

Assessment And Modeling Of Flood Risk In The Municipality Of Tamazoura (Algeria): Delineation Of The Public Hydraulic Domain And Prevention Strategies For Exceptional Flood Events

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Abstract: The flood phenomenon in Algeria is ranked second after earthquakes in terms of human and material damage. Given the multiple years of drought, especially in western Algeria, the wadis have lost their major beds (the flood zones). This is due to the harmful actions of citizens and public authorities (legal and illegal housing). The municipality of Tamazoura is one of the agglomerations threatened by the flood phenomenon. This risk was studied in order to avoid potential human and material damage and to delimit the flood zone used to determine the public hydraulic domain (the limits of the major bed of the Oued Tamazoura). A consistent hydrological study was established after recovering rainfall data from three neighboring stations (Tassala station, Es-Sania, and Tamazoura). At the end of this part, we were able to develop flood diagrams (20, 50, 100, and 1000 years). Given the importance of the Tamazoura watershed and the absence of storage areas upstream of the wadi, our study is based on the two exceptional floods of 100 and 1000 years. The hydraulic modeling is performed using the HEC-RAS calculation code (6.3.1). Our modeling is based on fairly reliable data, namely the topographic survey of the wadi and the DTM of the study area. A field survey was the foundation for developing the roughness map of the site. This survey allowed us to calibrate the simulation results by recovering the maximum levels of past exceptional floods. Several maps were produced to better exploit our results (floodplain map, water depth map, water velocity map). At the end of this study, we came to two relevant conclusions: firstly, the risk of overflow is strongly present in the city center. Secondly, we have managed to draw up a map of the flood zone, which will be a solid support for local authorities to delimit the public hydraulic domain of Oued Tamazoura (DPH), as required by Law No. 05-12 of August 4, 2005.

Keywords: Flood phenomenon , Tamazoura, , Algeria, Hydraulic modeling , HEC-RAS, Overflow risk, Public hydraulic domain (DPH), Law No. 05-12

1- INTRODUCTION

Floods, defined as a rapid and temporary increase in the flow of a river, result from various hydrometeorological factors such as intense precipitation, snowmelt, or exceptional hydrological phenomena (Chow et al., 1988). These events often cause severe flooding.

Floods represent one of the most devastating natural disasters, causing considerable human and economic losses worldwide. According to the World Meteorological Organization, water-related events have caused an average of 115 deaths and \$202 million in damages per day over the past fifty years (Association et al., 2022). This alarming trend is exacerbated by climate change, which is altering precipitation patterns and increasing the frequency and intensity of extreme weather events (Rijal et al., 2024). The IPCC's Sixth Assessment Report highlights that the impacts of climate change are already visible, with catastrophic consequences predicted for decades to come, including increased flooding (Lee et al., 2023).

Urban flooding, in particular, has become a major problem, mainly due to rapid urbanization and infrastructure degradation (Wang et al., 2023). These events can cause direct physical damage to property, buildings, and infrastructure, but also indirect impacts, such as disruptions to public services and economic activities, which increase the vulnerability of urban populations (Yin et al., 2016; Guo et al., 2022). Indeed,

floods are the leading cause of natural disaster-related deaths worldwide, and their increasing frequency underscores the urgency of developing effective management and mitigation strategies (Tellman et al., 2021). The increased vulnerability of urban areas to flooding is attributed to several factors, including high population density, surface sealing, and inadequate drainage systems (Bakhtiari et al., 2023). Furthermore, the rapid pace of urbanization and increasing global temperatures are exacerbating these risks, making cities more susceptible to catastrophic flooding (Luo et al., 2022). Despite advances in flood modeling research, challenges persist due to the complexity of urban systems and flood processes, as well as the lack of accurate data to assess the impact of these events (Merz et al., 2010).

Finally, the increase in the number of people exposed to flooding, which has doubled over the last forty years, poses additional challenges for public health. Flooding can lead to direct risks such as drowning and electrocution, as well as indirect health impacts, including contamination of drinking water, increased infectious diseases, and psychological disorders related to displacement (Alderman et al., 2012; Paterson et al., 2018). Therefore, it is imperative to adopt an integrated approach to flood management, which takes into account social, economic, and environmental dimensions to protect vulnerable populations and support urban resilience to the challenges of climate change.

Algeria is exposed to a wide range of natural hazards. Since the 1950s, floods have become more frequent, accounting for 61% of catastrophic events recorded in the international EM-DAT database. Based on this database (1954–2022), 51 flood events have been observed, resulting in 1,870 deaths, 809,145 people affected, and \$1,543,917,000 in economic losses.

In terms of trends, average annual temperatures have increased in Algeria since the 1950s, with an increase of 0.35 degrees Celsius per decade between 1951 and 2020. The average rainfall level is considered one of the lowest in the Mediterranean basin, with rainfall decreasing by 40% in the west of the country, 30% in the center, and 20% in the east since 1900 (EM-DAT).

