لجمهورية الجزائرية الديمقراطية الشعبية
وزارة التعليم العالي و البحث العلمي

NATIONAL HIGHER SCHOOL FOR HYDRAULICS
"The MujahidAbdellah ARBAOUI"

المدرسة الوطنية العليا للري
"المجاهد عبد الله عرباوي"
ⴰⵖⵓⵔⴱⴰⵣ ⴰⵖⵓⵍⵏⴰⵡ ⵉⵎⵉⵏⵓⴳ ⵏ ⵜⵎⵓⵙⵡⵉⵜ

MEMOIRE DE FIN D'ETUDES

Pour l'obtention du diplôme d'Ingénieur d'Etat en Hydraulique

Option: Ouvrage Hydrotechnique

THEME :

Étude de protection de la ville de Khemis Miliana (w. Ain Defla) contre les inondations causées par l'Oued Boutane

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Session 2023/ 2024

Praise is to Allah by Whose grace good deeds are completed

At the end of this thesis, I would like to extend my heartfelt thanks to

to all those who helped, encouraged, and supported me

in accomplishing this work.

Special thanks go to my promoter, Mr. S. Toumi

I would also like to thank all the professors at the École Nationale Supérieure de

l'Hydraulique

l'hydraulique who contributed to my training.

Dedication

I would like to dedicate this modest work to the following people, as a sign of gratitude for everything they have given me:

To my dear parents For their support, patience and sacrifices during my years of study and throughout the realization of this modest project, I owe to you what I am today and what I will be tomorrow. May Almighty Allah protect you, grant you health, happiness and paradise without punishment. To my grandparents, whose wisdom inspired me.

To Sihem marouf

To my brothers.

To my dear friends atmani chopa who have shared this path with me.

To all my friends, especially Selmane Abdelhakim, Abdous Achref, Seddiki Amine,

Ouadfel Mohammed Amine, Tafifet Chemsdine, Teta Zakaria, Tazi Abdelmadjid, Habib

Rachad, Bestaoui Youcef, , Seriari Sifou, Rais Achref, Chikh Nori, Bendedouch Ismail, , , Roubech Jobier, with whom I shared unforgettable moments during my studies.

To all my colleagues at the École Nationale Supérieure de l'Hydraulique, who have enriched my academic career.

الملخص :

الهدف من هذه الدراسة هو تحليل تدابير الحماية المطلوبة لوسط مدينة خميس مليانة بولاية عين الدفلى في مواجهة مخاطر الفيضانات التي يشكلها واد بوتان. استندت المقاربة المعتمدة على تحليل متعمق للمشاكل والمشاكل المطروحة باستخدام أدوات المحاكاة الهيدروليكية مثل ArcGIS و HEC-RAS. وعلى هذا الأساس، تم وضع متغير تقني واقتصادي يتضمن إنشاء قناة خرسانية مسلحة وبنية تحتية هيدروتقنية للتحكم في نظام المياه أثناء الفيضانات. هذا الاختيار هو نتيجة لتحليل مختلف سيناريوهات التنمية المقترحة التي تهدف إلى جعل المدينة أكثر أمانًا من الفيضانات

الكلمات المفتاحية: خميس مليانة ، الحماية، مخاطر الفيضانات، المحاكاة الهيدروليكية، المناطق المعرضة للفيضانات، المتغير التكنو-اقتصادي.

Résumé:

Cette étude vise à analyser les mesures de protection nécessaires pour le centre-ville de Khemis Miliana, dans la wilaya d'Aïn Defla, face aux risques d'inondation posés par l'oued Botan. L'approche adoptée pour repose sur une analyse approfondie les alias et les enjeux à l'aide d'outils de simulation hydraulique tels qu'ArcGIS et HEC-RAS.Sur cette base,une variante technico-économique a été développée, comprenant la construction d'un canal en béton armé et d'une infrastructure hydrotechnique pour contrôler le régime des eaux lors des crues. Ce choix résulte d'une analyse des différents scénarios d'aménagement proposés, visant à renforcer la sécurité de la ville face aux inondations.

Mots clés : khemis milliana , Protection, risques d'inondations, Simulation hydraulique, Zone inondables, Variante technico-économique.

Abstract :

The aim of this study is to analyze the protection measures required for the downtown area of Khemis Miliana, in the wilaya of Aïn Defla, in the face of flood risks posed by the Oued Botan. The approach adopted was based on an in-depth analysis of the aliases and challenges, using hydraulic simulation tools such as ArcGIS and HEC-RAS. On this basis, a technico-economic variant was developed, comprising the construction of a reinforced concrete canal and hydrotechnical infrastructure to control the water regime during floods. This choice resulted from an analysis of the various development scenarios proposed, aimed at enhancing the city's flood safety.

Key words: khemis milliana , Protection, Floods risks, Hydraulic simulation, Flood-prone areas, Technico-economic variant.

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Work tools :

Arc GIS :

ArcGIS is a comprehensive suite of geographic information system (GIS) software developed by the American company ESRI (Environmental Systems Research Institute, Inc.). A GIS is a computer system designed to capture, store, manipulate, analyze and present spatial data, enabling the understanding and visualization of geographically-related information. ArcGIS offers a set of tools and functionalities for the creation, management and analysis of geographic data, facilitating spatial-based decision-making. The suite includes applications such as:

- **ArcMap:**

Function: Edit files in geodatabase format.

Use: Cartography and geospatial analysis.

- **ArcCatalog:**

Function: Manage data, providing detailed information on edited objects.

Use: Geographic database management system.

- **ArcToolbox:**

Function: Bring together tools dedicated to data transformation.

Use: Facilitate processing and analysis operations on geographic data.

AutoCAD :

AutoCAD is computer-aided design (CAD) software developed by Autodesk. It is used to create precise drawings in two or three dimensions, and offers powerful modeling, drawing and documentation tools to support the design process.

HEC-RAS :

HEC-RAS (Hydrologic Engineering Center's River Analysis System) is a hydraulic modeling software package developed by the US Army Corps of Engineers. It is used to analyze flows in rivers, canals and other hydraulic systems. HECRAS can be used to simulate hydraulic characteristics such as flow rates, water levels and flow velocities, in order to assess flood risk, design hydraulic structures and plan riparian development.

Ras Mapper:

RAS Mapper is a software package integrated into HEC-RAS, specializing in the mapping of hydraulic and hydro sedimentary analysis results. It visualizes, analyzes

and graphically interprets the data generated by HEC-RAS, making it easier to understand hydraulic models and river simulations.

Flow Master:

Flow master software is a simulation tool specialized in fluid system modeling, enabling the behavior of fluids, such as liquids or gases, to be analyzed in complex systems. It is used to design and optimize fluid networks, such as hydraulic and pneumatic systems, offering advanced features for visualizing and analyzing results to improve fluid system performance.

General introduction

In recent years, floods in Algeria have become more frequent and more destructive, creating a major obstacle to the country's economic and social development. This phenomenon is the result of several factors, including river flooding, rising groundwater levels, and increased urban runoff, all of which have recently caused significant damage.

To manage floods, it is essential to adopt a watershed-scale approach by identifying specific risks and defining preventive measures, such as risk management plans and the construction of hydraulic structures to protect property and communities. In Algeria, where climate change and urban expansion are realities, addressing this issue has become crucial.

This study focuses on the construction of a protection system for the town of khemiss milliana , located in the wilaya of ain defla , against flooding from the Oued botan , which flows through the heart of the town. Which also had a major floods in 2017 in the south of the city and cracks in the Concrete ,teardowns , falling parts of the protection and soil deposition

protecting the city and its inhabitants has become a priority for the authorities, with the aim of reducing major risks.

The aim of this work is to propose structural measures to protect the areas crossed by the Bhutan Valley. To achieve this, our work is divided into six parts: Detailed presentation of the study area, analysis of the daily maximum precipitation leading to the potential maximum precipitation for project flow calculations, estimation of hydrographs, study of flows in watercourses in their natural state, creation of a flood map using ARC-GIS and HEC-RAS software, and proposal of solutions in the form of variants, including a proposed solution for the high slope. Finally, develop a work safety plan . to ensure the safety of the population and minimize the impact of flooding on the town of Khemiss Melliana.

Chapter one

General information’s on flood

Ⅰ Introduction :

Flooding occurs when a watercourse overflows its banks, usually during a period of high water, resulting in the submergence of adjacent land. This phenomenon can also include overflows from man-made infrastructures such as reservoirs or sewage systems. In addition, flooding can occur upstream of floods, when large quantities of water run off cultivated areas, causing mud floods. These events are among the most destructive natural disasters in terms of damage.

Ⅰ.1 Definition of the concepts covered:

Ⅰ.1.1 The risk :

Flood risk refers to the probability of a given area being affected by flooding, and the potential consequences of this event. This risk is determined by a number of factors, including rainfall frequency and intensity, soil type, topography, urban development and existing drainage systems.

Ⅰ.1.2 Alea :

Alea refers to the probability of occurrence of an extreme hydrological event, such as a flood, as well as the intensity of that event. This generally includes phenomena such as heavy rainfall, rapid snowmelt, flash floods or tropical storms, depending on the geographical region studied.

Ⅰ.1.3 Vulnerability :

Vulnerability in hydrology refers to the susceptibility of an area, population or infrastructure to be adversely affected by hydrological events such as floods, high water or droughts. This vulnerability is often influenced by a complex set of physical, social, economic and environmental factors.

On the physical level, vulnerability can be exacerbated by geographical features such as proximity to watercourses, relief, soil type and level of urbanization. For example, areas located on flood plains are more vulnerable to flooding than those at higher altitudes.

On a social level, vulnerability can be linked to factors such as population density, poverty, limited access to basic resources and services, and lack of protection and early warning infrastructures. Marginalized populations, such as the elderly, children, people with disabilities or disadvantaged communities, are often more vulnerable to the impacts of extreme hydrological events.

On the economic front, economic activities dependent on natural resources, such as agriculture, fishing and tourism, can be severely affected by hydrological events. Likewise, critical infrastructures such as roads, bridges, water supply and sewerage networks, as well as industrial facilities, can suffer considerable damage in the event of flooding.

Finally, in environmental terms, vulnerability can be exacerbated by inappropriate land management practices, such as deforestation, soil degradation and loss of natural habitats, which can compound the effects of extreme hydrological events.

Understanding and assessing vulnerability in hydrology is essential for developing effective risk management and climate change adaptation strategies, in order to reduce the negative impacts of hydrological events on populations, infrastructures and ecosystems.

I.2 Flooding :



Figure I city of Rio Grande do flooding

I.2.1 Definition :

Flooding is the submergence, rapid or slow, of an area usually out of water. The risk of flooding is the result of two factors: the water itself, which can leave its normal flow channel, and the human population, which settles in alluvial areas to build all kinds of buildings, equipment and activities. In the broadest sense, flooding includes river overflows, rising water tables, runoff resulting from heavy rainstorms, flooding caused

by the failure of protective structures (breach in dykes), estuarine flooding resulting from the combination of high tides, low-pressure situations and river flooding.

I.2.2 Type of flood :

It is conventional to distinguish at least six types of flooding :

I.2.3 Lowland flooding :



Figure 2 lowlands flood in usa due to heavy rain fall

Lowland floods, also known as fluvial floods, occur following prolonged periods of moderate oceanic precipitation. These rains fall on soils where runoff is delayed, meaning that the water takes a long time to reach the watercourse. As a result, the watercourse leaves its usual bed and extends into its major plain, causing flooding.

Flooding is characterized by a slow rise in water levels, and the overflowing of the river can sometimes be preceded by saturation of the water table. The duration of flooding can be prolonged, lasting from several days to several weeks.

I.2.4 Torrential flooding :

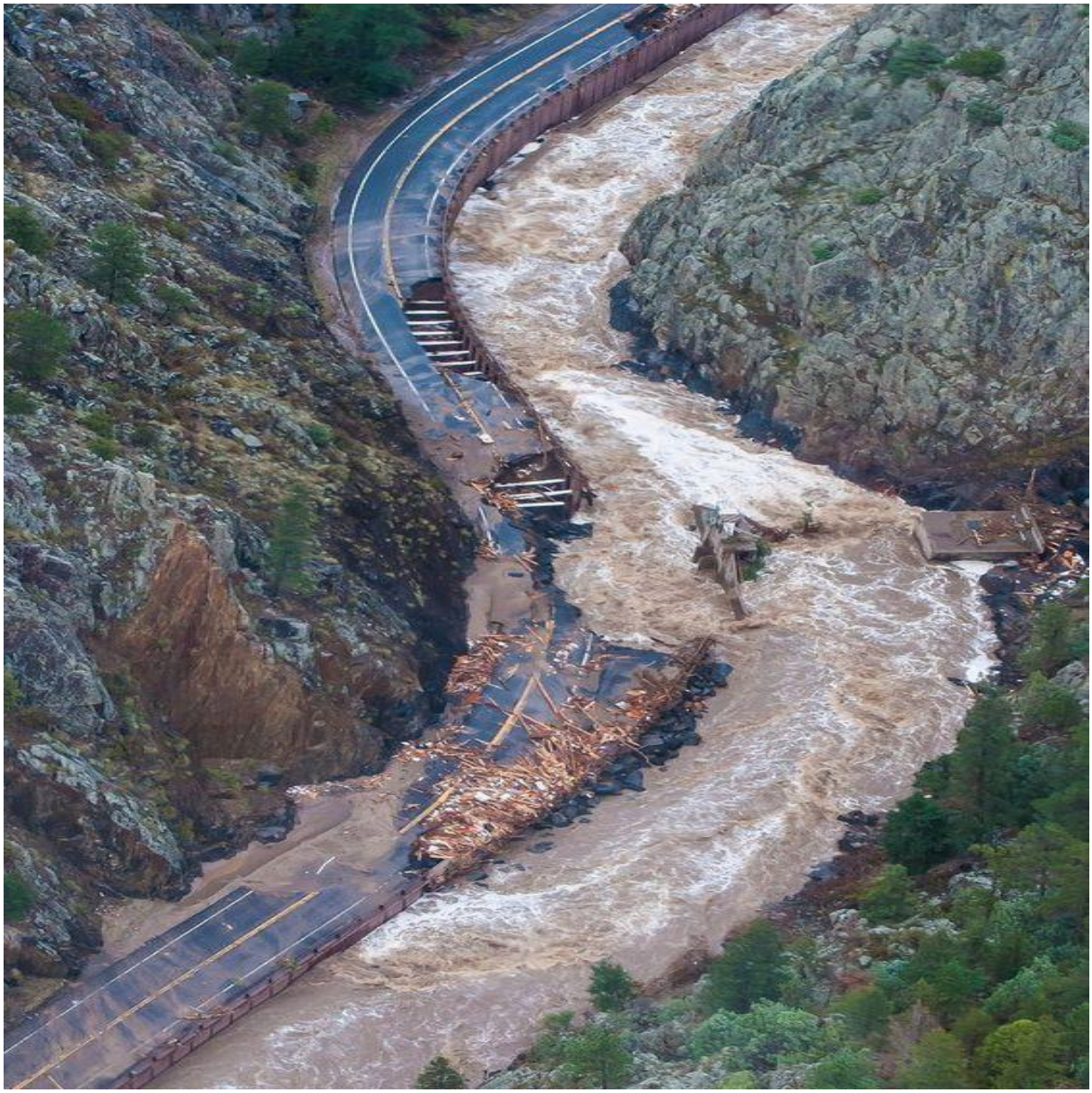


Figure 3 Hwy 34 destroyed through Big Thompson Canyon

Torrential floods are extreme hydrological phenomena that generally occur in mountainous or semi-arid regions. They are characterized by a sudden and rapid rise in water levels in rivers, often accompanied by high flows and significant sediment transport. Here are some key facts about torrential flooding in hydraulics:

a **Main causes :**

- Intense, localized precipitation
- Rapid snowmelt

- Rupture of natural or artificial dams

b **Characteristics :**

- Very rapid rise in water level (within hours or minutes)
- High peak flows
- Significant transport of sediment, debris and solid materials
- Considerable erosive energy

c **Potential impacts :**

- Destruction of infrastructure (bridges, roads, buildings)
- Erosion of banks and riverbeds
- Accumulation of debris and ice jams
- Risks to the safety of people and property

