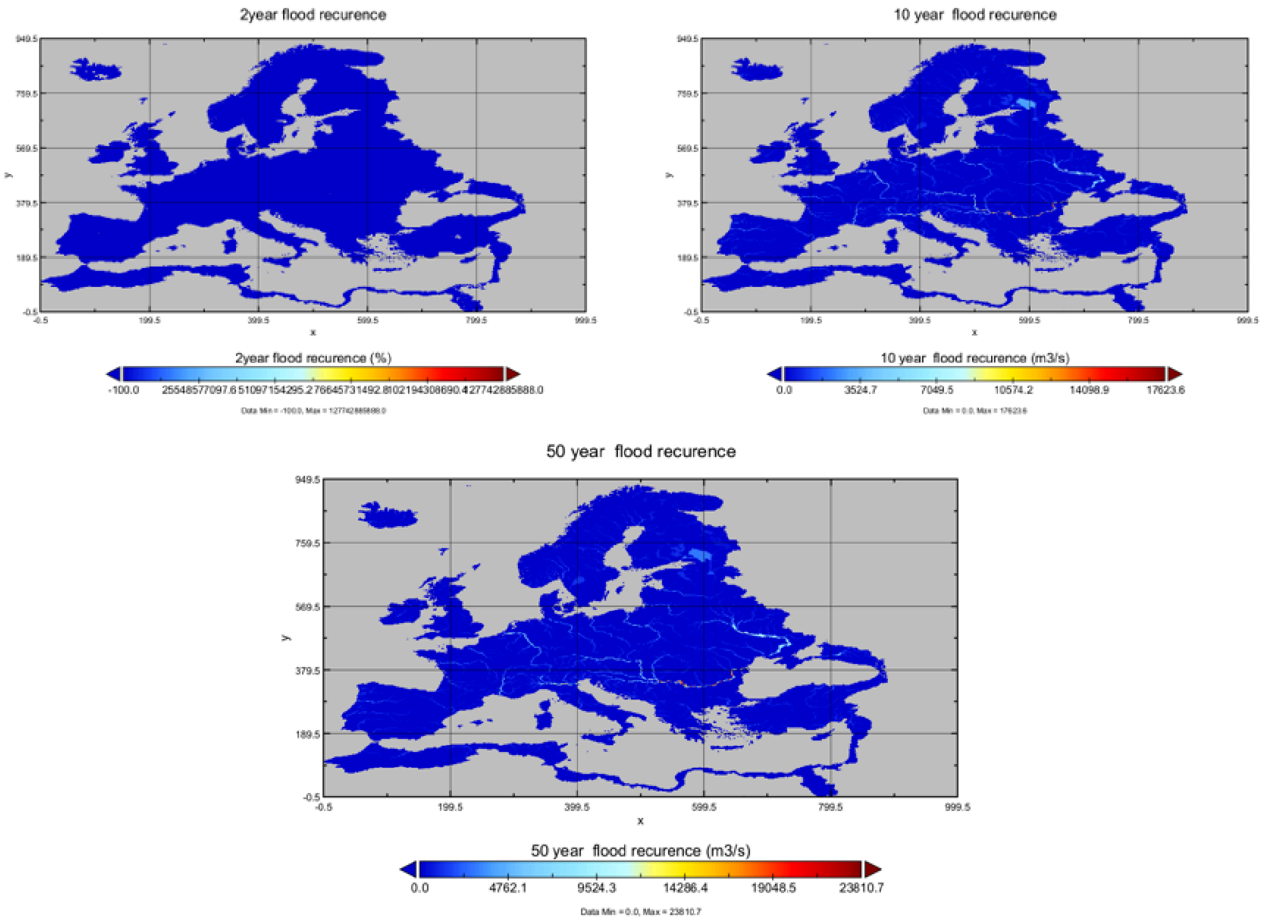

Figure 14 : flood recurrence

The Provence-Alpes-Côte d'Azur (PACA) region is projected to experience significant warming and changes in precipitation patterns (using RCP 8.5):

- Temperature increase: Up to +2.1°C by 2030, +3.1°C by 2050, and +5.2°C by 2080.
- Seasonal contrasts: Summers will be most affected, with autumn and winter also seeing notable warming trends.
- Precipitation decrease: A reduction of up to 200 mm per year by 2080, with spring experiencing the most significant declines.
- Hydrological impact: Accelerated snowmelt, reduced nival contributions, and increased reliance on pluvial inputs.