The country's vulnerability to flooding is increasing due to the combined effects of rapid urbanization and climate change. By 2050, Algeria is expected to see a 41% increase in exceptional storms that could cause flooding, landslides, and significant damage. The national flood risk assessment today identifies 865 sites at risk across Algeria, of which nearly 10% are considered to have high or very high risk.

The main flood risks are concentrated in northern Algeria, where much of the population and economic activity is located. These floods primarily stem from wadi overflows and urban runoff. Algeria is one of the Mediterranean regions affected by sudden floods, which are difficult to predict, rise quickly, and have relatively high specific flows. They are generally linked to intense rainfall episodes in medium-sized basins. Several disasters caused by such floods have been recorded in Algeria, such as those in Algiers (November 2001), Sidi Bel Abbès (April 2007), and Ghardaïa and Béchar (October 2008).

Urban areas with high population concentrations are particularly threatened by the devastating effects of floods, which are often exacerbated by human actions.

The main factors aggravating the effects of floods are:

- “Anarchic” urbanization through the occupation of flood-prone lands.
- The accumulation of rubble and debris in wadis.

Floods often occur following ordinary and seasonal events that are not particularly remarkable.

Reducing the damage caused by these disasters requires, first and foremost, a precise identification of regions at risk of flooding and the factors that promote and amplify damage. This would serve as a valuable tool for planners to establish land use plans, build protective structures, and develop flood forecasting and warning systems that mitigate the extent of damage caused by these floods.

Law No. 05-12 of August 4, 2005, related to water, aims to regulate the use of the public hydraulic domain (DPH) at the national level.

Studies concerning the delimitation of the public hydraulic domain serve to define its boundaries relative to neighboring properties, thus preserving it against encroachment or potential claims of possession, as well as protecting it from pollution.

This delimitation also facilitates better management of DPH usage requests, such as temporary occupation and diversions of watercourses. It is conducted on the basis of topographical, hydrological, and hydraulic studies (on scientific bases), while referring to previous rainfall events to set boundaries as accurately as

possible. These boundaries are subsequently reviewed with the relevant departments before being transmitted to the central level for approval by ministerial decree and marked on the ground.

The legal establishment of easements of general interest for the public domain limits the actions of organizations with control authority over its conservation. This is the focus of our doctoral work.

The aim of our hydrodynamic modeling of the Oued Tamazoura is to delimit the flood zone of the wadi for centennial and millennial floods, thereby determining its public hydraulic domain. We aim to analyze the influence of the watershed on the watercourse's behavior, especially during extreme events. This objective arises from observations made during a 2013 rainfall event, where the watercourse's violent flow caused significant damage to its structures.

II- DATA AND METHODS

a- Study area

1- Geographical and Administrative Context of Tamazoura

The commune of Tamazoura, historically designated as *Saint-Maur* during the colonial era, is the largest municipality in the wilaya of Aïn Témouchent, administratively subordinate to the daïra of Aïn Larba. Since its integration into the wilaya in 1984, Tamazoura has occupied a strategic position in the eastern sector of Aïn Témouchent. The commune spans an area of 229.06 km² (22,906 hectares) and is bordered by:

North: The municipality of Missegline (wilaya of Oran)

South: The municipality of Aïn Thrid (wilaya of Sidi Bel Abbès)

East: The municipality of Taфраoui (wilaya of Oran)

West: The municipality of Oued Sabah (wilaya of Aïn Témouchent)

This central location facilitates regional connectivity between adjacent wilayas (Figure 1).

2- Hydrological and Morphometric Characterization of the Oued Tamazoura Watershed

The Oued Tamazoura watershed, located in the Tell Oranais region (Wilaya of Aïn Témouchent), is a hydrologically significant system within the Tessala Mountains. It comprises two principal wadis: **Oued Hammam** (southwest), originating from Djebel Bouhnech, Hammar Lakhdar, and Djebel El Karma, and **Oued Ibel** (southeast), fed by Hammar Labiad and Djebel Sidi Mohamed. The watershed exhibits pronounced topographic variability, with elevations ranging from **194 m to 946 m**, and is bounded by key geomorphological features such as Djebel Bouhnech (west) and Hammar Labiad (east).

Morphometric analysis reveals a total area of **57.21 km²** and a perimeter of **38.9 km**, structured into three distinct zones:

Mountainous upstream (steep slopes, high elevations),

Downstream plain (low-gradient terrain),

Wadi valley (primary drainage channel).

Critical indices include:

Compactness index (Kc): 1.44 (moderately elongated shape),

Hydrological concentration time: 3.92 hours,

Slope distribution : 76% of the basin has gradients of 13–26% (high torrentiality), while 21% exhibits gentler slopes (3–13%, low erosion sensitivity).

Climatically, the watershed lies in a **semi-arid zone**, with:

Annual precipitation: 350–400 mm (wet season: October–March),

Temperature range: 10.8°C (January) to 35.5°C (August).