I.2.5 Urban runoff flooding :

Urban and agricultural runoff floods occur when heavy rainfall encounters impervious surfaces, such as concrete in urban areas or compacted soils in agricultural areas.

One of the main causes of urban flooding is that impermeable surfaces such as roads, parking lots and roofs prevent water from infiltrating into the ground, resulting in rapid runoff into drainage channels and sewage systems. In agricultural areas, excessive ploughing, deforestation and loss of vegetation cover also increase rainwater runoff on soils, which can lead to flooding.

Urban and agricultural runoff floods can be localized, affecting mainly low-lying areas where water accumulates rapidly due to topography or urban density. However, they can also affect vast expanses of agricultural land lacking soil conservation measures.

These floods can be very sudden and violent, particularly in urban areas where runoff is accentuated by impermeable surfaces and inadequate drainage systems.

Urban and agricultural runoff floods can cause damage to urban infrastructure such as roads, bridges and sewer systems, as well as to farmland, crops and buildings. They can also lead to significant economic losses and risks to public safety.

I.2.6 Groundwater flooding :

Rising groundwater flooding is a different type of flood from torrential flooding, but just as worrying in hydraulic terms. Here are the main characteristics of this phenomenon:

a **Main causes :**

- Outcropping or shallow water tables
- Heavy and/or persistent precipitation
- Heavy runoff and infiltration of water into the ground

b **Mechanism :**

- When the soil is saturated with water, the water table rises.
- If it reaches the ground surface, it causes flooding.

c **Characteristics :**

- Slow, gradual flooding
- Large areas of land affected
- Stagnant water over long periods
- Risk of infiltration into homes, cellars and basements.

d **Potential impacts :**

- Damage to infrastructure and buildings
- Health problems (stagnant water, mold)
- Disruption to agricultural and economic activities
- Risks to stability of hydraulic structures

I.2.7 Debris:

are extreme and dangerous hydrological phenomena that often occur in mountainous or semi-arid regions. Here are the main characteristics of mudflows in hydraulics:



Figure 4 A debris flow at the lower section of Illgraben (ethz.ch)

a **Definition :**

Highly concentrated mixture of water and solid materials (rock debris, gravel, mud, etc.).

Both liquid and solid behavior

b **Formation :**

- Generally triggered by heavy rainfall or rapid snowmelt
- Intense erosion of slopes and rive-beds
- Incorporation of solid materials into the flow

c **Characteristics :**

- Rapid, turbulent flow, sometimes reaching speeds in excess of 10 m/s
- High transport capacity for solid materials
- High impact force and erosive potential
- Volume can reach several million cubic meters

d **Potential impacts :**

- Destruction of infrastructure (roads, bridges, buildings)
- Burial of inhabited areas
- Obstruction of watercourses and risk of downstream flooding
- Threats to personal safety

I.2.8 Flooding due to protection failure :



Figure 5 protection failure in Germany

Hydraulic flooding is an extremely dangerous event, with potentially catastrophic consequences. They occur when a flood protection structure, such as a dam,or floodwall, fails or is overtaken by water. Here are the main characteristics of this type of flood :

a **Causes of failure :**

Structural failure of the structure (ageing, design or construction faults)

Overflow due to exceeding the capacity of the structure (exceptional flood)

Internal or external erosion of the structure

Sabotage or malicious act

b **Flood characteristics :**

- Sudden and violent flood wave
- Very high flow speeds
- Huge impact forces and destructive potential
- Large volumes of water released in a short space of time

c **Potential impacts :**

- High loss of life due to sudden and violent onset
- Massive destruction of infrastructure and buildings
- Extensive flooding of downstream areas
- Environmental damage (erosion, pollution)

I.2.9 Marine flooding :

Marine floods, also known as marine submergence, are a type of flooding caused by rising sea or ocean levels. In hydraulics, these phenomena present specific characteristics and challenges :



Figure 6 North Carolina's coast raid with sea water

a **Main causes :**

- Exceptional spring tides
- Rising average sea levels (climate change)
- Storms, hurricanes and storm waves

- Tsunamis

b **Mechanisms :**

- Crossing or failure of coastal protection structures
- Submergence of low-lying coastal areas
- Saltwater intrusion into river systems and aquifers

c **Characteristics :**

- Progressive or sudden flooding, depending on cause
- Saltwater intrusion can damage infrastructure
- Large volumes of water and large flooded areas

d **Potential impacts :**

- Damage to coastal infrastructure (roads, buildings, ports)
- Erosion and retreat of coastline
- Contamination of freshwater resources
- Disruption of economic activities (fishing, tourism)

I.3 Parameters that characterize a flood

I.3.1 Flood return period :

The return period (or recurrence period) of floods is a fundamental concept used to characterize the probability of occurrence and intensity of flooding events.

The return period T represents the statistical mean time interval, expressed in years, between two occurrences of a flood event of a given intensity.

In other words, the return period T corresponds to the annual probability of occurrence 1/T of a flood event of a given magnitude.

The return period is determined by statistical analysis of historical hydrological data (flows, water levels, etc.), by fitting a probability law (Gumbel's law, GEV, etc.) to the observations.

It is important to note that the return period does not mean that the event occurs exactly at regular intervals, but rather represents an average probability of occurrence over time.

I.3.2 Submergence height and duration :

a **Submergence height :**

- Corresponds to the maximum height reached by flood waters above ground level.
- Generally expressed in meters.
- This is a crucial parameter that determines the extent of the flood zone and the impact on infrastructure and buildings.
- The higher the submersion height, the greater the potential damage.

b Flood duration :

- Represents the length of time a given area remains flooded.
- Usually expressed in hours or days.
- This is a key factor influencing the extent of damage and disruption caused by flooding.
- Long periods of inundation can lead to additional structural, health and environmental problems.

I.3.3 Current speed :

Current speed is the horizontal flow velocity of flood waters. It is generally expressed in meters per second (m/s).

a Impacts of current speed :

- High velocity increases the impact force and erosive potential of water.
- This can cause major structural damage to infrastructure and buildings.
- People and vehicles can be swept away by fast-moving currents.
- Bank erosion and sediment transport are amplified.

b Orders of magnitude :

- Speed less than 0.5 m/s : low risk for people and light structures.
- Speed between 0.5 and 1.5 m/s : moderate risk, difficult to move around on foot.
- Speed greater than 1.5 m/s : high risk, significant impact force and erosion.

c Volume of material transported :

This represents the quantity of sediment, debris and solid materials carried by flood waters. The main information concerning this parameter is as follows :

- The volume of material transported corresponds to the total solid load transported by the watercourse during the flood.
- It is generally expressed in cubic meters (m3) or tons.

Origins of transported materials :

- Erosion of river banks and bed
- Runoff and sediment input from watersheds
- Plant debris and other materials washed downstream

I.4 What makes the flooding worse :

There are several factors that can aggravate flooding and increase its impact :

a Intense, long-lasting precipitation

heavy rainfall, particularly when concentrated in time and space, can rapidly saturate soils and cause sudden, major flooding of watercourses.

b Rapid snowmelt

The sudden melting of a large snowpack, combined with heavy rainfall, can lead to exceptional flood flows and major flooding.

Relief and soil sealing: Urban areas and mountainous regions encourage rapid water runoff, limiting infiltration and amplifying floods. Soil sealing accentuates this phenomenon.

c **Obstructions and failure of structures**

Ice jams, debris jams or the failure of dykes, dams or other protective structures can cause devastating flash floods.

d **Inadequate drainage systems**

Undersized or poorly maintained storm drainage systems can quickly be overwhelmed by intense rainfall, causing localized flooding.

e **High tides and coastal storms**

In coastal areas, exceptional spring tides, storms and marine surges can aggravate flooding by marine submersion.

f **Climate change**

The increased frequency and intensity of extreme events linked to climate change (torrential rains, heat waves, etc.) may exacerbate flood risks in many regions.

II Flood protection :

II.1 Direct protection :

II.1.1 Dredging :



Figure 7 debergin rivers in UK

This consists of removing sediment, plant debris and other materials accumulated in the bed of rivers, streams and canals.

Its aim is to

- Restore the flow capacity of the watercourse by increasing the flow cross-section
- Reduce the risk of obstruction and overflow during floods
- Facilitate rapid evacuation of floodwaters

II.1.2 Reshaping:

This involves modifying the cross-sectional profile and geometry of the bed and banks of a watercourse to increase its flow capacity. Its aims are to :

- Increase the flow cross-section of the watercourse to allow higher flood flows to pass through.
- Reduce the risk of overflow and flooding
- Facilitate rapid evacuation of water during floods.

II.1.3 Recalibration techniques :

Widening the minor and/or major bed

- Deepening the bed
- Reprofiling of banks (softening of slopes)
- Rectifying the course (elimination of tight meanders)

II.1.4 Reinforcement of structures :

The aim is to improve the resistance and capacity of these structures in order to adapt them to current and future hydrological conditions. Here are the main aspects of strengthening flood protection structures :

II.1.5 Types of structures concerned :

- Dams to protect against flooding and marine submersion
- Flood control dams
- Protective walls along watercourses
- Coastal structures (breakwaters, groins, etc.)

II.1.6 Reinforcement techniques :

- Raising the crest of dams to increase freeboard
- Widening dams to improve stability
- Reinforcing foundations and anchors
- Erosion protection (geotextiles)
- Repairing breaches and structural defect

II.1.7 Creation of canals:

These structures divert and evacuate flood waters to protect vulnerable areas. Here are the main aspects of canal construction for flood protection :

a Types of canals:

- Diversion canals : diverting part of the floodwater to a less vulnerable area
- Bypass canals: bypass an urbanized area to avoid flooding
- Drainage channels: evacuation of rainwater and runoff.

b **Channel design :**

- Hydraulic dimensioning (cross-section, slope, lining) according to flow rates to be evacuated
- Layout adapted to topography and site constraints
- Ancillary structures : inlet/outlet structures, chutes, gates, etc.

II.1.8 Bank protection :

The main objectives are to stabilize banks, limit erosion and preserve the flow capacity of the minor bed. Here are the main aspects of bank protection :



Figure 8 Banks protection using gabions (gabionbarriers.com)

a **Protection techniques :**

- Riprap (stones, gabions)
- Masonry rip-rap
- Plant techniques (vegetal engineering, planting)
- Combinations of mineral and plant techniques

b **Role in flood protection :**

- Ensures the durability and effectiveness of other structures (dikes, groins, etc.).

- Reduces the risk of structure failure during floods.
- Limits damage to riverside infrastructure
- Preserves natural flood expansion zones

c **Environmental aspects :**

- Consider impacts on aquatic and riparian habitats
- Encourage more environmentally-friendly planting techniques
- Preserve wetlands and natural flood expansion zones

II.1.9 Seasonal maintenance of drainage systems:

Seasonal maintenance of drainage systems (sewer systems, ditches, etc.) is an important measure for protecting against hydraulic flooding. Regular maintenance ensures the proper flow of rainwater and floodwater, and prevents the risk of blockages and overflow. Here are the main aspects of this measure:

a **Seasonal maintenance operations:**

- Cleaning and unclogging of networks and ditches
- Clearing and pruning of verges
- Cleaning of gratings and gullies
- Checking the condition of structures (nozzles, scuppers, etc.)

b **Periodicity:**

- Before high-risk seasons (spring, autumn)
- After major meteorological events (heavy rainfall, flooding)
- Frequency adapted to local conditions

c **Benefits:**

- Maintains hydraulic capacity of networks
- Avoids blockages and localized overflows
- Facilitates rapid evacuation of water during rainy episodes
- Reduces the risk of flooding in urban areas

II.2 Indirect protection

II.2.1 Creation of perimeter channels :

These structures divert flood flows around urbanized or vulnerable areas. Here are the main aspects of creating peripheral channels:

a **Objectives :**

- **Bypass** areas to be protected to avoid flooding
- Divert floodwaters to less vulnerable areas
- Reduce flows in the main watercourse

b **Channel design :**

- Hydraulic sizing based on flows to be diverted
- Peripheral layout around areas to be protected
- Inlet/outlet structures for connection to the river system

- Flow regulation structures (weirs, gates, etc.)

c **Benefits:**

- Effectively protects vulnerable areas from flooding
- Avoids the high cost of localized protection (dikes, embankments)
- Preserves the flow capacity of the main watercourse

II.2.2 Creation of dams or weirs:

These structures regulate river flows and temporarily store floodwater. Here are the main aspects of this type of structure :

a **Types of structures :**

- Reservoir dams: long-term storage and flood control
- Barrages : temporary storage of floodwaters
- Weirs and spillways: raise upstream water levels.

b **Flood protection functions:**

- Peak flow reduction during floods
- Laminate floodwaters by temporarily storing them
- Regulate downstream flows to limit flooding

c **Main components :**

- Retaining structure (dam, spillway)
- Reservoir or temporary storage area
- Discharge structures and spillways

d **The benefits:**

- Effective flood protection for downstream areas
- Control of river flows
- Multi-use potential (water, energy, recreation)

III Flooding in Algeria and around the world :

III.1 Algeria :

In recent years, Algeria has unfortunately been hit by several episodes of severe flooding, causing significant material damage and loss of life. Here are some of the most notable events:

- October 2022 : Torrential rains hit eastern Algeria, particularly the wilayas of Tébessa, El-Tarf and Skikda. At least 4 people lost their lives and hundreds of families had to be evacuated due to flooding.