Hydrological and Flood Risks

The river Var exhibits a bimodal hydrological regime, with:

- Spring floods driven by snowmelt.
- Autumn floods are driven by heavy precipitation.
- A shift towards more pluvial-dominated flooding due to reduced snowpack contributions.

Flood frequency data indicate:

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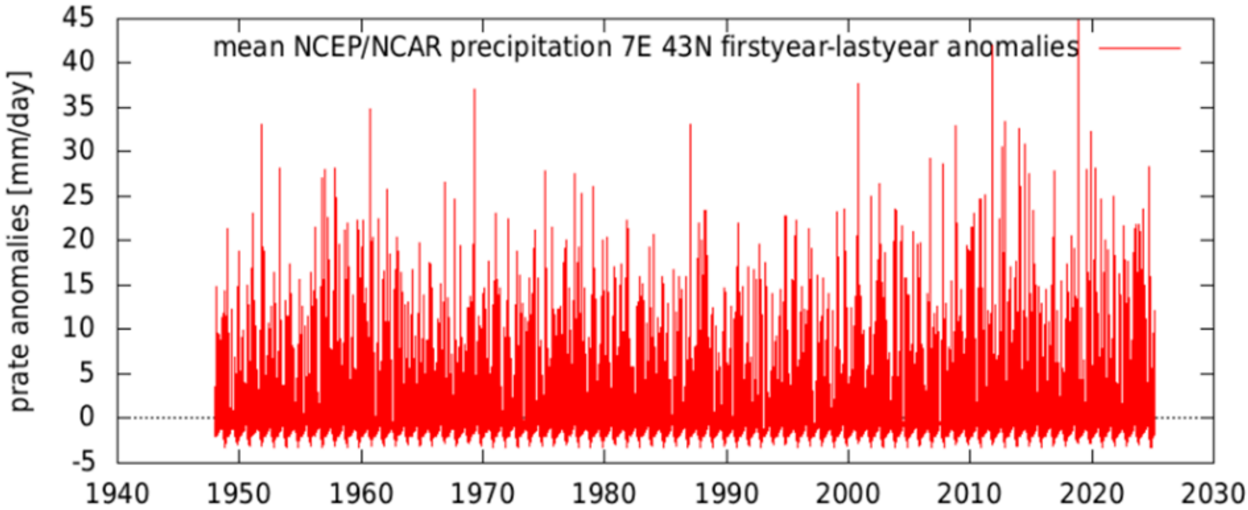
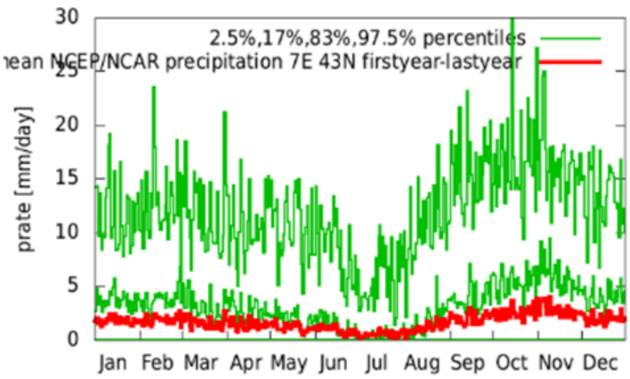
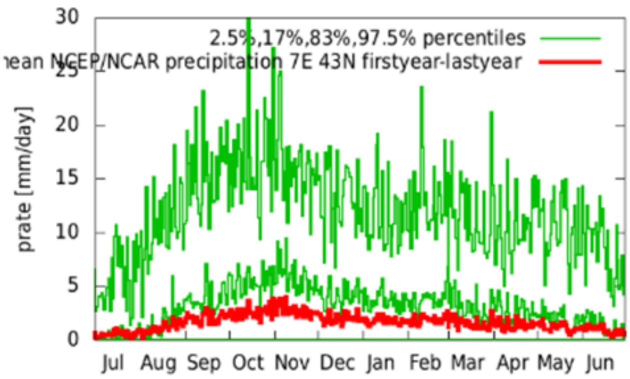
- Increased probability of extreme rainfall events leading to flash floods.
- Higher flood peaks in autumn and winter, are exacerbated by urbanization and land-use changes.