Hydrological processes are influenced by lithology and vegetation, with infiltration dominant in permeable zones and stagnation in impermeable areas. The **hypsothetic curve** indicates **moderate erosive potential**, reflecting balanced sediment dynamics. These factors collectively shape the watershed's flood risks, runoff behavior, and erosion susceptibility, necessitating targeted management strategies.

The floodplain soils are characterized by **minimally developed, vertic alluvial deposits** with a **clay-loam texture**, exhibiting **surface shrinkage cracks** during dry periods due to their high clay content. These properties influence water infiltration and soil stability, particularly under seasonal climatic variations.

Land use in the watershed is dominated by **natural forests (3,748 ha)**, followed by **arable agricultural land (1,777 ha)** and **built-up areas (47 ha)**. This distribution highlights the **ecological and anthropogenic**

influences on hydrological processes, including water retention, runoff generation, and sediment transport. The coexistence of forested, agricultural, and urban zones necessitates **integrated watershed management** to mitigate flood risks, sustain agricultural productivity, and preserve ecosystem functions.

The interplay of morphometric, climatic, and geological factors necessitates integrated strategies for:

Flood mitigation (e.g., reinforced channel infrastructure)

Erosion control (e.g., slope stabilization in high-torrentiality zones)

Data gaps: Enhanced hydrological monitoring to address spatial and temporal variability.

This synthesis underscores the watershed's complexity.

b- FIELDWORK

In 2008, a major flood affected the city of Tamazoura, caused by the overflow of floodwaters from Oued Tamazoura. This event resulted in significant damage, including:

- Road disruptions;
- Extensive material damages;
- Flooding of residences located in the immediate vicinity of the wadi.

Following this event, local authorities in the Wilaya initiated several development projects to reduce future risks by :

- Construction of stone masonry over a length of 1,500 linear meters.
- Recalibration using reinforced concrete and natural soil over 900 linear meters downstream of the city (Source: WRD of Aïn Témouchent).
- Development of the wadi affecting the Meftah settlement over a length of 13,000 meters.
- Construction of open reinforced concrete channels in the center of Tamazoura over 2,500 linear meters.
- Installation of a rainwater drainage collector in Tamazoura spanning 1,500 linear meters with a diameter of 1,000 mm.
- Opening of a natural soil channel at the exit of Tamazoura over 2,000 linear meters (Source: WRD of Aïn Témouchent).

Despite these measures, deterioration of hard infrastructure was noted, particularly in the upstream section of the wadi. This degradation is mainly attributed to the high velocity of water flow during exceptional floods, which carry medium-sized rocks (approximately 200 mm).

A survey was conducted among residents to gather qualitative information about the floods that impacted the city of Tamazoura. However, the reliability of the collected data remains limited due to several factors:

- Dependence on residents' memory, often altered over time.
- Difficulty in pinpointing the exact dates of past floods, particularly for events that occurred many years ago.

The analysis of the collected data reveals that Oued Tamazoura caused significant flooding, impacting the urban fabric and nearby infrastructure. During the 2008 flood, water levels reached an average height of 3.30 meters (refer to technical sheets for more details).

These observations highlight the importance of maintaining and reinforcing existing infrastructure to prevent future flood events.

- Presentation of Collected Rainfall Data

The stations of Tamazoura and Tessala were selected as reference stations based on:

- Their geographically representative location within the basin.
- The length and reliability of their observation series.
- Their operation during major flood periods.

These stations provided a reliable relationship between rainfall and floods, forming the basis for Rainfall-Runoff modeling of vulnerable sites in Tamazoura.(see table 2 and figure 9)

Rainfall and hydrological analyses highlight the challenges associated with interpreting and utilizing data in the Tamazoura basin. The selected stations, particularly Tessala, provide essential information for modeling floods and guiding development decisions. However, improving existing infrastructure and enforcing strict control over unauthorized occupations within the public hydraulic domain are necessary to mitigate flood risks in the region.

- **Terrain Roughness**

The estimation of terrain roughness, which influences floodwater flow in channels and floodplains, was conducted through several steps:

1. **Land Use Mapping:**

A base roughness map was created using reference tables and Cowan's formula, incorporating the various surface types within the basin.

2. **Hydraulic Calibration**

The roughness coefficient was adjusted based on field measurements, particularly observed water heights. For Oued Tamazoura, a roughness coefficient of 0.025 was determined following intensive studies and hydraulic simulations.

- **Data Implementation: Terrain Model**

The development of a digital terrain model (DTM) is a key step for hydrological and hydraulic analysis of the Oued Tamazoura watershed. This model is based on detailed topographic surveys and provides sufficient resolution to represent the main hydraulic features of the fluvial system.

Enhancements for Improved Representation

the terrain model was enhanced by:

- **Satellite Data Integration:**

Satellite data covering the entire study area, as shown in Figure 13, were used to complement the existing model.