- November 2021 : Bad weather hit several northern regions, including around Algiers and Tizi-Ouzou. At least 7 people died in the devastating floods.

- January 2020 : The city of Ouargla and its surrounding region were hard hit by torrential rains, leaving at least 5 people dead and enormous material damage.

- November 2019 : Torrential rains hit the Tlemcen region, causing major urban flooding and considerable damage.

- October 2019 : The wilayas of Skikda, Guelma and Annaba were hit by exceptional flooding following heavy rains that claimed several lives.

- May 2018 : Torrential rains hit the capital Algiers, causing deadly flooding in several neighborhoods.

These events are a reminder of Algeria's vulnerability to extreme weather phenomena and the importance of strengthening flood prevention and protection measures, particularly in at-risk urban areas.

III.2 Worldwide :

Here are some of the major flooding episodes that have occurred in different parts of the world in recent years:

a Europe :

- July 2021 : Catastrophic flooding in Germany, Belgium and the Netherlands following torrential rains, killing more than 200 people.

- October 2022 : Record flooding in several regions of Italy following torrential rains, causing extensive damage.

b Asia :

- August 2022 : Deadly floods in Pakistan affecting a third of the country, the worst in decades.

- July 2021 : Massive floods in central China killing dozens in Henan province.

- August 2018 : Kerala in India hit by the worst floods in a century after extreme monsoon rains.

America:

- September 2022 : Hurricane Fiona causes devastating floods in the Caribbean and eastern Canada.

- August 2022 : Record flooding in the Dallas region of the USA after torrential rains.

- November 2021 : Flash floods in the Brazilian state of Bahia kill dozens.

Africa:

- April-May 2022 : Dramatic flooding in southern Africa (South Africa, Mozambique) caused by intense tropical rains.

- September 2020 : Severe flooding in Sudan, affecting hundreds of thousands of people.

Conclusion

The detailed description of the flood hazard in this chapter highlights its complexity and dangerous nature. It is essential to understand the mechanisms of this

phenomenon in order to effectively prevent the associated risks. It is therefore recommended that an in-depth study be carried out to assess the maximum floods in our study area. This study will provide precise information on expected flows and water heights during flood periods, which will contribute to the implementation of appropriate prevention and risk management measures.

Chapter Two

Overview of the study area

Ⅰ Introduction

The second chapter of this study provides a comprehensive overview of the study area's watershed, emphasizing the critical role of geographical and physiographical factors in understanding hydrological mechanisms. These factors, including altitude, slope, watershed shape, and lithology, form the foundational basis for analyzing how water moves and behaves within the basin.

Altitude serves as a fundamental parameter influencing hydrological processes. Higher altitudes often experience more precipitation, leading to increased water inputs into the watershed. This precipitation can manifest as rain, snow, or a combination, affecting runoff rates, groundwater recharge, and overall water availability. Understanding altitude variations helps hydrologists assess the distribution of precipitation and its impact on water resources.

The slope of the terrain plays a significant role in shaping hydrological responses. Steeper slopes tend to generate faster runoff, as gravity accelerates water movement downhill. This rapid runoff can contribute to erosion, sediment transport, and surface water flows. In contrast, gentler slopes may facilitate greater infiltration, groundwater recharge, and baseflow contributions to streams and rivers. Analyzing slope gradients aids in predicting runoff patterns, erosion potential, and sedimentation rates within the watershed.

Watershed shape and drainage patterns are crucial considerations in hydrological analysis. The configuration of the watershed, including its size, orientation, and internal drainage network, influences how water is routed through the basin. Watersheds with complex drainage patterns may exhibit diverse flow pathways, affecting flood routing, streamflow variability, and water quality dynamics. Evaluating watershed shape helps hydrologists understand flow connectivity, identify contributing areas to specific water bodies, and assess flood risk distribution.

Lithology, referring to the geological composition of the watershed's substrate, provides insights into water storage, infiltration rates, and groundwater behavior. Different rock types and soil textures have varying permeability levels, influencing how water moves through the subsurface environment. Hydrologists analyze lithological characteristics to assess groundwater potential, delineate aquifer boundaries, and model groundwater flow paths.

By conducting an in-depth analysis of these geographical and physical characteristics, hydrologists gain a nuanced understanding of the hydrological processes operating within the watershed. This understanding is essential for water resource management, flood risk assessment, ecosystem protection, and sustainable development planning within the study area. Incorporating data on altitude, slope, watershed shape, and lithology enables a holistic approach to hydrological modeling and decision-making, ensuring effective management of water resources and resilience to hydrological challenges.

II The study zone

Khemis Miliana is a town in northern Algeria. It is a university town located 120 kilometers west of Algiers. It was known as Malliana in Roman times, then Affreville during the French colonial era . It is crossed by the RN 4 and the East–West Highway. A new highway will link the town of Khemis-Miliana and Berrouaghia with Bordj Bouarreridj in eastern Algeria. And it is located about 50 km north of the capital of the wilaya Ain Defla. It can be reached via national road N4B.

The commune was established in 1848, with an area of 57 square kilometers, and a population of: 210000 inhabitants (updated census), bordered from the north by the commune of Melliana, from the south by the Oued Chlef River, from the east by the commune of Ain El Sultan, and from the west by the commune of Sidi Lakhdar.

Wells and resources: There are ten wells with a flow of between 25 and 40 l/s at an average of 20 hours of pumping per day, and the town is also supported by about 12000 m3/day from the Sidi Amhamed Ben Taiba dam.

Reservoirs: There are 14 reservoirs with a capacity of 15,700 m3, and the town of Khemais Melliana was supported by three new reservoirs, the first with a capacity of 2000 m3 in the Kalitous area.

Distribution network: The city benefits from the restoration of the potable water grid at a distance of 120,000 meters and the process is about to be completed.

City and commune

Coordinates: **36.26°N 2.20°E**

Country : Algeria **demography :** 2008 (84574)-2023(210000)

Province : Aïn Defla Province **area :** 58 km

District : Khemis Miliana District

Time zone : UTC+1 (West Africa Time)

Botan valley travels through south of milliana, east of zougala to khemiss milliana in the center of the city from the north to the south

Our study zone contain 4 valleys the malah and sofain valley in the east botan in the center, rihan valley in the east

II.1 Geographical location :

The Botan Valley, originating from the Zeccar Mountains north of Khemiss Miliana, stretches approximately 12 kilometers towards the northwest, reaching Ain Defla, the capital, located about 50 kilometers away. This valley plays a crucial role in the hydrological dynamics of the region, particularly concerning its connection to the Chilef River, situated approximately 10 kilometers from the valley's end.

From a hydrological perspective, the Botan Valley's geographical layout influences various aspects of water flow and distribution. The mountainous terrain at the valley's source contributes to enhanced precipitation rates, especially during rainy seasons or intense weather events. This increased precipitation can lead to higher water inputs into the valley, affecting streamflow rates and groundwater recharge along the valley floor.

The valley's northwest direction towards Ain Defla influences surface runoff pathways and drainage networks. Water naturally follows the slope gradients and channel characteristics within the valley, eventually converging towards the Chilef River. Understanding these flow patterns is essential for managing water resources, assessing flood risks, and optimizing water utilization within the Botan Valley.

Lithological considerations within the Botan Valley also impact its hydrological processes. The geological composition of the valley's substrate influences water infiltration rates, groundwater storage capacities, and aquifer recharge dynamics. These factors play a role in determining the availability of groundwater resources and the resilience of the valley's water supply.

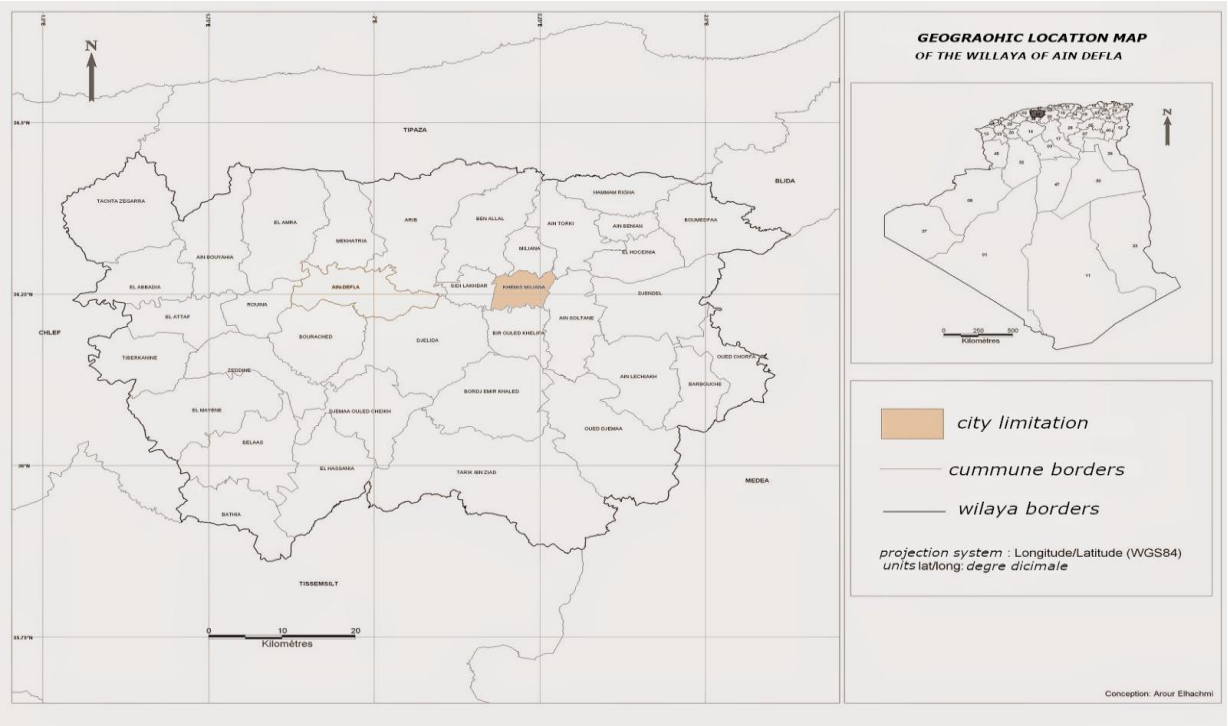


Figure geografical locatin map for ain defla with khemiss milliana highlite on

II.2 The valley watershed:

The Khemis-Miliana lowland belongs to the Haut Cheliff sub-basins Haut Cheliff N°: 01-15, 16 and 17, it covers an area of 359 Km² and a perimeter of 159 Km, characterized by an average altitude of 270 m. It is one of the largest groundwater reservoirs in the region. It is located between latitudes (36°18'-36°6') N and longitudes (2°-2°27' E, bounded to the north by the Zaccar massif (1576 m), and to the south by the first reliefs of the Ouarsenis, entering from the east via the Djendel threshold, and exiting from the west via the Doui threshold (Meziani and Bong , 2013). The lowland has a semi-arid climate with Saharan influences in summer and Mediterranean influences in winter, characterized by two distinct seasons: a wet, cold winter and a dry, hot summer (Ismail and Abakar, 2011).