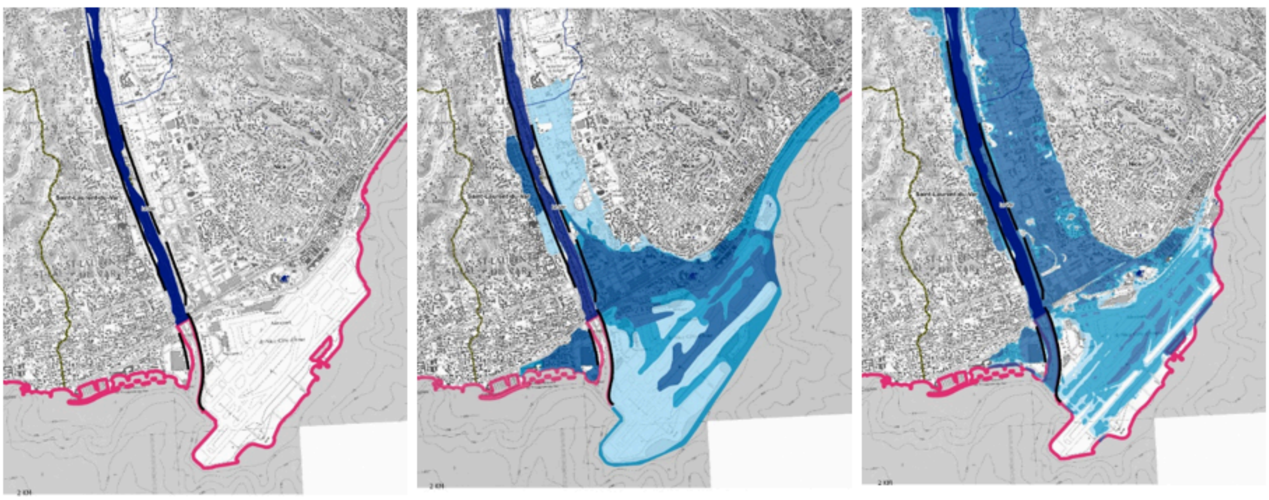
Here are the current situation we have for the precipitation rate (1940-2025):







And here are some scenarios map of the flood impact at lower var area for usual, moderate and extreme events (20, 50 and 95 percentile for change factor):