- **High-Resolution DTM Fusion:**

Combining precise topographic surveys with a 1-meter resolution DTM. This integration, illustrated in Figure 14, provides a uniform and continuous representation of the study area, including both urban zones and floodplains.

This enriched terrain model ensures accurate and comprehensive spatial analysis, essential for effective flood risk assessment and management planning.

Stream Morphology

The morphology of the streams is entirely derived from the topographic data included in the DTM. Key features provided by this model include:

- **Longitudinal slope of the streams**, which affects flow velocity and regime.
- **Width and depth of cross-sections.**
- **Local variations** caused by erosion or alluvial deposits.

Integration into Hydraulic Analyses

This terrain model serves as the foundation for:

- Simulating floods and modeling hydraulic flows using software such as HEC-RAS.
- Identifying areas vulnerable to flooding.
- Assessing the impacts of existing and planned infrastructure.

The combined terrain model, enhanced by satellite data (ASAL) and precise topographic surveys (HPE), provides a consistent and reliable representation of the study area. It is an essential tool for flood analysis, risk management, and hydraulic planning within the Oued Tamazoura watershed. (figure 15)

Integration of the Hydrological Model

After simulating the hydraulic model using HEC-RAS, validation through a calibration process is necessary. In this case, calibration focuses primarily on adjusting flood marks and the roughness parameter. This adjustment ensures simulation results closely align with field measurements.

In fluvial hydraulics, this process involves varying Manning's roughness coefficient (n) so that the modeled water surface profile for a given discharge matches observed or measured levels as accurately as possible.

The goal of calibration is to establish optimal alignment between hydraulic model results and field data, such as flood marks left by historical reference floods. These marks may be recorded on tree trunks, walls, bridge piers, or other structures exposed to flooding.

Integration of Flood Hydrographs

Flood hydrographs are incorporated as input data into the software. They follow the configuration detailed in the screenshot presented below.

Integration of Hydraulic Structures

Crossing structures are defined by their key characteristics, including the elevation of the foundation slab, the soffit level, and the total section. These details help identify infrastructure within the study area that may disrupt flows during flood events.

A detailed description of the structures present along Oued Tamazoura is provided in the figure below. (figure 20 and table 03)

III- RESULTS AND ANALYSIS

Model Outputs and Visualization

The hydraulic simulation of Oued Tamazoura produced comprehensive results across multiple configurations, including:

- Longitudinal profiles of the simulated section with water levels for each return period
- Three-dimensional floodplain visualizations
- Detailed hydraulic parameter tables (water depth, velocity, shear stress)
- Rating curves for critical sections
- Flood extent mapping under various scenarios

Key visual outputs included hydro-geomorphological analyses both with and without existing structures (Figures 20-21), providing comparative insights into infrastructure impacts.

Critical Hydraulic Structures

The bridge at Station 6300 demonstrated adequate capacity during simulated events:

- Bottom elevation: 176.2 m
- Deck elevation: 183.5 m
- Maximum water elevation (100-year flood): 178 m
- Performance: No overflow observed (Table 04)

Floodplain Characteristics

The 100-year flood event analysis revealed:

- Total inundated area: 0.10 km²
- Depth distribution:
 - >1 m depth: 79.36% (high risk)
 - 0.5-1 m: 20.63%
 - <0.5 m: negligible (Table 05)
- Velocity distribution:
 - >1 m/s: 92.46% of flooded area
 - 0.5-1 m/s: 3.33%
 - <0.5 m/s: 4.21% (Table 06, Figure 27)

Upstream Hydraulic Behavior

The critical 50-meter entrance section exhibited:

1. **Channel constriction** reducing flow capacity by ~30%
2. **Sediment deposition** (aggregates/pebbles) from upstream transport
3. **Hydraulic jump formation** due to slope transition (5% → 1.5%)
4. **Localized water level increases** up to 1.2 m above downstream sections

These phenomena collectively increase flood risks by:

- Reducing effective channel capacity
- Creating flow turbulence
- Accelerating bank erosion

Hazard Classification

The hazard mapping (Figures 28-29) identified:

- **High hazard zones (79.36%):** Minor riverbed and adjacent urban areas
- **Moderate hazard (20.63%):** Major riverbed periphery
- **Low hazard (negligible):** Distal floodplain areas

Key risk drivers:

- Combined water depth (>1 m) and velocity (>1 m/s)
- Proximity to constricted sections
- Existing infrastructure constraints

Recommendations for Risk Mitigation

Structural Measures:

1. Upstream sediment traps (rock check dams)
2. Channel widening at constricted sections (minimum 15% increase)
3. Bank stabilization using riprap ($D_{50} = 400$ mm)

Non-Structural Measures:

1. Establish hydraulic domain demarcation (1:5000 scale)
2. Implement early warning system for velocities >3 m/s
3. Community preparedness programs for high-hazard zones

Monitoring Requirements:

- Annual bathymetric surveys (pre/post flood season)
- Real-time velocity monitoring at 3 critical sections
- Sediment transport capacity reassessment every 5 years

ANALYSIS

The simulation results demonstrate that while existing structures generally perform adequately, the upstream constriction and sediment dynamics create localized flood risks. The predominance of high-velocity (>1 m/s), deep-water (>1 m) conditions across 79% of inundated areas necessitates prioritized intervention in Tamazoura's urban center. The developed hazard maps provide a scientifically-grounded basis for land-use planning and emergency preparedness.