The botan valley sub-watersheds belongs to haut cheliff n 17

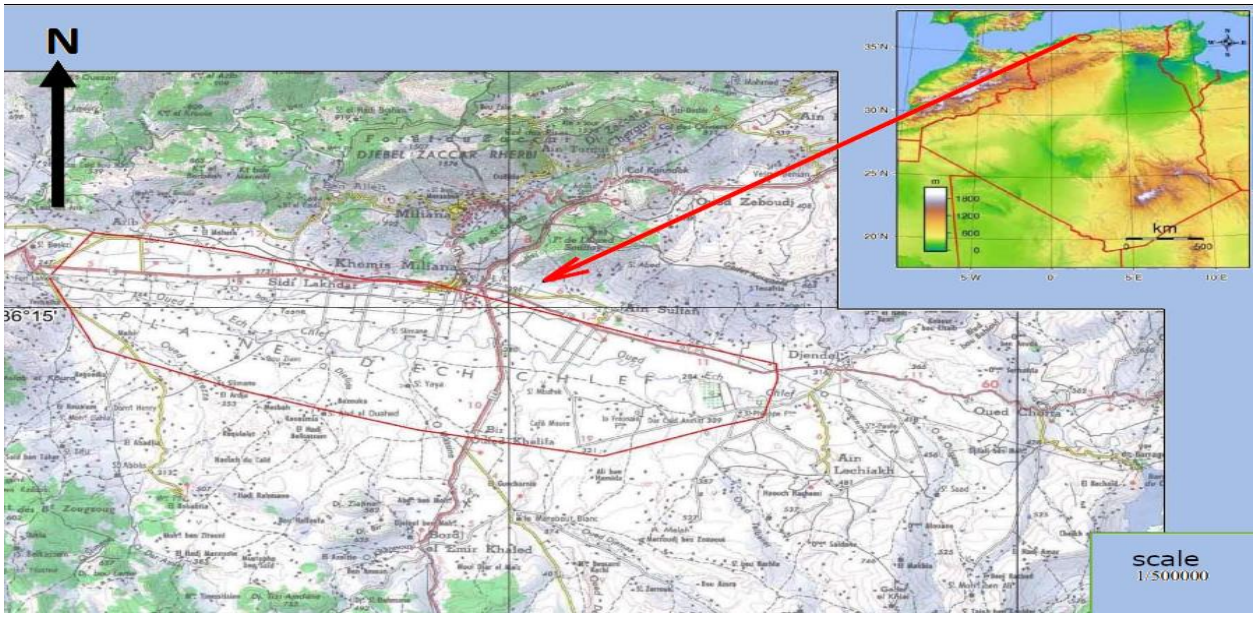


Figure 9 khemiss milliana sub water shed

II.2.1 The hydrographic network:



Figure 10 the ain defla area with khemiss millia marked in

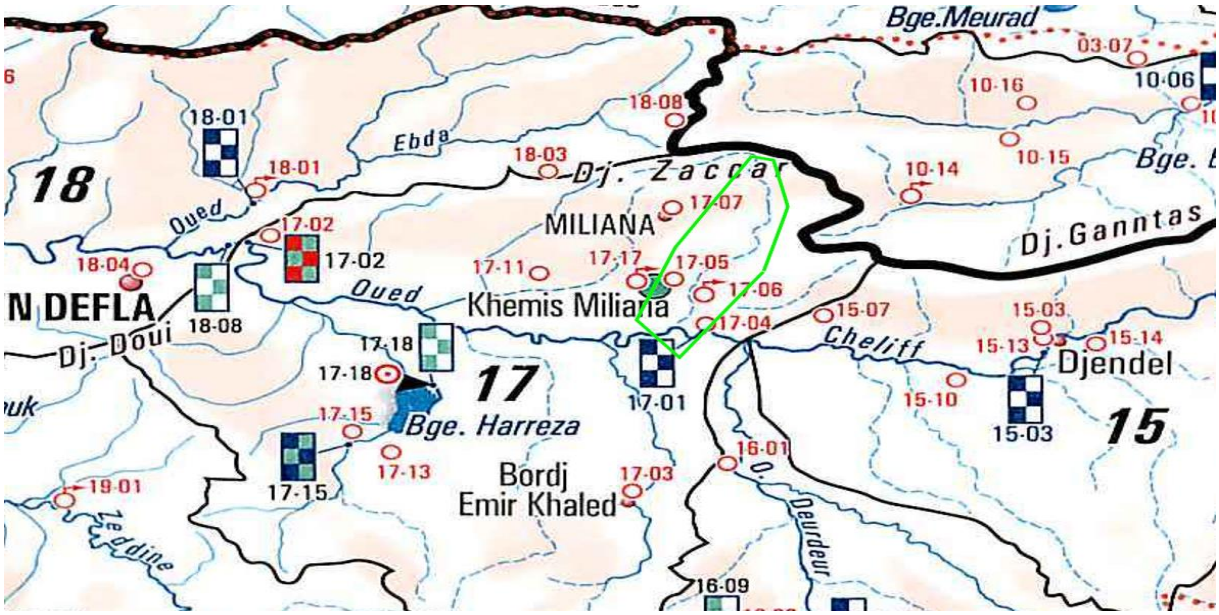


Figure 11 hydroclimatological network and water quality monitoring map for northern algeria

II.3 Earthquake activity:

Due to its location in a tectonically active region, the country experiences a high level of seismic activity, leading to a heightened risk of earthquakes. Over time, this geological setting has resulted in several destructive earthquakes that have had significant impacts on the region's hydrological infrastructure.

Ain Defla, situated in the second seismic zone B, is categorized as being in a moderately hazardous area in terms of seismic risk concerning hydrological structures. This classification implies that while the likelihood of earthquakes is present, it is not as severe as in some other regions within the country. Nonetheless, it's essential to recognize that even moderately hazardous zones can still encounter damaging seismic events, albeit less frequently compared to higher-risk areas.

In hydrological terms, seismic activity in zone B may manifest as occasional moderate earthquakes that can potentially damage dams, reservoirs, pipelines, and other water-related infrastructure if they are not designed or retrofitted to withstand such events. Therefore, engineering standards for hydrological structures in Ain Defla and similar zones often incorporate seismic-resistant designs and construction practices to mitigate the risks posed by earthquakes.

Furthermore, ensuring the resilience of water supply systems, flood management infrastructure, and irrigation networks in seismic zones is vital. This includes implementing robust maintenance protocols, conducting risk assessments, and developing emergency response plans tailored to seismic events. Public awareness campaigns about seismic risks to hydrological systems and the importance of preparedness measures can also contribute significantly to reducing the vulnerability of communities to earthquake-related hydrological disruptions.

In summary, while Ain Defla falls into a moderately hazardous seismic zone concerning hydrological infrastructure, proactive measures in engineering, maintenance, emergency planning, and public education can help minimize the potential impacts of earthquakes on water-related systems and enhance the overall resilience of the region's hydrological networks.

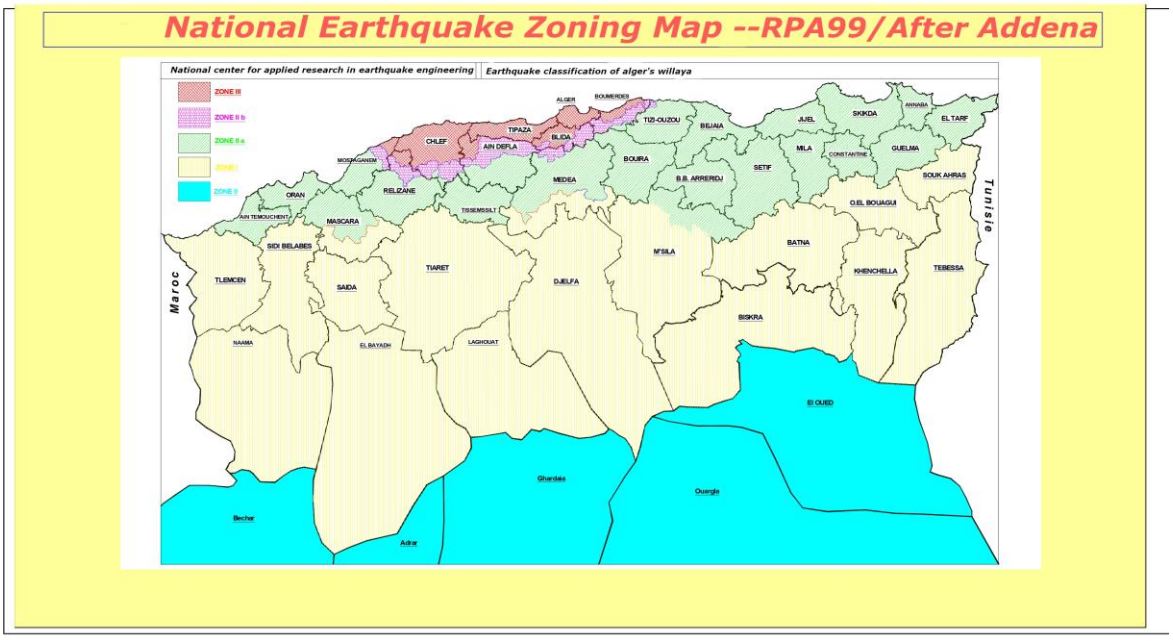


Figure 12 National earthquake zoning map

II.4 Climatological factors:

The warm and temperate climate classified as Csa in the Köppen-Geiger climate classification system indicates that the study area experiences distinct climatic

characteristics typical of a semi-arid climate. This classification implies a combination of features such as relatively mild winters, hot summers, and limited precipitation throughout the year, particularly during the summer months.

In this semi-arid climate, winters are generally mild, with temperatures often remaining above freezing but occasionally dropping to cooler levels. Frost can occur in winter, especially during colder spells, impacting vegetation and agricultural activities. However, overall, winters are not as severe as in colder climate zones.

During the summer season, the study area experiences intense heat, with temperatures frequently rising to high levels. This hot and dry period contributes to increased evaporation rates and can lead to water scarcity, affecting both natural ecosystems and human activities such as agriculture, water supply, and energy production.

Precipitation in a semi-arid climate like Csa is typically limited and variable, with most rainfall occurring during the cooler months. The combination of higher temperatures and lower rainfall during summer often results in arid conditions, necessitating efficient water management practices and adaptations to cope with the climatic challenges.

The semi-arid climate classification influences various aspects of life in the study area, including land use, water resource management, biodiversity, and the resilience of communities to climate-related risks such as droughts and heatwaves. Understanding and responding to the specific characteristics of this climate type are essential for sustainable development and environmental stewardship.

II.5 temperature :

The average annual temperature is 16°C. Winters are cold, with temperatures dropping down to 2°C, often accompanied by frosty mornings and chilly evenings. This colder period is marked by a decrease in overall precipitation, although occasional rainfall and snowfall can occur.

In contrast, summers in the city are characterized by scorching heat, with average temperatures soaring up to 43°C or even higher during heatwaves. The summer season is typically dry, with limited rainfall and long periods of clear skies and intense sunlight. These hot conditions contribute to high rates of evaporation, especially from bodies of water like lakes and reservoirs and valleys, dams

The significant temperature difference between winter and summer creates a distinct seasonal pattern, affecting various aspects of life and activities in Khemis Miliana. It influences agricultural practices, water management strategies, tourism patterns, and the overall lifestyle of the local population.

Table I Temperature of the study area

Month	sep	oct	nov	dec	jan	feb	mar	april	mai	jun	jul	aug	yearly
low	154.80	114.40	46.86	16.14	15.71	22.60	36.00	78.14	100.50	145.29	208.20	192.25	15.71
high	372.80	347.40	279.67	229.40	220.33	245.80	290.17	322.57	354.67	401.00	429.20	401.50	429.20
avr	206.36	225.56	156.93	118.49	119.54	134.84	153.62	191.85	224.11	279.25	309.43	294.15	20

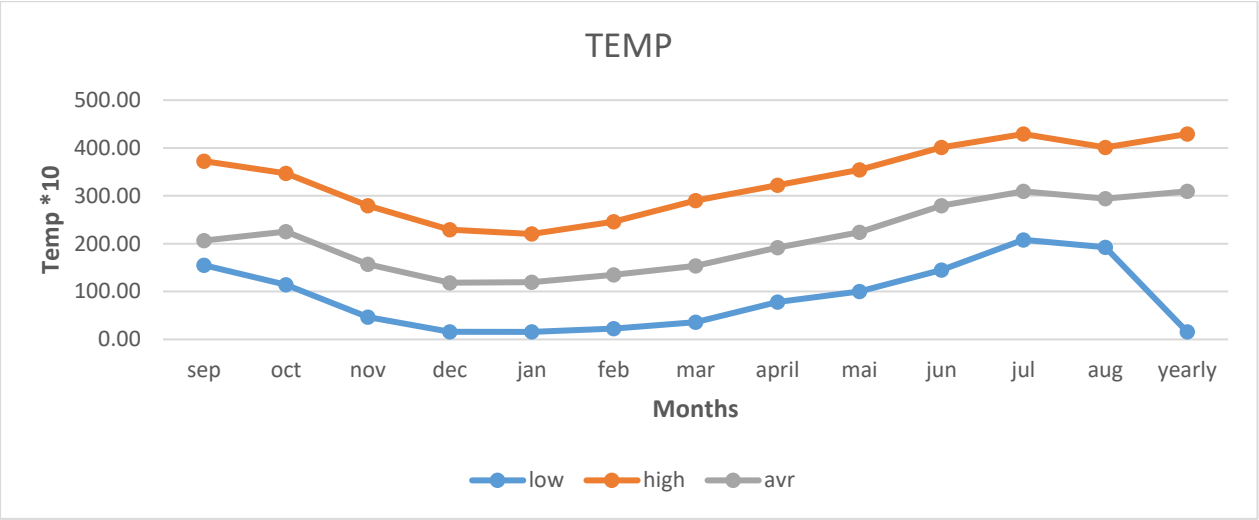


Figure 13 temp grapth of the study area

II.6 Evaporation:

The high evaporation rates observed at the Ghrib and Herraza dams, averaging over 1,400 mm and about 1,300 mm per year, respectively, are particularly relevant to the valleys in the surrounding area. These valleys, characterized by their unique topography and hydrological features, often contain rivers, streams, and reservoirs that are susceptible to significant water loss through evaporation

Valleys are inherently vulnerable to high evaporation rates due to several factors. First, the topographic configuration of valleys can lead to increased solar exposure, as the surrounding mountains or hillsides can channel sunlight directly onto the water surfaces within the valleys. This prolonged exposure to intense sunlight enhances evaporation rates, especially during the warmer months when solar radiation is at its peak.

Secondly, valleys in semi-arid or arid regions often experience elevated temperatures, particularly in low-lying areas where warm air can accumulate. These higher temperatures further accelerate evaporation processes, leading to greater water losses from valley water bodies such as rivers, lakes, and reservoirs.

The impact of high evaporation rates on valleys' hydrological resources is significant. It can result in reduced water levels in rivers and reservoirs, affecting ecosystems, agricultural activities, and water supply for local communities. In valleys where water resources are already limited or subject to seasonal variations, addressing evaporation losses becomes crucial for maintaining water availability and ecological balance.

To address these challenges, strategies tailored to valley ecosystems can be implemented. For instance, introducing vegetative cover along riverbanks and reservoir edges can provide shading, reducing direct sunlight exposure and mitigating evaporation rates. Wetland restoration and enhancement projects within valleys can

also help retain moisture, improve water retention, and support biodiversity conservation.

Furthermore, implementing efficient water management practices, such as optimizing irrigation techniques and promoting water recycling and reuse initiatives, can contribute to reducing overall water demand in valleys. Integrated watershed management approaches that consider the interconnectedness of valleys, rivers, and surrounding landscapes are essential for sustainable water resource management and resilience against evaporation-related challenges in valley ecosystems.

II.7 Rainfall :

In Khemis Miliana, precipitation shows a significant seasonal variation, with higher levels in winter .This trend is typical of regions with a Mediterranean climate, where winter seasons are generally wetter.