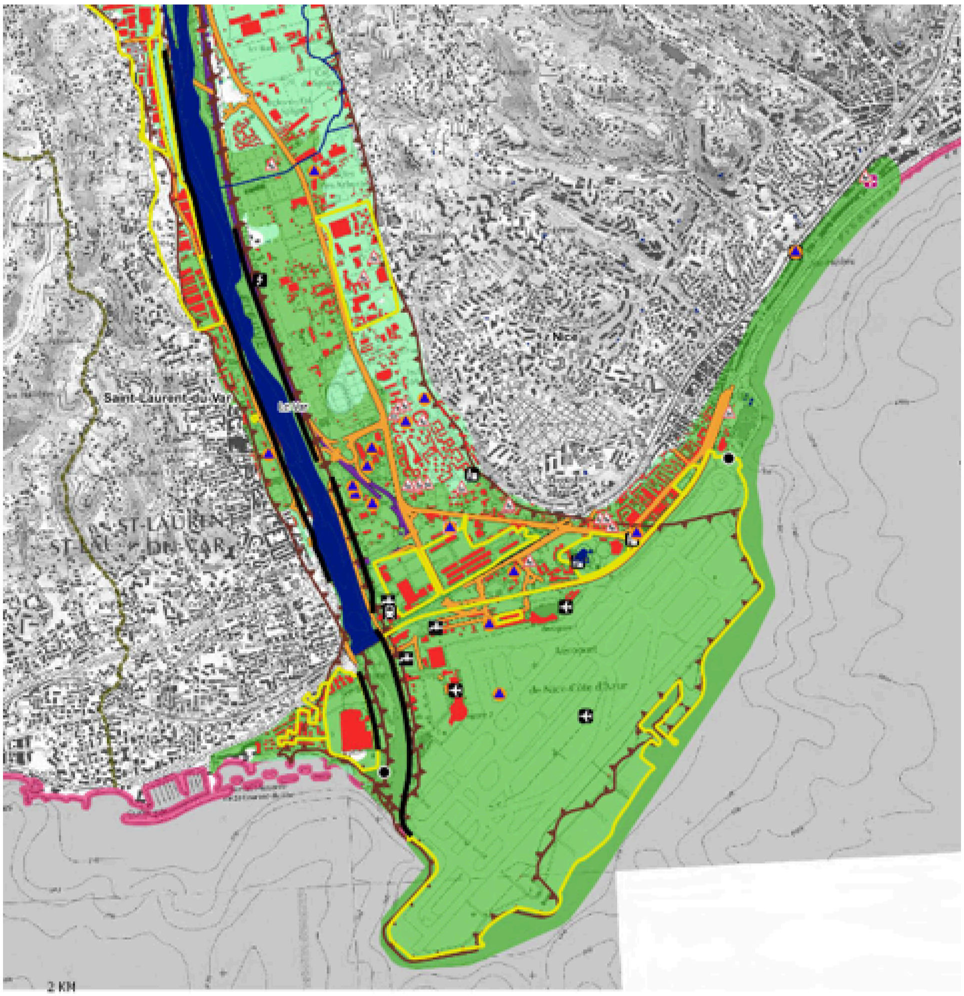
Vulnerability Assessment

- **Urban and Infrastructure Risks:** Urban expansion into flood-prone areas increases vulnerability.
- **Groundwater Interactions:** Changes in groundwater recharge could alter baseflow conditions, impacting flood dynamics.
- **Agricultural and Ecological Impacts:** Soil erosion and habitat loss due to extreme hydrological events.

Mitigation and Adaptation Strategies

- **Improved Forecasting & Monitoring:** Enhance real-time flood prediction systems.
- **Sustainable Land Use Planning:** Restrict developments in flood-prone zones.
- **Flood Defense Infrastructure:** Reinforce levees and drainage systems.
- **Water Resource Management:** Optimize reservoir operations to buffer against extreme events.

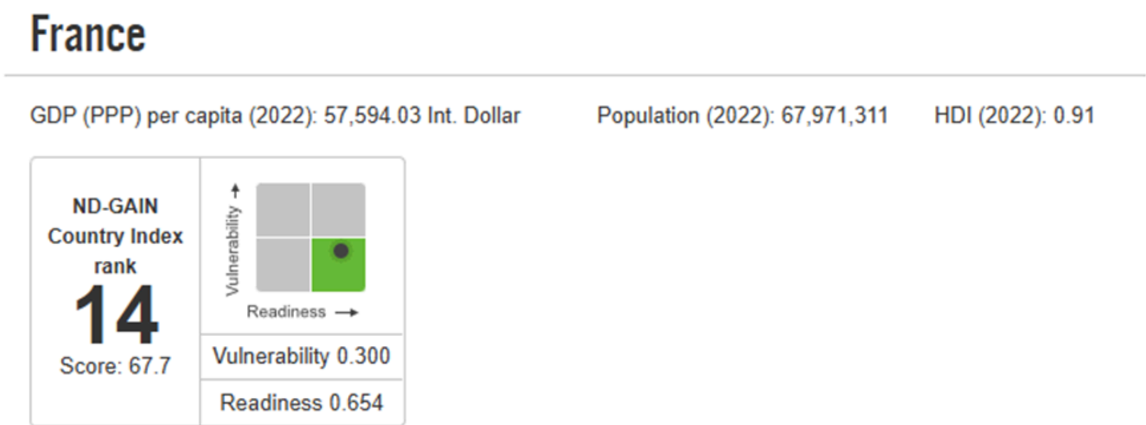
Here is the example of mitigation map:



Vulnerability Under BAU (Bussiness as Usual)

- **Uncontrolled Urban Expansion:** Continued construction in flood-prone zones increases human and infrastructure exposure.
- **Lack of Flood Resilience Measures:** Without adaptive infrastructure improvements, existing flood defences may fail under extreme conditions.
- **Water Resource Mismanagement:** Poor regulation of water withdrawals and reservoir management could exacerbate flood and drought cycles.
- **Environmental Degradation:** Loss of wetlands and buffer zones will reduce natural flood absorption capacity.

Here is the data from ND-GAIN on how vulnerable and ready the French for the upcoming disaster



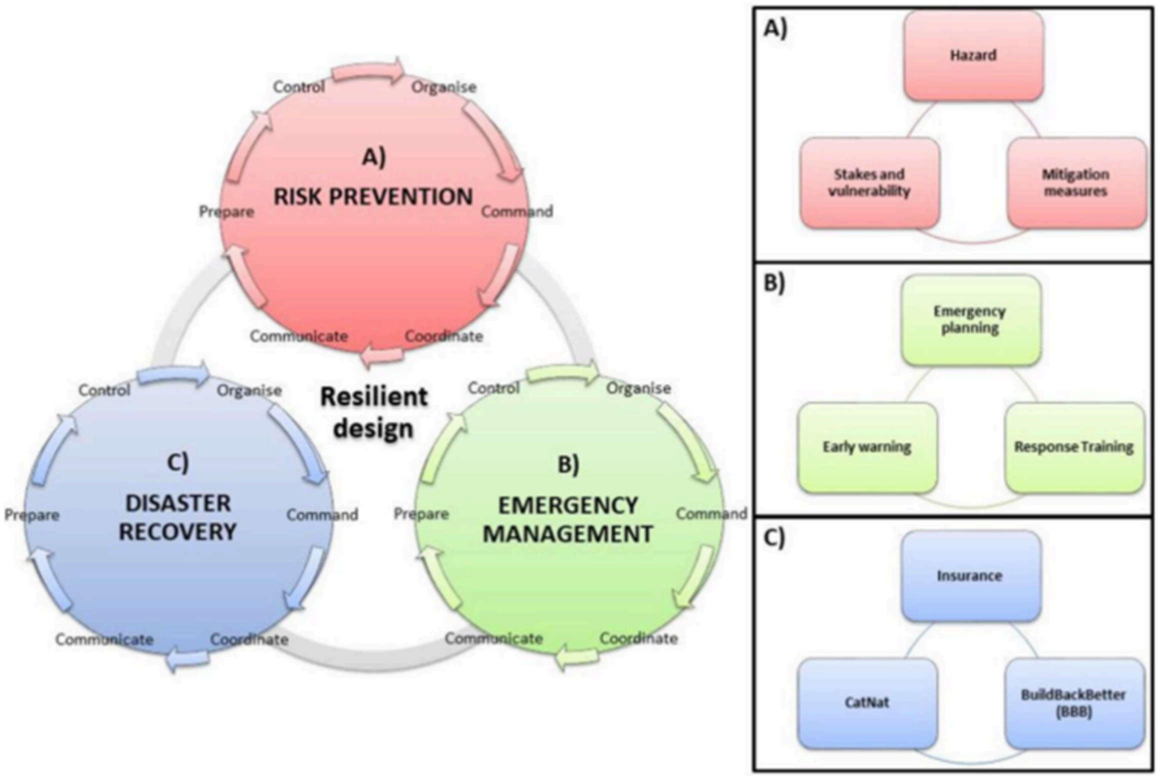
Socioeconomic Implications

- **Increased Damage Costs:** Rising flood-related damages to homes, businesses, and infrastructure.
- **Disruptions to Agriculture & Industry:** Waterlogging and soil erosion could lead to significant crop and supply chain losses.
- **Insurance and Financial Risks:** Higher premiums and potential withdrawal of coverage for flood-prone areas.