IV- GENERAL CONCLUSION

Oued Tamazoura drains a significant watershed area of 57.21 km², characterized by high torrential behavior ($C_t = 19.82$). The flow from this basin reaches the outlet with a concerning velocity of 5.21 m/s, indicating a dynamic and risky hydrological behavior. The centennial flood simulation highlights the alarming extent of the floodplain. A significant part of the city will be submerged, with water depths ranging from 0.3 m to 5 m. Except for a few stagnant zones, floodwaters flow rapidly towards the sebkha.

This situation becomes even more concerning due to the high flow velocity, often exceeding 5 m/s, presenting two major dangers :

1. **Solid Material Transport:** Large pebbles and stones carried to the outlet alter the hydrodynamic behavior of the river, complicating proposed stabilization measures.
2. **High Shear Forces:** These forces directly impact the stability of structures and buildings, increasing the risk of structural damage.

These hydrodynamic conditions grant floodwaters significant carrying power, endangering everything in their path, including human lives. In the case of a millennial flood, the scenario would be even more catastrophic due to the absence of upstream protection or storage structures to mitigate impacts.

Through this study, we have :

- Evaluated the behavior of the watershed and the hydrodynamic flow of the river.
- Analyzed environmental risks associated with centennial and millennial floods.
- Delimited the floodplain, a crucial element in defining the hydraulic public domain (HPD) of Oued Tamazoura.

The delimitation of the floodplain represents the most significant contribution of this project. This step not only identifies zones to be expropriated and protected by the state but also provides an essential framework for sustainable hydraulic risk management. In Algeria, the delimitation of the HPD is almost non-existent. This work can serve as a reference and model to initiate this task on a national scale.

Recommendations

- **Hydraulic Developments:** Develop solutions to stabilize the banks, widen narrow sections, and install upstream retention basins.

- **Risk Prevention:** Implement warning systems, adaptive infrastructure, and evacuation plans to protect the most vulnerable zones.
- **National Expansion:** Generalize this type of work for other rivers in the country to establish a structured hydraulic risk management policy.

This project highlights the urgency of taking concrete measures to prevent flood-related disasters while offering a methodological framework applicable in other regions of Algeria.

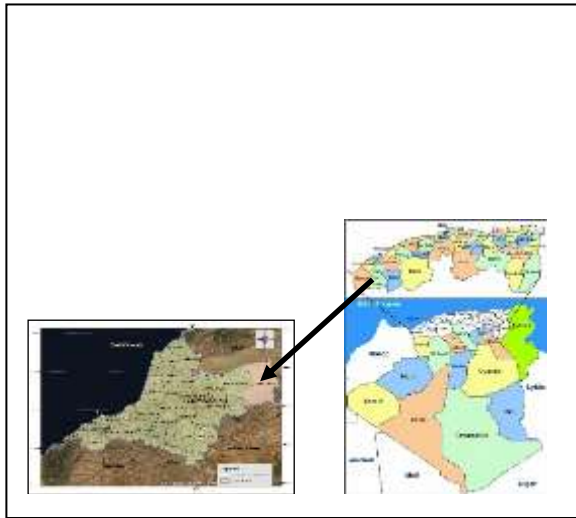


Figure 1: Geographical situation of Tamazoura, "Wilaya of Ain Témouchent".