During the winter months, which generally run from November to February, Khemis Miliana receives most of its precipitation. Winter weather systems, such as atmospheric lows and cold fronts, bring regular downpours and sometimes intense rain showers. This precipitation makes a significant role in recharging groundwater reserves and regenerating local streams.

By contrast, the summer months, from June to September, are generally drier, with less frequent rainfall, often concentrated in brief but intense thunderstorms. This summer season also sees higher temperatures, leading to more rapid evaporation of water from the ground and water surfaces.

Average annual rainfall in the city typically varies between 150 mm and 415 mm. This variation in rainfall from one year to the next can be influenced by meteorological phenomena such as drought years or abundant monsoons, as well as by larger-scale climatic factors, such as oceanic atmospheric oscillations.

Understanding these seasonal variations in rainfall is essential for water resource management, agricultural planning, flood risk management and the protection of local ecosystems.

Table 2 precipitation data for khemiss milliana

year	sep	oct	nov	dec	jen	feb	mar	apri	may	jun	jul	aug	total
1975	0	2.4	87.3	55.8	49.5	113.7	42.4	33.4	80.7	11	5.4	17.9	499.5
1976	23.2	119.8	33.3	64.4	56.8	14.9	10.6	45.9	49.3	18.3	1	5.5	443
1977	25	18.4	54.5	22	85.2	18	60.4	83.7	56.9	6.7	0	0	430.8
1978	11	87.8	48.4	25.7	60.3	116.1	109.7	24.3	11.9	10.4	1.1	3	509.7
1979	94.9	100.5	49.4	46.2	95.6	21.9	100.7	60.6	22.6	0	0.1	7.5	600
1980	7.1	19.7	47.5	171.9	20.3	45.7	50.4	77.1	25.8	4.2	2.2	8.8	480.7
1981	6.9	11	0	73.1	82.5	84.4	34.5	16.9	20.7	8.8	0	3.8	342.6
1982	8.6	80	141	65.1	1.2	49.6	21.4	11.8	7.6	0	6.7	0.6	393.6
1983	0	7	62.5	38.4	50.3	53.3	42.6	23.1	68.5	23.5	0	0.3	369.5
1984	17.3	77.9	47.5	66.7	45	69	66.9	9.1	69.9	1	0	0	470.3
1985	36.3	5.4	51.7	33.4	115.8	122.1	69.1	14.2	2.5	12.4	4.7	3	470.6
1986	21.8	52.3	47.1	110.5	88.8	126.8	20.5	0.2	6.6	2.9	41.3	1.2	520
1987	5.4	12.6	61.4	34.5	28.4	10.5	43.9	35.3	52.5	27	0	0	311.5
1988	6	28.1	19.3	96.1	15.9	45.1	82.3	56.8	3.3	50.2	3.6	22.4	429.1
1989	12.9	3.1	21.8	18.5	51.7	0	47.4	70.8	30.1	7.3	19.6	3.4	286.6
1990	39.1	19.1	41.3	70	49.5	74.7	60.3	22.1	10.1	19.9	0.4	16.4	422.9
1991	5.2	44.1	45.4	6.5	161.3	12.9	75.7	45.5	54.1	22.2	3.1	1.6	477.6
1992	2	28.8	37.6	32.1	3	70.3	24.6	66.4	20	0	0	3.4	288.2
1993	30	5.5	21.8	27.3	29.4	49.7	3.7	17.2	7.5	0	0	0	192.1
1994	78.1	26.2	48.8	38.8	123.7	27.5	69.1	13.8	1.2	8.1	0	8.2	443.5
1995	30.3	28.8	56	38.1	63.6	155.2	75.1	78.6	29.6	23.1	11.2	0.9	590.5
1996	20.3	34.4	7.8	57.9	57.2	11.5	1.7	76.8	32.1	1.2	2	10	312.9
1997	41.7	37.7	110	39.7	18.4	31.1	18.2	32.9	100.8	2.8	0	0.1	433.4
1998	19.6	31	33	22.7	73	117.9	72	3.9	7.5	14.2	0	20.4	415.2
1999	21.1	13.5	42.7	123.5	8.6	0	7.5	22.7	3.8	0.2	0	0.5	244.1
2000	23.5	47	100.6	46.2	107.4	16.1	1.2	58.5	15	0.4	0	2	417.9
2001	34	39.1	77.1	29.1	23.3	17.5	23.8	24.2	32.9	0.5	0.5	15	317
2002	10.9	20.9	51.4	47.4	111.4	78.6	8.3	40	12.5	0	0.1	0.3	381.8
2003	21	28.1	72.5	78.2	36	33.6	39.4	25.3	35	6.3	0	2.8	378.2
2004	11.1	20.6	55.8	102.3	70	86.2	23.5	11.7	0.5	0	0.2	0	381.9
2005	10.2	61	52.9	74	55.2	76.3	25.2	6.5	50.3	6.8	0	3	421.4
2006	21.5	1.4	12.2	71	16.5	47.6	123.6	70.7	4.6	0.4	7.5	2	379
2007	60.2	73.3	105.6	31.4	24.9	13.7	64.9	5.1	36.7	25.3	1.9	0.1	443.1
2008	23.6	113.2	77.2	105	89.4	31.8	73.5	74.9	19.1	0.4	3.1	1.7	612.9
2009	24.3	3.8	67.3	83.4	95.6	91.5	48.2	19.8	21.2	0.7	0	40.2	496
2010	1.5	88.3	86	37.9	64.9	72.6	31	59.5	56.7	14.4	3.2	0.8	516.8
2011	0.2	34.7	107.6	35.5	30.9	127.5	76.7	87.3	20.2	2.1	0	0	522.7
2012	1.4	33.4	69.5	7.1	85.4	69.8	60.2	51.8	44.2	0.1	2	22.3	447.2
2013	22.8	4.1	68.7	55.1	61.4	40.8	80.6	8.4	8.2	21	0	0.2	371.3
2014	13.8	15.8	47.7	100.1	67.1	106.9	39.5	0	4.1	12.7	0.5	10.9	419.1
2015	18	30.7	16.3	0	32.3	57.1	150	35.4	22.1	1.1	7	0	370
2016	3.8	8.4	53.2	81.6	235	10.6		0.9	4.3	46.1	0	0.3	444.2
2017	9.1	37.8	48.9	83.7	33.8	69.4	132.2	85.2	25.8	43.8	0	14.2	583.9
2018	62.6	47.9	68.4	73.4	101.7	17.4	26.2	41.4	29.9	0.8	7.4	0.3	477.4
2019	57.6	6.6	77.9	21.3		0	44.8	94.9	8	3.2	0	0	314.3
2020	9.2	8.5	10.6	68.7	0	0	0	0	0	0	0	0	97

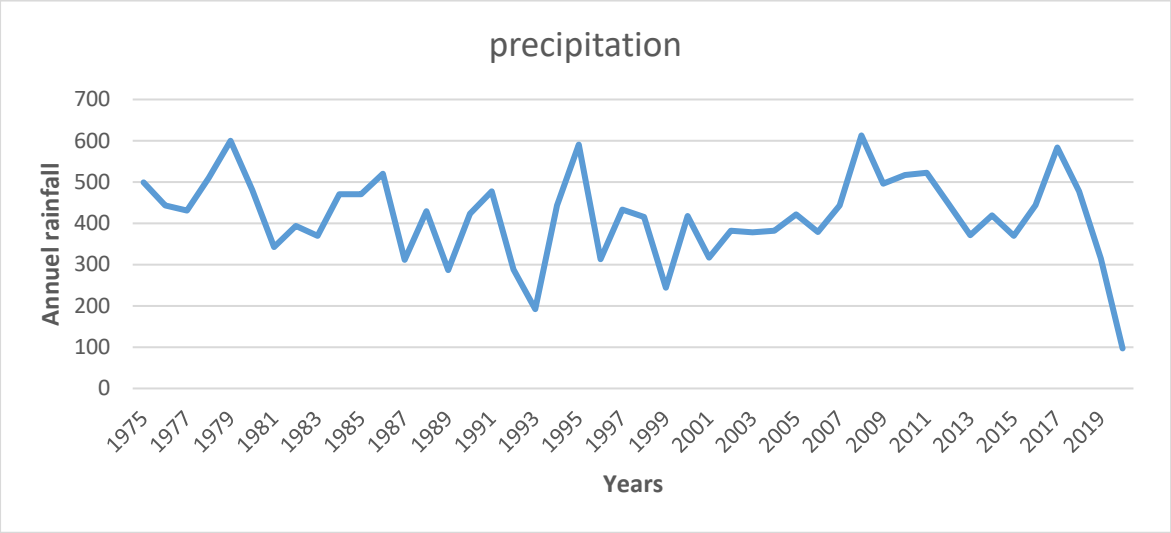


Figure 14 precipitaion linegraphe for khemiss millana

II.8 WIND :

The average wind speed in Khemis Miliana is approximately 3.2 kilometers per hour (km/h). This moderate wind speed is characteristic of the region, providing a gentle breeze that contributes to the overall climate comfort. It's important to note that this average represents typical conditions, and actual wind speeds can vary throughout the day and across different seasons.

During calm weather conditions, the wind speed may be even lower than the average, creating tranquil and still atmospheres. Conversely, during periods of atmospheric instability or weather disturbances, the wind speed can temporarily increase, bringing gustier conditions to the area.

Table 3 average wind speed in khemiss milliana

MONTHS	sept	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug
avg wind (km)	2.8	2.6	3.1	3.2	3.9	3.9	3.3	3.2	3.7	2.7	2.8	2.9

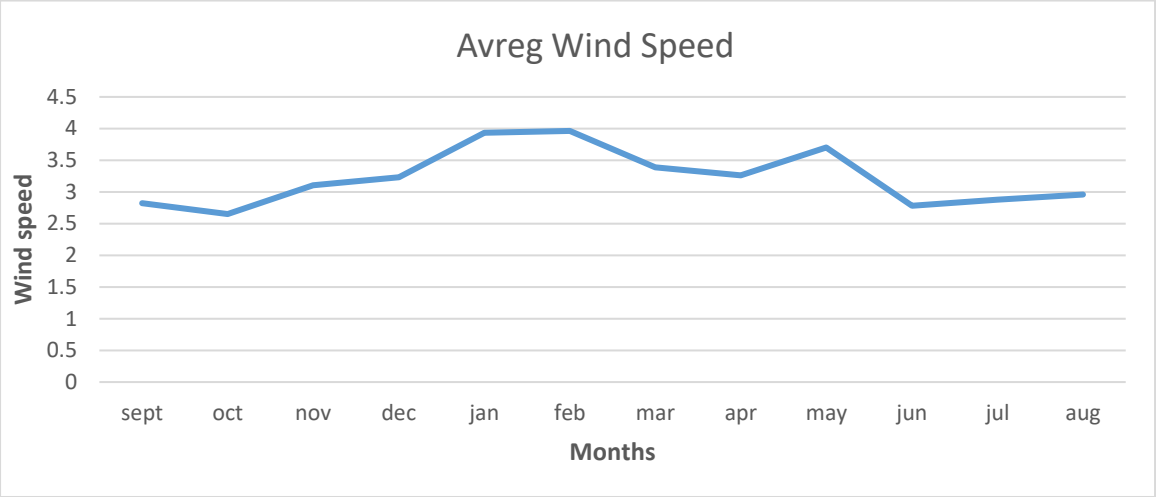


Figure 15 wind speed linegraph in khemiss milliana

III Geological and geotechnical structure:

The city geological and geotechnical structure is influenced by its location within the Tell Atlas mountain range and the underlying geological formations prevalent in the region. Here are some key aspects of city geological and geotechnical structure:

Geological Formation: city is situated within the Tell Atlas, a mountain range that runs parallel to the Mediterranean coast of Algeria. The geological formations in this region primarily consist of sedimentary rocks, including limestone, marl, sandstone, and shale. These formations has been shaped over millions of years through tectonic activity, erosion, and sedimentation processes.

Structural Features: The Tell Atlas exhibits various structural features such as folds, faults, and thrusts, resulting from the complex tectonic history of the region. These structural elements influence the distribution of rock layers, the orientation of geological formations, and the overall stability of the terrain.

Geological Hazards: The geological structure of the city may pose certain hazards, including the potential for landslides, rockfalls, and slope instability. Areas with steep slopes, weathered rock layers, or weak geological formations are particularly susceptible to these hazards, especially during periods of heavy rainfall or seismic activity.

Geotechnical Considerations: Geotechnical studies in the city focus on assessing the mechanical properties of the underlying rocks and soils. Engineers and geologists analyze parameters such as soil composition, shear strength, permeability, and compaction characteristics to evaluate the suitability of the ground for construction, infrastructure development, and land use planning.

Valleys and Rivers: the city geological and geotechnical structure also influences the formation and characteristics of valleys and rivers in the region. The underlying geological formations, such as limestone, sandstone, and shale, contribute to the topographic diversity and hydrological dynamics of the area.

Valleys: The Tell Atlas mountain range, where city is located, features numerous valleys with varying orientations and gradients. The geological structure, including fault lines and rock types, shapes the morphology of these valleys, influencing factors such as drainage patterns, sediment transport, and erosion susceptibility. Understanding the geological context of valleys is crucial for land use planning, water resource management, and mitigating natural hazards such as flash floods and landslides.