Comparison with Climate Change Mitigation Scenarios

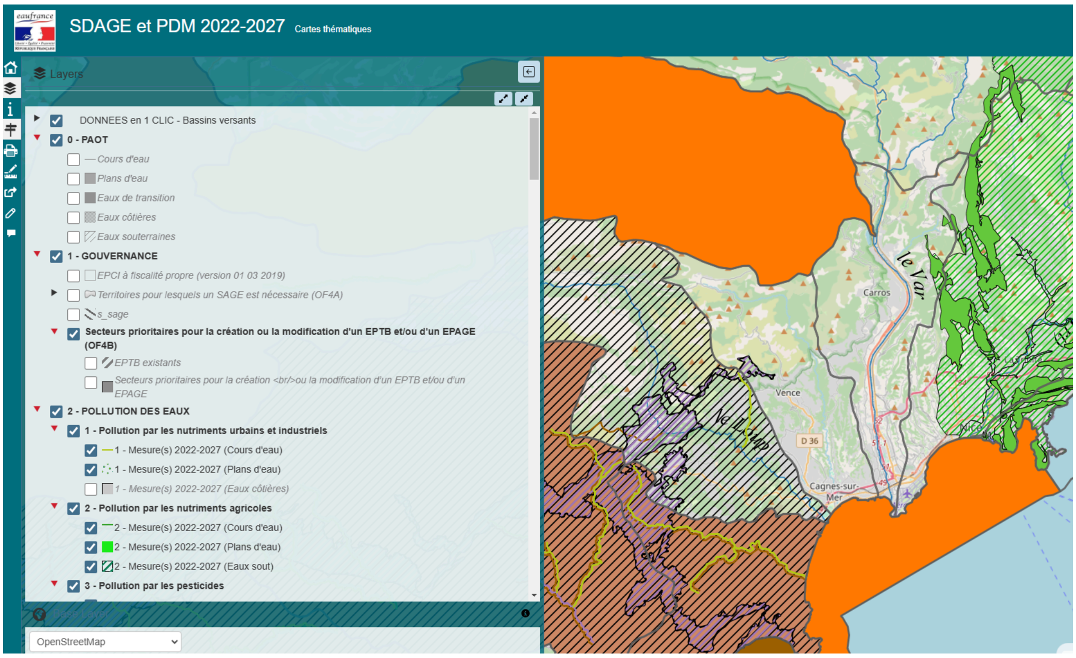
- Under an adaptive scenario with climate change mitigation strategies, flood risks can be managed through proactive land-use planning, enhanced drainage systems, and improved hydrological forecasting.
- The BAU scenario, by contrast, predicts a worsening trend in flood frequency and intensity due to the lack of preventive measures.
- Infrastructure investments in resilient designs and urban planning interventions could significantly reduce vulnerability to extreme flooding events.

Here is an example of the adaptation design process:



Near upcoming challenge for Var Catchment:

Here is the example of accidental pollution event in near time for challenges with regard to the objective of overall reduction of discharges and emissions of substances for total flow of substances more than 0.5 tons a year.



12 Possible solutions

The increase in the frequency and intensity of hydrometeorological hazards, exacerbated by climate change and urbanisation, poses significant challenges for flood risk management and the preservation of water quality.

Floods remain one of the most frequent and devastating natural disasters globally, accounting for 43% of all disasters recorded between 1995 and 2015 (United Nations Office for Disaster Risk Reduction). While it is impossible to completely eliminate flood risk, it is possible to reduce damage and mitigate risks through well-designed nature-based interventions.

In order to respond to the need to address the challenges related to flood risk and water pollution in a more sustainable, resilient and effective way, Nature-based Solutions (NbS) as well as mixed solutions combining NbS with conventional infrastructures are proposed.