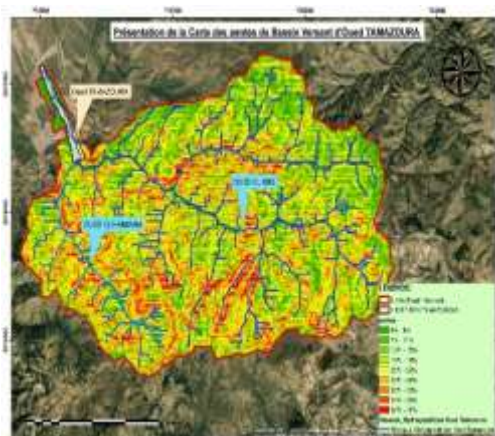


Figure 4: Map of the slopes of the watershed of the Tamazoura study

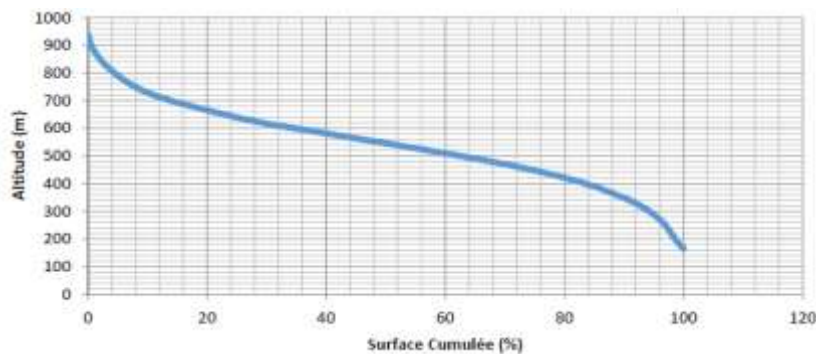


Figure N°7: Hypsometric curve of the global watershed of Tamazoura.

Table 01 HIGH WATER MARKS RECORD

No. Marker	Marker Code	UTM Coordinates		Height (m)	NGA Level (m)	Date of Flood	Type of Flood Deposits	Quality of Marker
		X	Y					
01	M	71 30 86	39 20 298	1.64	194.43	1985	Old Ruined House	Very reliable
02	B D	71 32 22	39 20 302	1.40	200.42	-	Sediment and Rust Debris Deposition Due to Water Presence	Very reliable
03	G	71 31 54	39 20 415	1.70	191.39	-	Sediment Deposition on the Second Layer of the Gabion on the Right Bank	Very reliable
04	B.D et BG	71 31 18	39 20 478	3.16	189.13	-	Sediment Deposition on Both Former Banks, Overflow Zone, and Canal Deterioration	Very reliable
05	A	71 29 27	39 20 983	5.64	185.16	-	Sediment Deposition on the Bank and Eucalyptus Tree	Reliable
06	P	71 28 89	39 21 131	5.00	176.42	1988	Flood Mark Trace on the Bridge	Reliable
07	A	71 27 76	39 21 255	4.00	176.24	-	Flood Mark on Tree Trunk	Reliable
08	BD	71 27 60	39 21 282	3.80	175.26	-	At the BD Level	Reliable
09	A	71 27 36	39 21.372	3.80	174.05	-	Mark on Tree Trunk	Very reliable
10	BG	71 25 12	39 21 555	3.00	172.72	-	Old BG	Reliable

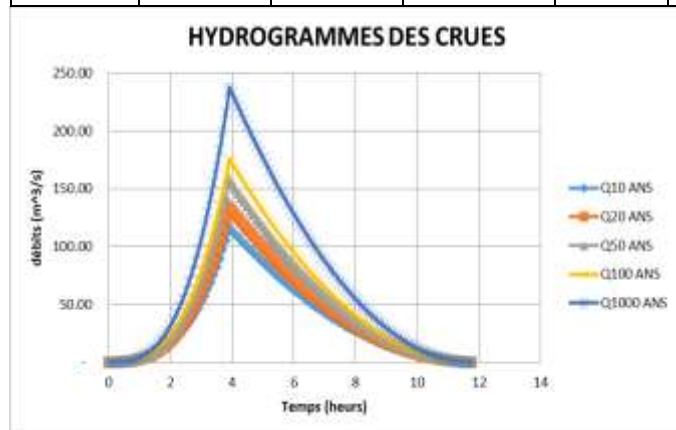


Figure 12 : Flood hydrograph of exceptional floods.

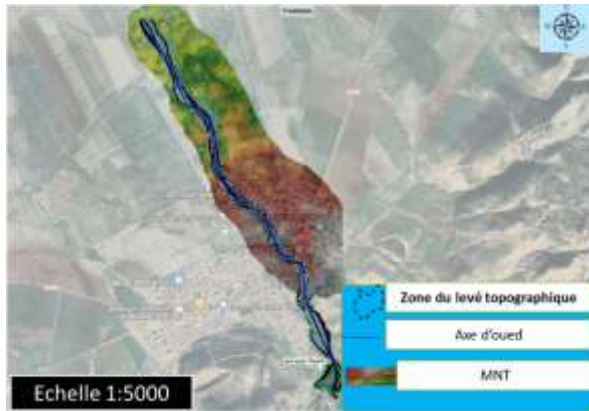


Figure 13: Terrain Overlaid on Satellite Map: Overview with Enlarged Upstream Segment.