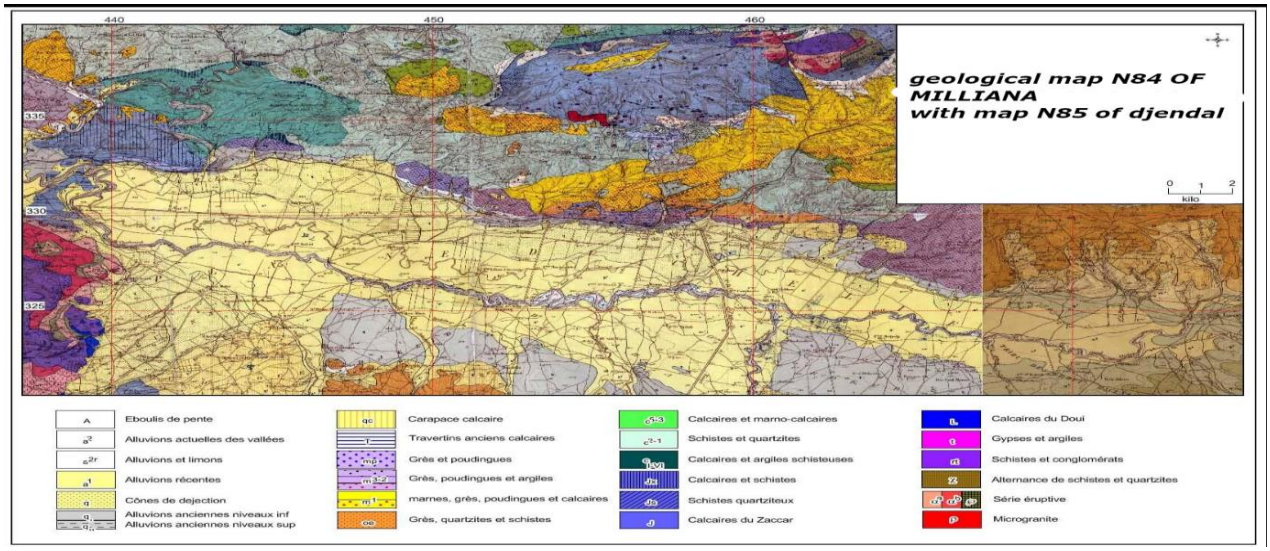


Figure 16 geological map of milliana N84

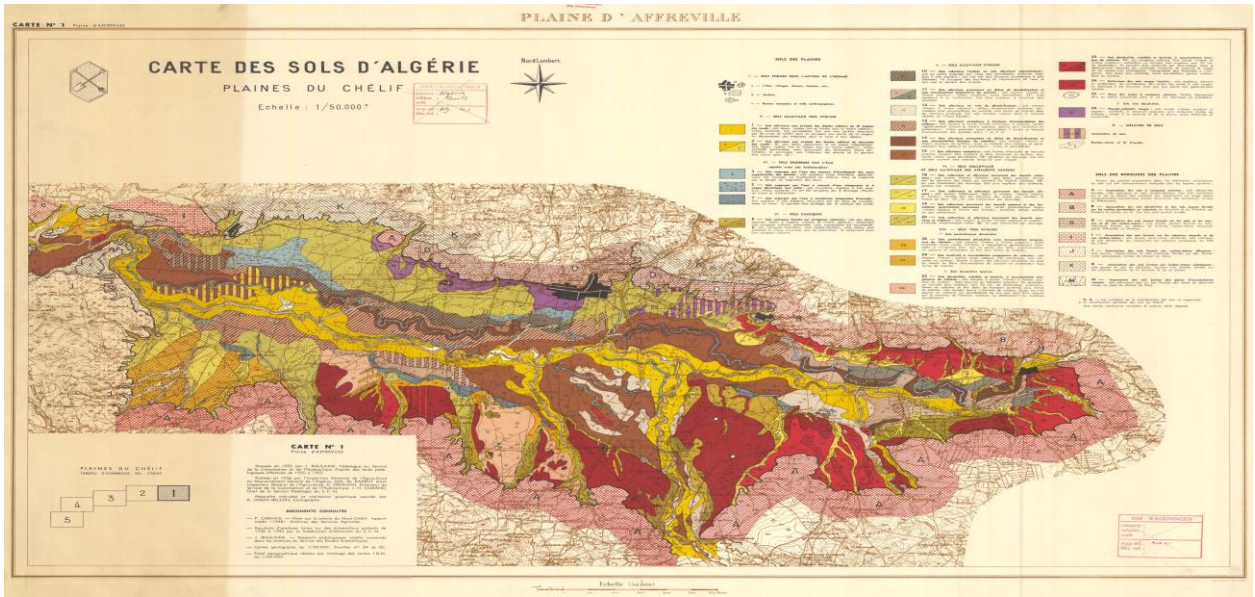


Figure 17 geological map of haut chelif basin

III.1 Topography:

Based on the topographical map and the provided information, the city situated in a rugged and mountainous region characterized by an open basin. Here are some key points based on the relief description:

Rugged and Mountainous Terrain: The relief in the area characterized by rugged terrain, indicating steep slopes, valleys, and possibly rocky outcrops. This terrain type can influence water drainage patterns, erosion processes, and the overall landscape aesthetics.

Open Basin Formation: The open basin refers to a topographic feature where the landforms create a relatively flat or gently sloping area surrounded by higher elevations. In this context, the basin may collect water runoff from the surrounding mountains, contributing to local hydrology and potentially forming streams or small rivers.

Height Range: The heights in the area range from 250 meters to 1560 meters above sea level. This elevation gradient indicates significant topographic variation, with lower-lying areas in the basin and higher peaks or ridges surrounding it.

Altitude of the city: it is located to the south of this watershed, at an altitude of 260 meters. Being located at a relatively low altitude within the basin, the city may experience different climatic conditions compared to higher elevations, such as temperature variations and precipitation patterns.

Hydrological Significance: The rugged and mountainous relief, along with the open basin formation, has hydrological implications. It can affect water flow, groundwater recharge, and the potential for water storage in natural reservoirs such as lakes or wetlands. Understanding these hydrological dynamics is important for water resource management and environmental conservation.



Figure 18 city topografy

Conclusion:

This chapter has given us a general overview of our study area, and presented and visualized the data required for our study.

Chapter Two: overview of the study area

Chapter Three
Hydrological study

I Introduction

Hydrological analysis is a fundamental step in the study of water resources and hydrological phenomena. It examines in detail the parameters and processes of the water cycle, providing an essential basis for the sustainable management of water resources, the design of hydraulic infrastructures and the prevention of water-related natural hazards.

The objective of the hydrological study is as follows:

- Identify the hydro morphometric characteristics of the watershed.
- Determine the characteristics of the hydrographic network.
- Examine precipitation models and flow patterns.
- Calculate flood properties for different return periods.
- Select the return period and flood discharge for the project in question.

I.1 Basin and Watershed:

I.1.1 Definition:

A watershed is the entire geographical area from which precipitation flows to a river and its tributaries upstream of a specific section. It is the area delimited by the contours where the water flows towards a specific point in the river or stream, also known as the drainage basin.

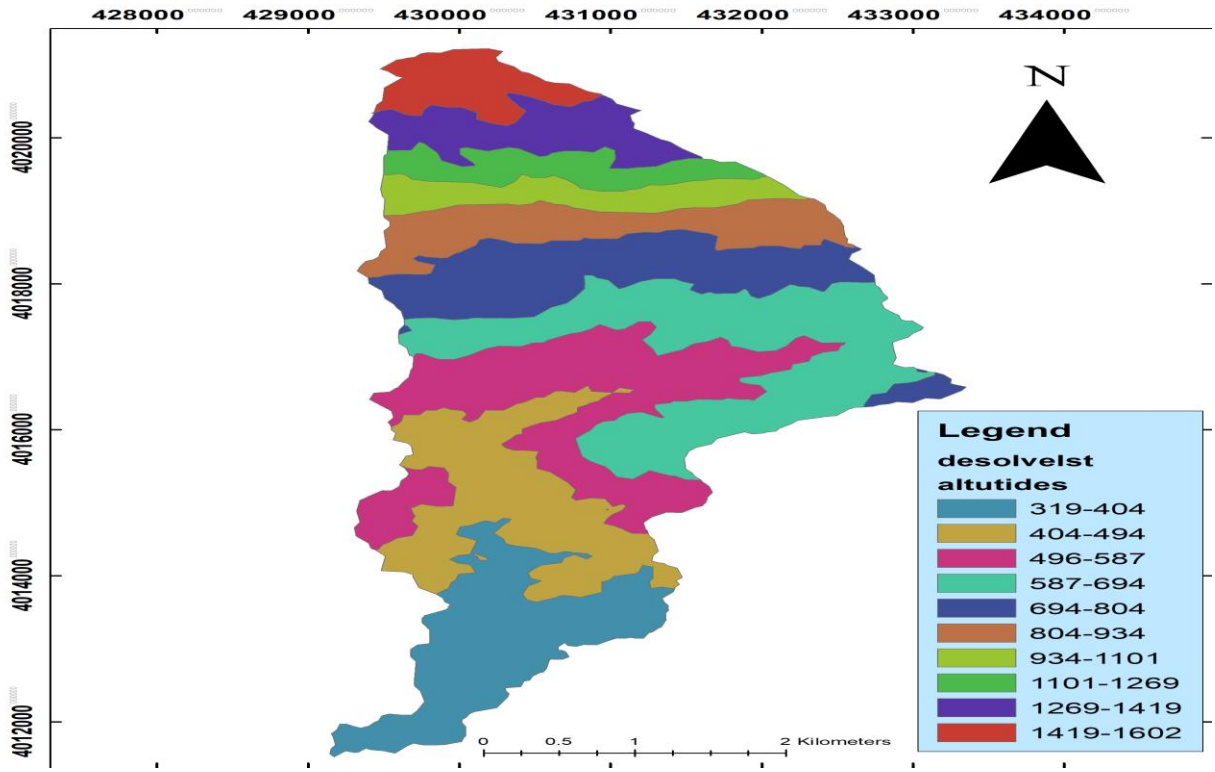


Figure 19 watershed arc gis

I.2 Hydro metric characteristics of the watershed:

I.2.1 Surface area:

The watershed's surface area is the most crucial parameter among its characteristics. This value is determined using the ARCGIS software, based on the staff map.

Generally expressed in km², the surface area "S" of the watershed is a fundamental measure for its evaluation.

S= 20,18 Km²

I.2.2 Perimeter:

The watershed's outer border, known as the perimeter, is defined by the ridgeline that separates water flows between different basins. This natural boundary is determined using ARCGIS software, a geographic information system tool. The watershed perimeter is expressed in kilometers (km), providing an accurate measure of the total length of the watershed divide.

P= 27,6 Km

I.2.3 Gravelius compacity index "Kg»:

The "Kg" compacity index defines the general flow pattern in relation to the shape of the

form of the watershed. It is determined using the following formula:

$$K_C = \frac{\mathbf{P}}{2\sqrt{\pi . \mathbf{S}}} \approx 0,28 \, . \frac{P}{\sqrt{S}}$$

With:

P: Watershed perimeter in (km)

S: Watershed area in (Km²)

If Kg = 1 => watershed

If Kg> 1 => pelvis lengthened;

We find**: Kg=1.73**, which implies that our pelvis is elongated.

I.2.4 Equivalent rectangle:

It is assumed that the flow over a given catchment area is similar to that of a rectangle with the same surface area, Gravelius index, hypsometric distribution and distribution of soils, vegetation and drainage density.

The equivalent rectangle is characterized by the length "L" and width "l" defined

respectively by:

$$L=\frac{K_C \, . \sqrt{S}}{1,128}\left(1+\sqrt{1-(\frac{1,128}{Kc})^2}\right)$$

$$l=\frac{K_C \, . \sqrt{S}}{1,128}\left(1-\sqrt{1-(\frac{1,128}{Kc})^2}\right)$$

Where: (L) represents the length of the equivalent rectangle and (l) its width.

Basin	S (km²) (Surface area)	P (km) (Perimeter)	Kg	Le (Km)	le (Km)
watershad	20,18	27,6	1,73	12,11	1,66

I.3 Distribution and hypsometric curve:

This is a curve representing the percentage of watershed area above a certain elevation. Elevation is shown on the y-axis (in meters), while cumulative area is displayed on the x-axis (in percent). The creation of this curve is essential for studying the relief of a watershed.

Table 4 hypsometric graph table

Sub-areas PRC	Sub-areas	Cumulative areas	FROM	TO
12.8%	2.59	100.0	319	404
13.2%	2.66	87.2	404	496
16.6%	3.35	74.0	496	587
18.3%	3.70	57.4	587	694
12.2%	2.45	39.1	694	804
8.0%	1.62	26.9	804	934
4.6%	0.94	18.9	934	1101
4.4%	0.88	14.3	1101	1269
5.7%	1.16	9.9	1269	1419
4.2%	0.84	4.2	1419	1602

I.3.1 Hypsometric curve by Excel :