Another motivation for proposing NbS is the RECONNECT project (Regenerating ECOsystems with Nature-based solutions for hydro-meteorological risk rEduCTion). This is an initiative funded by the European Union's Horizon 2020 programme, which aims to demonstrate and scale up the use of Nature-Based Solutions (NBS) to reduce hydro-meteorological risks such as floods, droughts and landslides. The project aims to integrate ecological processes with sustainable spatial planning to effectively mitigate these risks.

12.1 Nature-Based Solutions (NBS)

The adoption of NbS in flood-prone areas, such as riparian strips, constructed wetlands and biofiltration systems, not only contributes to the reduction of flood risk, but also to the improvement of water quality by filtering out pollutants such as ammonium (NH_4^+), nitrates (NO_3-), phosphates (PO_4^3-) and heavy metals (Ag^{2+}, Al^{2+}). In addition, such solutions can provide co-benefits such as biodiversity enhancement, carbon sequestration and regulation of the hydrological cycle.

It is important to emphasize that the capacity of these solutions are only effective to manage hydrological events which are limited to return periods of approximately 5 to 10 years. So, for extreme hydrometeorological scenarios, these solutions should be complemented with additional structural flood protection measures to ensure long-term resilience and minimize potential risks.

12.1.1 Constructed Wetlands

Constructed wetland systems are increasingly being employed for treatment of wastewater, sewage sludges and industrial effluents as a cost-effective, low energy and robust alternative to traditional engineered biological treatment such as the activated sludge process.

The natural ability of soils to filter suspended solids mechanically and chemical reactions with sewage constituents are other forms of cleaning mechanisms, which interact. They have been used successfully in the treatment of domestic sewage, urban, highway and stormwater runoff, acid mine drainage, agricultural wastewater and industrial effluents (including landfill leachate). BOD and solids reduction occurs through microbial activity and removal of nitrogen and phosphorus through the processes of filtration, denitrification, plant uptake and sorption.

Figure 9 : An example of constructed wetland: Sanya Dong'an Wetland Park (Sanya, China).

Effectiveness: Removes NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, heavy metals (Ag^{2+}, Al^{2+})

Mechanism: Adsorption, denitrification, phytoremediation, and sedimentation through wetland vegetation and microorganisms.

Types:

- Horizontal subsurface flow
- Vertical subsurface flow
- Free water surface flow
- Raw wastewater treatment
- Artificially aerated constructed wetland (water saturated, pulse-loaded, vertical subsurface flow)
- Root mat filter

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Advantages:

- High efficiency in nutrient and metal removal
- Enhances biodiversity and ecological resilience
- Provides additional benefits such as carbon sequestration and habitat creation

Disadvantages:

- Requires land space
- Long establishment period before full efficiency is achieved
- Potential methane emissions if not properly managed

12.1.2 Riparian Buffer Zones and Vegetation Strips

A riparian buffer zone is an area of land kept under permanent vegetation to help maintain surface water quality and soil. Buffer zones trap sediment and enhance filtration of nutrients and pollutants by slowing runoff that could enter the local surface waters.

Effectiveness: Retains NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, heavy metals.

Mechanism: Root filtration, sediment stabilization, and pollutant absorption through riparian vegetation.

Advantages:

- Simple and low-cost implementation
- Prevents soil erosion and enhances landscape aesthetics
- Requires minimal maintenance once established

Disadvantages:

- Takes time to develop effective filtering capacity
- May not remove contaminants completely if pollutant loads are high
- Limited effectiveness in urban areas with restricted land availability

12.1.3 Green Filters and Bioactive Barriers

Green filters use vegetation, soil, and microorganisms to absorb, retain, and break down pollutants such as nitrates, phosphates, heavy metals, and organic matter, mimicking natural wetlands and often implemented along riverbanks or in floodplains.

Bioactive barriers, on the other hand, are permeable structures made of materials like biochar, zeolites, or microbial substrates, strategically placed within or along river channels to trap contaminants, intercept sediments, and promote microbial degradation. By integrating natural processes, these solutions enhance biodiversity, reduce pollution, and increase ecosystem resilience, offering a sustainable and effective alternative for water management, flood mitigation, and climate adaptation.