Figure 15: Construction of the Combined Terrain for the Hydraulic Model



Figure 16: Integration of Flood Marks



Figure 19: Location of Crossing Structures on the Site

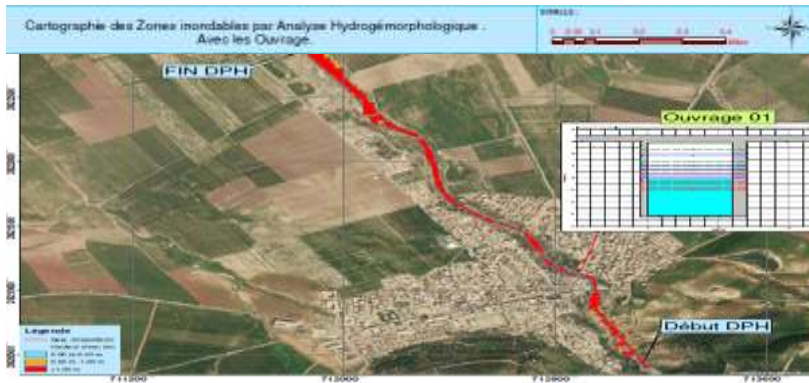


Figure 20: Floodplain Mapping Through Hydro-Geomorphological Analysis With Structures

Longitudinal Profiles

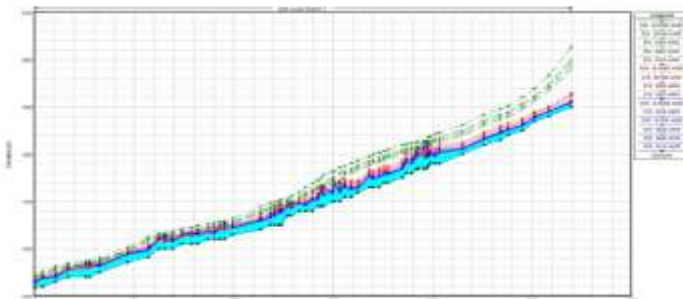


Figure 22: Global Water Depth Field in the Oued Tamazoura (100-Year Flood Without Structures)

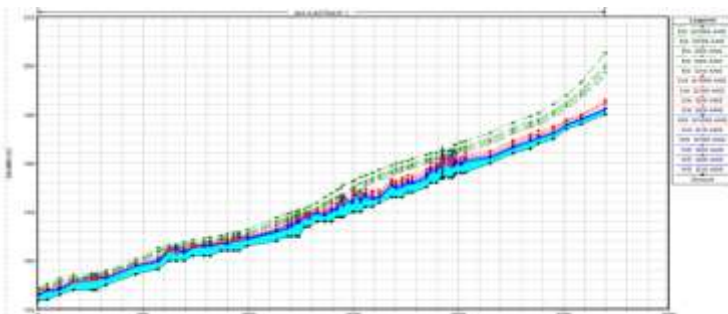


Figure 23 : Global Water Depth Field in the Oued Tamazoura (100-Year Flood With Structures)



Figure 25: Water Depth Mapping for the Section Passing Through the City Center of Tamazoura

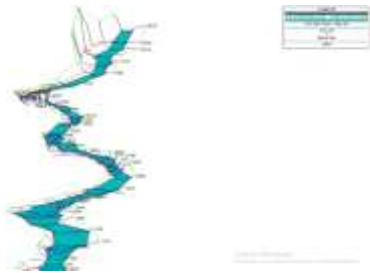


Figure 26: 3D View of the Study Area.

Delimitation of Flood-Prone Areas for Oued Tamazoura

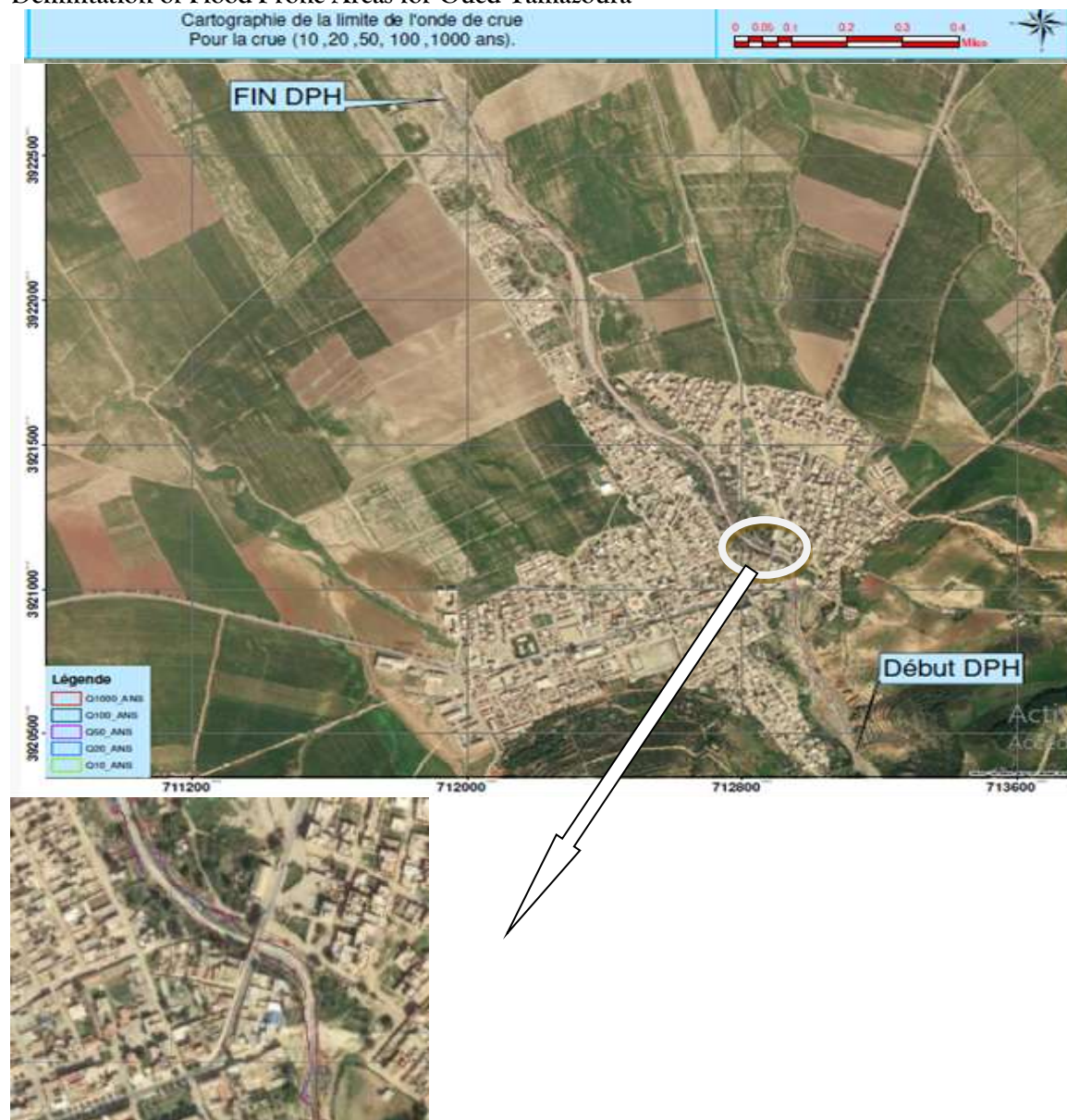


Figure 28 : Mapping of the flood wave extent for the (10, 20, 50, 100, 1000-year) flood

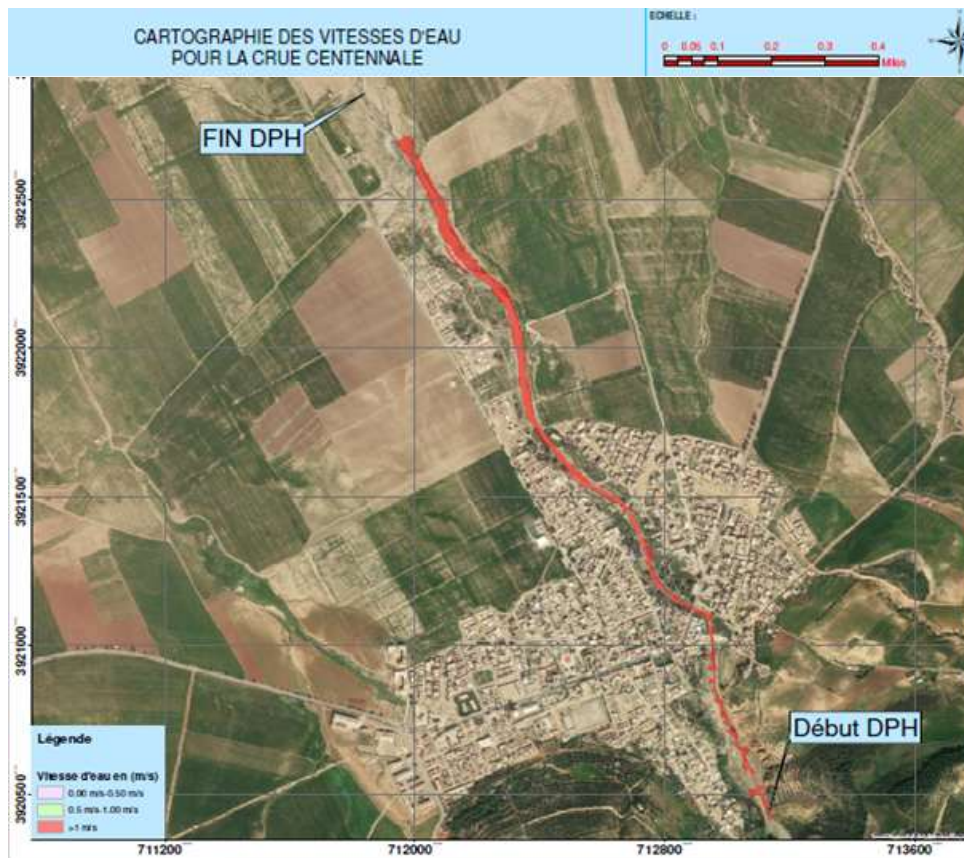


Figure 27: Cartography of water velocities for the centennial flood.



Figure 29 : Hazard mapping

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