Effectiveness: Removes NO_3^-, PO_4^{3-}, heavy metals (Ag^{2+}, Al^{2+})

Mechanism: Natural substrates like biochar or plant roots capture pollutants before entering rivers and lakes.

Advantages:

- Cost-effective compared to conventional treatment
- Can be integrated with existing vegetation or green infrastructure
- Targets specific contaminants effectively

Disadvantages:

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- ❖ Requires regular replacement of filtering materials
- ❖ Effectiveness varies depending on the pollutant concentration
- ❖ May not handle large-scale contamination efficiently

12.2 Mixed solutions (NBS + Conventional Technology)

The decision to propose mixed solutions, combining Nature-Based Solutions (NBS) with conventional infrastructure, stems from the need to increase flood resilience and improve water quality in a cost-effective and sustainable way.

Although traditional infrastructures (such as dams, dikes and drainage systems) have been effective in controlling floods, they entail high maintenance costs, environmental degradation and lower adaptability to climate change.

On the other hand, NBSs take advantage of natural processes to reduce flood risks, filter pollutants and restore ecosystems, offering multiple co-benefits such as biodiversity conservation and carbon sequestration. However, in highly urbanised or flood-prone areas, NBS alone may not provide sufficient protection and need to be integrated with engineered solutions to optimise their effectiveness.

By adopting a hybrid approach, it is possible to maximise resilience, improve water retention capacity and ensure long-term sustainability, aligning with global frameworks such as the EU's Horizon 2020 programme and the UN's 2030 Sustainable Development Goals.

12.2.1 Biofiltration Systems Combined with Sustainable Drainage (SuDS)

Biofiltration Systems Combined with Sustainable Drainage Systems (SuDS) are an integrated approach to stormwater management that combines natural filtration processes with engineered drainage solutions to improve water quality, reduce flood risk, and enhance urban resilience using vegetation, soil and microbial activity to capture, filter and break down pollutants from runoff, removing pollutants and sediments before they reach water bodies.

Effectiveness: Captures NO_2^-, NO_3^-, PO_4^{3-}, heavy metals

Mechanism: Microbial biofilters combined with sand and vegetation to enhance pollutant removal, integrated into urban Sustainable Drainage Systems (SuDS).

Advantages:

- ❖ Suitable for urban environments
- ❖ Reduces flood risks and enhances groundwater recharge
- ❖ Low maintenance compared to conventional drainage systems

Disadvantages:

- ❖ Limited effectiveness for high-concentration pollutants
- ❖ Requires initial investment in urban infrastructure
- ❖ Can become clogged if not properly maintained
- ❖ Biofiltration systems are difficult to implement in rivers due to the limitation of stabilization in fluctuating variables such as flow, pollutant load, as well as the physical-chemical conditions of the river itself

12.2.2 Incorporate lateral water catchment areas into planned flood zones

Incorporate lateral catchment areas with natural materials to allow infiltration and purification of water in times of flooding (it could be similar to the function of a storm tank, only in a natural way).

Advantages:

- Reduces flood risk by providing additional storage capacity
- Improves water quality by filtering sediments, nutrients and pollutants
- Enhances biodiversity, creating new wetlands and riparian habitats
- Cost-effective compared to large-scales grey infrastructure (e.g., storm tanks)

Disadvantages:

- Land use constraints
- Maintenance needed to prevent clogging by sediments and invasive species
- Efficiency depends on soil permeability

12.2.3 Incorporate bioadsorbents in bed layers

Biochar or zeolite can be mixed with the gravel to capture contaminants and promote microbial activity. Microorganisms will colonize the material, promoting denitrification and biodegradation of organic contaminants.

Advantages:

- Supports riverbed microbiome, enhancing biodegradation of organic pollutants
- Cost-effective and low-maintenances, as bioadsorbents have long-lasting effects
- Compatible with existing river restoration efforts, requiring minimal structural modifications

Disadvantages:

- Potential bioadsorbent saturation (materials need periodic replacement or regeneration)
- Requires evaluation of water flow, pollutant concentration and microbial activity for optimal results
- Possible ecological impact

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