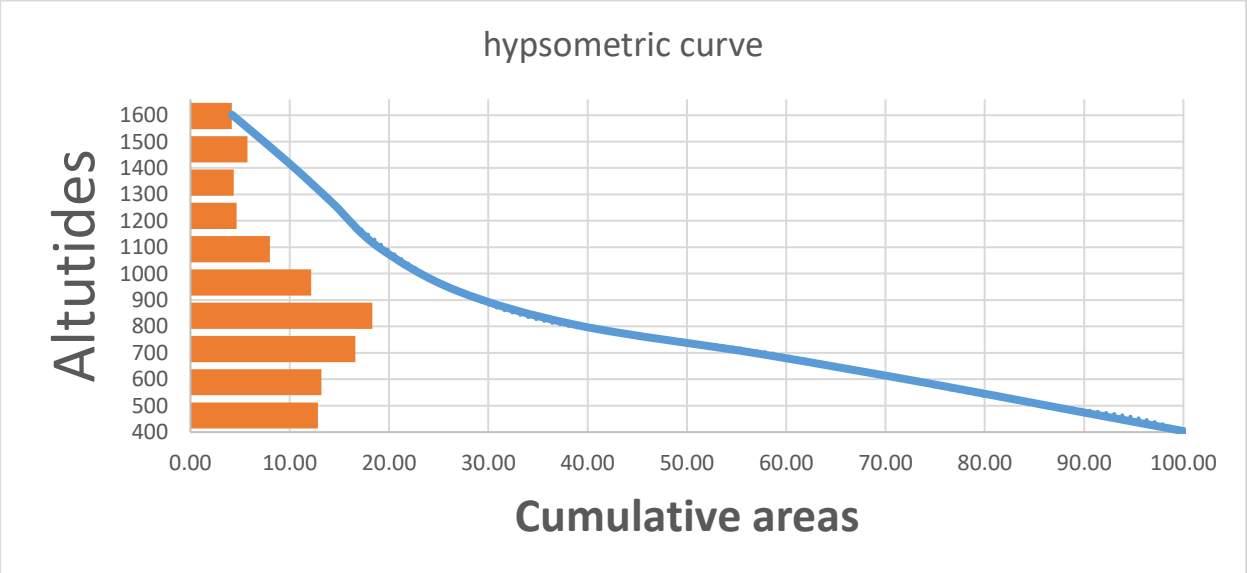


Figure 20 hypsometric curve by Excel

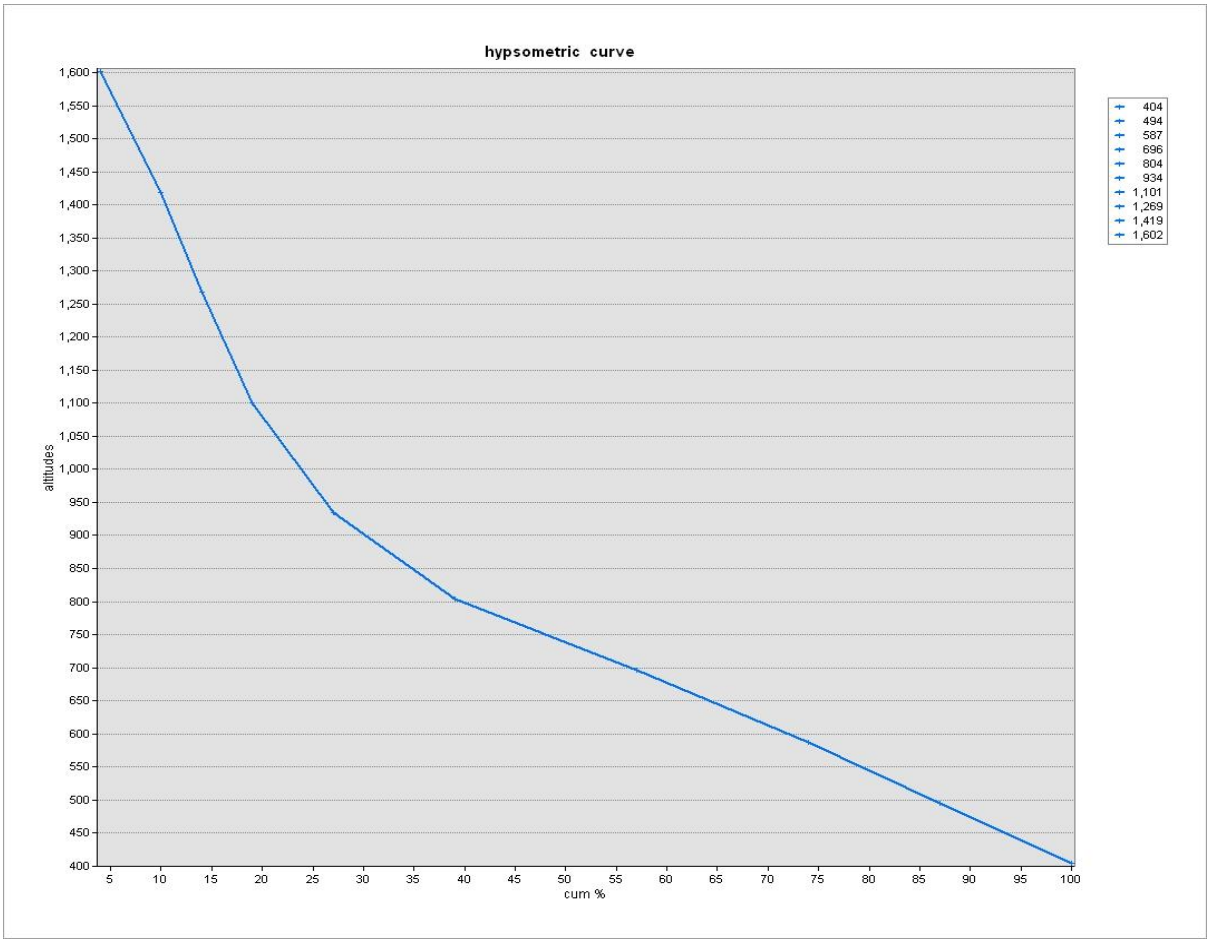


Figure 21 hypsometric curve from arc gis

I.4 Characteristic altitudes:

They are obtained directly from topographic maps. The maximum altitude represents the highest point in the basin, while the minimum altitude represents the lowest point.

H_{max} **=1602 m NGA** H_{min} **=319 m NGA**

-The median altitude or H 50٪ is determined on the hypsometric curve.

H_{med} **=736m NGA**

-The average altitude H_{Avg} is calculated using the following formula:

$$Havg = \frac{\sum_{i=0}^{n} S_i . H_i}{S}$$

$$H_i = \frac{H_{n-1} + H_n}{2}$$

With:

H_i: Average altitude between 2 consecutive contour lines (n-1) and (n), expressed in (m).

S_i: Partial area between 2 consecutive contour lines (n-1) and (n), expressed in

In (Km^2).

S: Total watershed area in (Km^2).

Table 5 Average altitudes multiplied by partial areas

FROM	TO	deltH	Sub-areas	Hi*Si(Km2.m)
319	404	85	2.59	219.9
404	496	92	2.66	244.6
496	587	91	3.35	304.9
587	694	107	3.70	395.5
694	804	110	2.45	269.8
804	934	130	1.62	210.1
934	1101	167	0.94	156.6
1101	1269	168	0.88	147.5
1269	1419	150	1.16	173.6
1419	1602	183	0.84	154.3

$$H_{avg} = \frac{2276.9}{20.18} = 113$$

Table 6 elevation results

H_{max}	H_{min}	H_{med}	H_{avg}
1602	**319**	**736**	**113**

I.5 Global slope index (I_g):

This index is defined as the ratio between the altitude corresponding to 5% and 95% of the watershed surface and the length of an equivalent rectangle. To calculate this index, two points, S1 and S2, are selected on the abscissa axis so that 90% of the watershed surface lies between these two values, while 5% of the total surface is below S1 and 5% is above S2.

The corresponding altitudes are read from the hypsometric curve. This index is calculated using the following formula:

$$Ig = \frac{D}{L} = \frac{H_{5\%} - H_{95\%}}{L}$$

With:

$H_{5\%}$ and $H_{95\%}$ are the altitudes corresponding to $S_{5\%}$ and $S_{95\%}$ respectively:

$H5_{\%}$ =……1550…… m

$H_{95\%}$ = …430…….. m

Le=12,11km (length of equivalent rectangle).

$$\boldsymbol{Ig = \frac{430 - 1550}{1211} * 100\%} = 9{,}3\% = 0{,}093 m/m$$

Table 7 Relief classification (O.R.S.T.O.M).

R1	Very low relief	Ig ≤ 0,002
R2	Low relief	0,002 ≤ Ig ≤ 0,005
R3	Quite low relief	0,005≤ Ig ≤ 0,01
R4	Moderate relief	0,01 ≤ Ig ≤ 0,02
R5	Fairly strong relief	0,02 ≤ Ig ≤ 0,05
R6	Strong relief	0,05≤ Ig ≤ 0,1
R7	Very strong relief	0.1 ≤ Ig

In our case: Ig=0.093, so according to the table, our landform is classified as type R6, which means it's a strong relief.

I.6 Average basin slope (I_m):

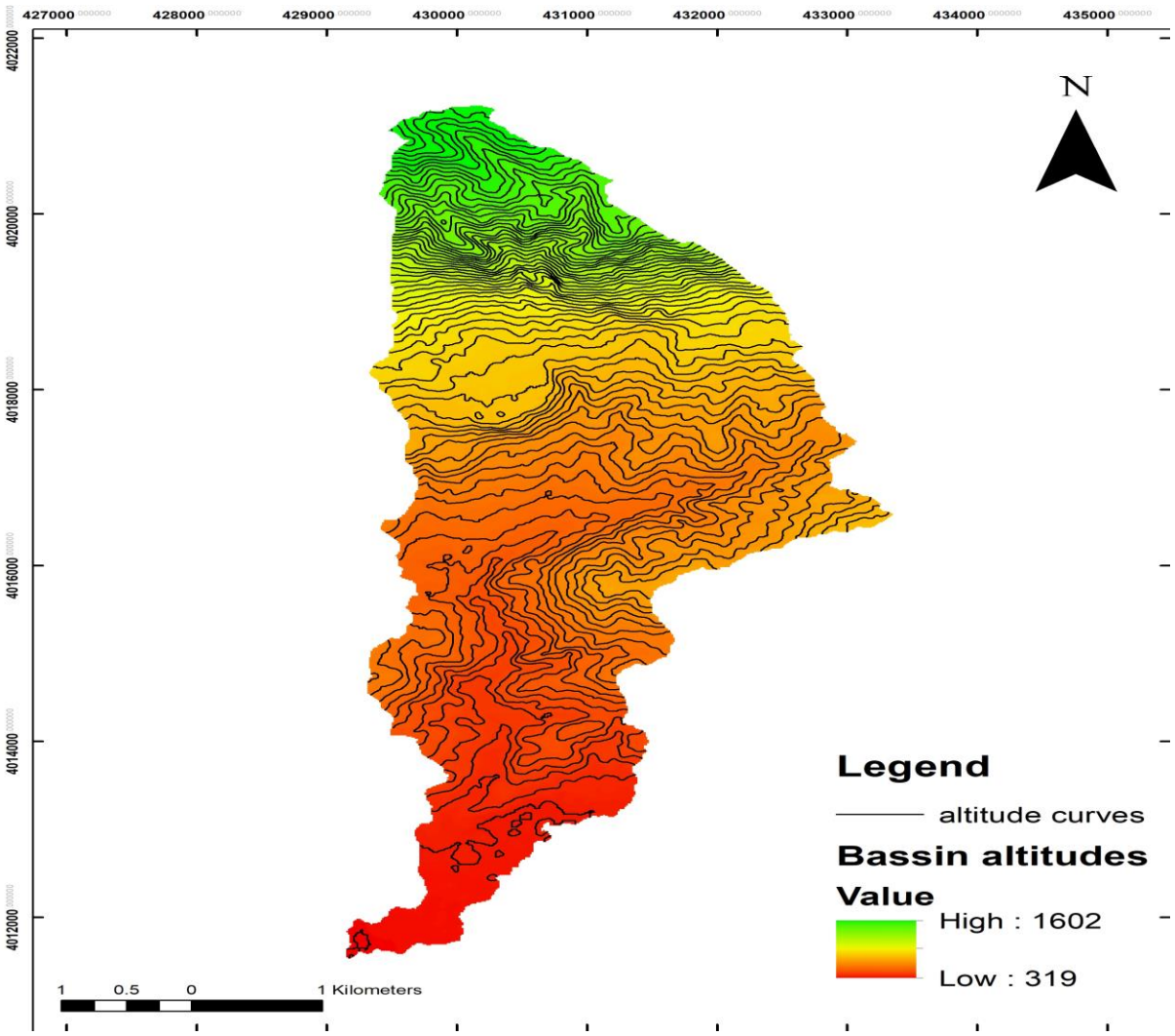


Figure 22 Contour line

Average slope is a key element in understanding the topography of a basin. As an independent variable, it provides a valuable indication of the travel time of direct runoff, and therefore of the time of concentration Tc, and has a direct influence on peak flow in the event of precipitation. It is calculated as follows:

$$I_m = \frac{\Delta H(0,5l_1 + l_2 + l_3 + \cdots + 0,5l_n)}{S}$$

where

***ΔH**: height difference in (m)*

***Li**: length of the curve of order 1,2, ...n (m)*

***S**: watershed area (Km²)*

Table 8 average slope calculation.

Altitude	Length	Altitude	Length	Altitude	Length
320	0.91	860	3.31	1400	2.53
340	5.82	880	3.31	1420	2.44
360	2.92	900	3.14	1440	2.48
380	3.13	920	2.98	1460	2.31
400	5.65	940	2.95	1480	2.01
420	6.82	960	2.91	1500	1.89
440	6.14	980	2.93	1520	1.87
460	6.44	1000	2.98	1540	1.57
480	7.63	1020	3.03	1560	0.57
500	7.56	1040	2.85	1580	0.36
520	8.49	1060	2.79	1600	0.01
540	8.19	1080	2.78		
560	7.40	1100	2.85		
580	8.05	1120	2.85		
600	9.69	1140	2.86		
620	10.18	1160	2.92		
640	9.49	1180	3.14		
660	7.54	1200	3.21		
680	5.41	1220	3.38		
700	4.83	1240	3.40		
720	4.76	1260	3.22		
740	4.54	1280	3.12		
760	4.78	1300	0.13		
780	4.28	1320	3.21		
800	4.30	1340	3.26		
820	4.06	1360	3.47		
840	3.52	1380	3.15		

I.7 Flow network characteristics:

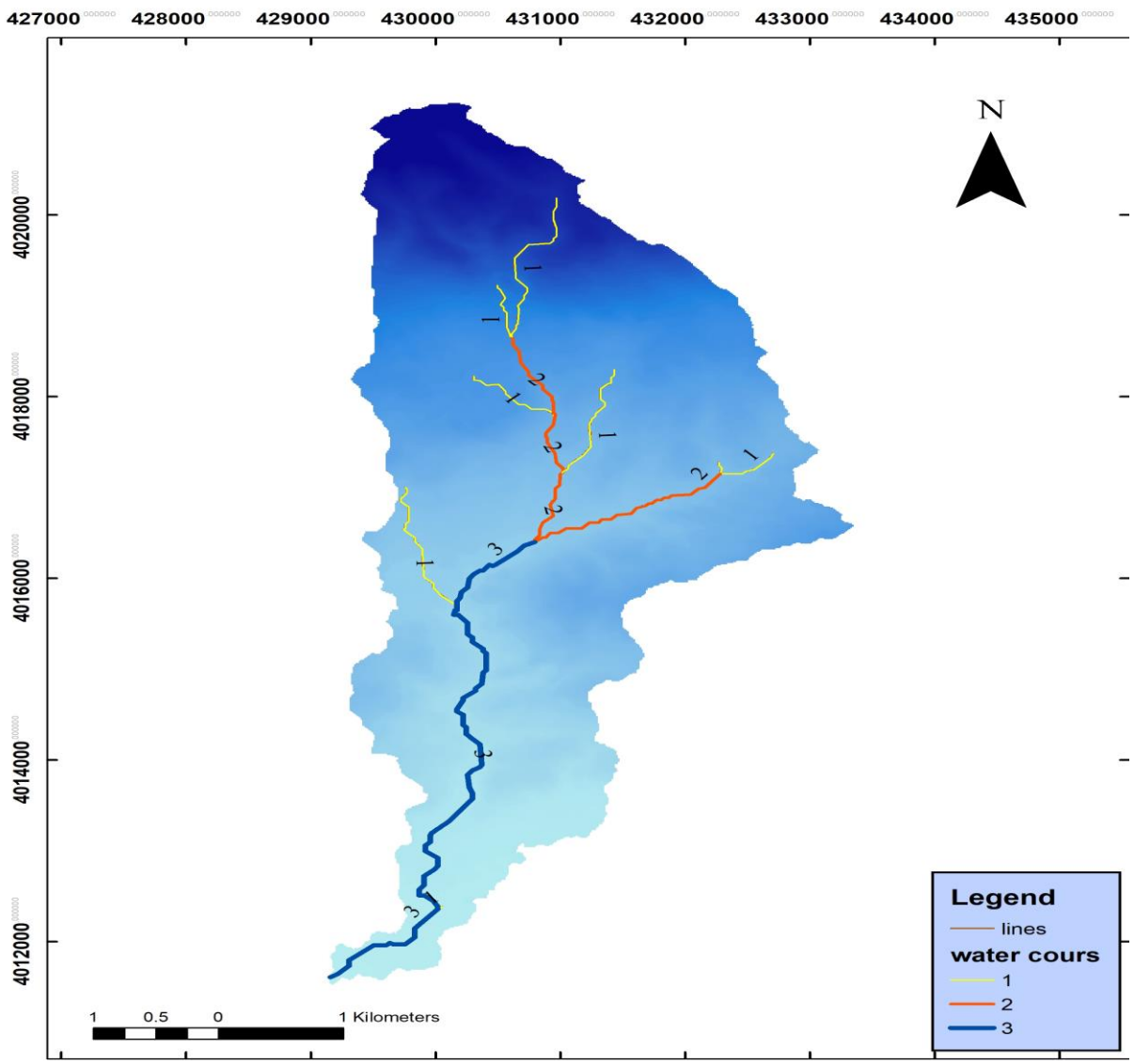


Figure 23 Hydrographic map and watershed classification

I.7.1 Draining density (D_d):

Drainage density is defined as the ratio between the total length of all watercourses or talwegs, noted "Li", in a watershed and the total surface area of this watershed, noted "S". This coefficient helps to understand the dynamics of the basin, the stability of its hydrographic network and the dominant type of surface runoff.

It is expressed in (Km/ Km²), using the following formula:

$$D_d = \frac{\sum L_i}{S}$$

With:

D_d: drainage density [km/km²]

Li: length of watercourse [km]

S: watershed area [km²].

$$Dd = \frac{17.74}{20.18} = 0.88$$

I.7.2 Average main stream slope (I_c):

The average slope of the watercourse is essential in determining the speed at which water reaches the basin outlet, which influences the calculation of the time of concentration. It also affects the maximum flow rate observed. A steep slope favors rapid surface runoff, while a shallow or absent slope allows partial or total infiltration of water into the soil.

Calculation of the average and partial gradient of a watercourse is based on the longitudinal profile of the main watercourse and its tributaries. The usual method for determining longitudinal gradient is to divide the difference in altitude between the highest and lowest points of the profile by the total length of the watercourse.

$$Ic = \frac{\Delta H}{\Delta L} = \frac{483 - 319}{6410} = 0{,}025 = 2{,}5\%$$

I.7.3 Concentration time:

The time of concentration (Tc) corresponds to the time required for a water particle at maximum hydraulic distance to reach the basin outlet. This time has a direct impact on flood flows. Theoretically, the time of concentration is defined as the period between the end of net precipitation and the end of surface runoff. In practice, it can be determined by field measurements or estimated using generally empirical formulas.

a GIANDOTTI's formula:

$$Tc = \frac{4\sqrt{S} + 1{,}5 * L}{0{,}8 * \sqrt{H_{avg} - H_{min}}}$$

With:

S: Watershed area in [Km²];

L: length of the main talweg in [Km];

H_{avg}, H_{min}: respectively the average and minimum height of the watershed in [m];

b KIRPICH formula:

$$Tc = 0{,}1147 \frac{L^{0{,}77}}{{L_{avg}}^{0{,}385}}$$

With:

L: length of main talweg in [m],

I_{moy}: average slope of main watercourse (m/m),

c **PASSINI's formula:**

$$Tc = 0,108 * \frac{(S * L)^{1/3}}{\sqrt{l_{avg}}}$$

With:

S: Watershed area in [Km²];

:L length of main talweg in [m],

I_{avg}: average slope of main watercourse (m/m),

Tableau I Results of calculation formulas.

Formula	Tc(h)
GIANDOTTI	**1.68**
KIRPICH	**0.81**
PASSINI	**1.02**

d **Interpretation:**

The timing is 0.81 h

I.7.4 Average runoff speed:

This speed is given by the formula :

$$Vr = \frac{L}{Tc}$$

With:

L: Length of main talweg in [Km];

Tc: time of concentration in [hour].

$$Vr = \textbf{5,21km/h}$$

I.8 The basin caractrestics :

The botan valley watershed caratrectics were gathered in the table below :

Table 9 recapitulation of botan valley watershed characteristics

Characteristics	Value	
area	km²	20.18
perimeter	km	27.6
length of the equivalent rectangle	km	12.11
width of the equivalent rectangle	km	1.66
graveLuis capacity index Kc		1.73
Maximum altitude	m	1602
Minimum altitude	m	319
average altitude	M	113
median altitude	M	736
global slope index		9.3
average basin slope	%	2.6w
average main stream slope	%	2.5
main stream length	km	6.41
concentration time	h	1.23
average runoff speed	km/h	5.21

II Hydrological study:

II.1 Introduction:

In Algeria, flooding is mainly caused by episodes of heavy precipitation. To assess the risks associated with these events, it is essential to analyze maximum daily rainfall. This analysis aims to understand the frequency and intensity of exceptional rainfall events across different return periods. By studying historical data, we can better anticipate floods, optimize risk management strategies and strengthen the resilience of communities to extreme climatic conditions. This approach will later enable us to calculate rainfall over short periods.

II.2 Choice of rainfall station:

We opted for data from the Khemis miliana rainfall station (01-17-15), provided by ANRH, because of its proximity to the study area and the continuity of the data available over a long period.

II.2.1 Khemiss milliana rainfall station

Table 10 khemiss milliana station coordinat

Rainfall station of khemis miliana	Code	X(km)	Y(km)	Z(m)	Observation period	Number of years
	11717	443,95	318,05	320	1975-2020	48

Table 11 missing rain fall data complement table

NASA Power Data	Latitude	Longitude	Hight	Year of observaion	Series numbers
	36.27	2.22		2018-2024	6

Table 12 Daily maximum rainfall

Value	Year	Value	Year
32.5	1997	47.5	1972
64.8	1998	60.3	1973
30.65	1999	33	1974
24.22	2000	42.2	1975
24.3	2001	36.4	1976
33.2	2002	24.7	1977
59.6	2003	63.6	1978
42.3	2004	20.6	1979
40.5	2005	44.1	1980
25	2006	31.1	1981
43	2007	41.7	1982
26.6	2008	20.3	1983
22.6	2009	49.3	1984
24.6	2010	57.3	1985
37.1	2011	22.1	1986
34.7	2012	27.8	1987
42.3	2013	31.7	1988
27.7	2014	34.3	1989
44.9	2015	37.3	1990
26.2	2016	30.7	1991
73.7	2017	56.7	1992
82.81	2018	50.1	1993
23.67	2019	31.8	1994
24.16	2020	33.2	1995
78.89	2021		1996
33.12	2022		
31.43	2023		
30.79	2024		

II.2.2 The ababbsa hydrometric station characteristics :

Table 13 hydrometric station coordonate

Station hdrometric of ababbsa	Code	X(km)	Y(km)	Z(m)	Période d'observation	Nombre d'années
	011715	443,95	318,05	320	1972-2020	48

Table 14 hydrometric satation characteristics

Value	Year	Value	Year
38.5	1972	30	1993
44	1973	26.5	1994
22.2	1974	16.1	1995
31.8	1975	24.2	1996
33.5	1976	41.2	1997
39	1977	25.4	1998
34.7	1978	35.1	1999
48.6	1979	24.7	2000
37.5	1980	28.4	2001
46.1	1981	23.2	2002
45.5	1982	42.4	2003
63.7	1983	28.4	2004
29.6	1984	34.7	2005
49.3	1985	25.4	2006
28.9	1986	41	2007
31.2	1987	46	2008
34.1	1988	25.2	2009
30.2	1989	44.6	2010
42.1	1990	27.5	2011
27.1	1991	56.5	2012
21	1992		

II.3 Uniformity testing:

II.3.1 Rainfall station

The homogeneity test is performed by entering the two series into HYFRAN and applying the Willcoxon homogeneity test.

Willcoxon homogeneity test, which gives us the following result:

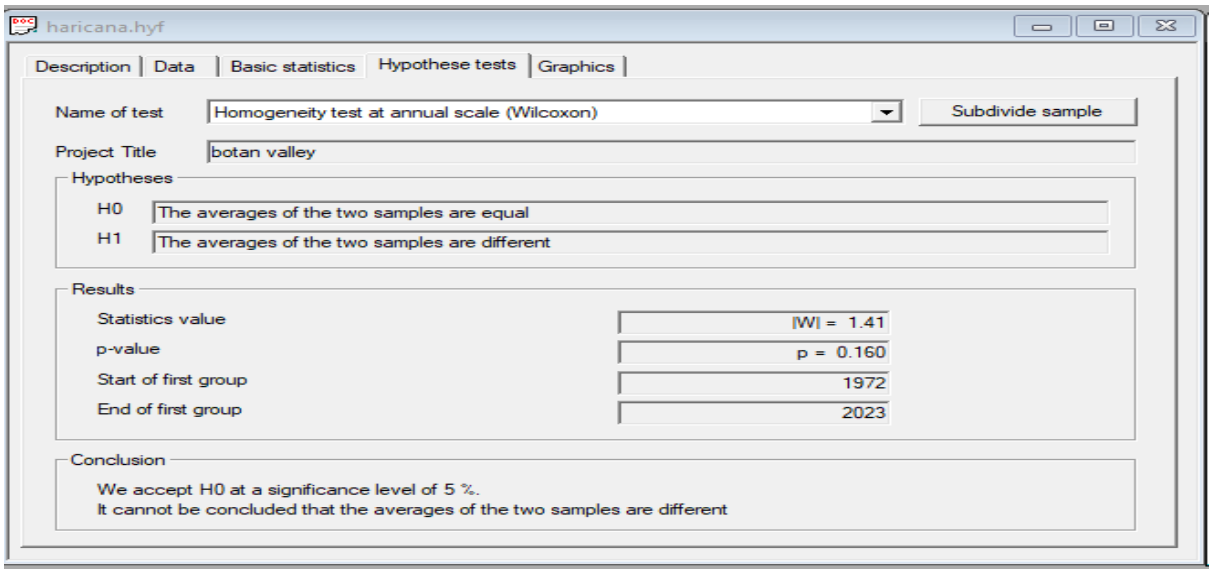
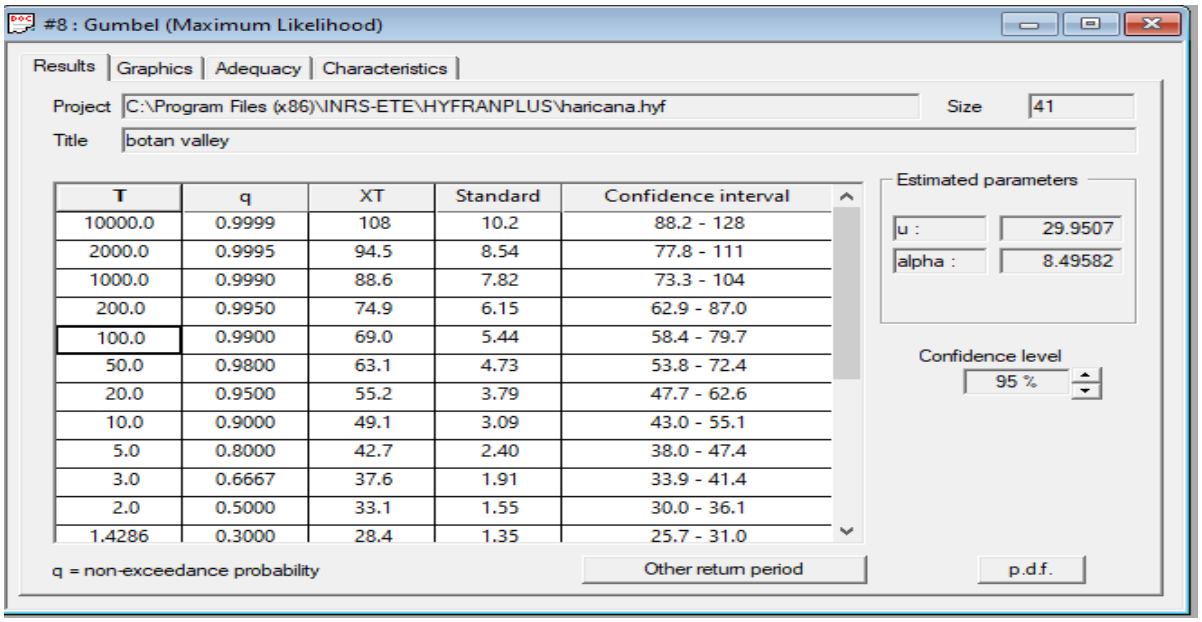


Figure 24 Result of homogeneity test (Willcoxon) on HYFRAN.

The result of the homogeneity test indicates that the two series are homogeneous, so they can be used as a single series for fitting.

II.3.2 Hydrometric series characteristics:

The characteristics of the series were determined using the "HYFRAN" software. in the following :



The characteristics of the series were determined using the "HYFRAN" software. in the following

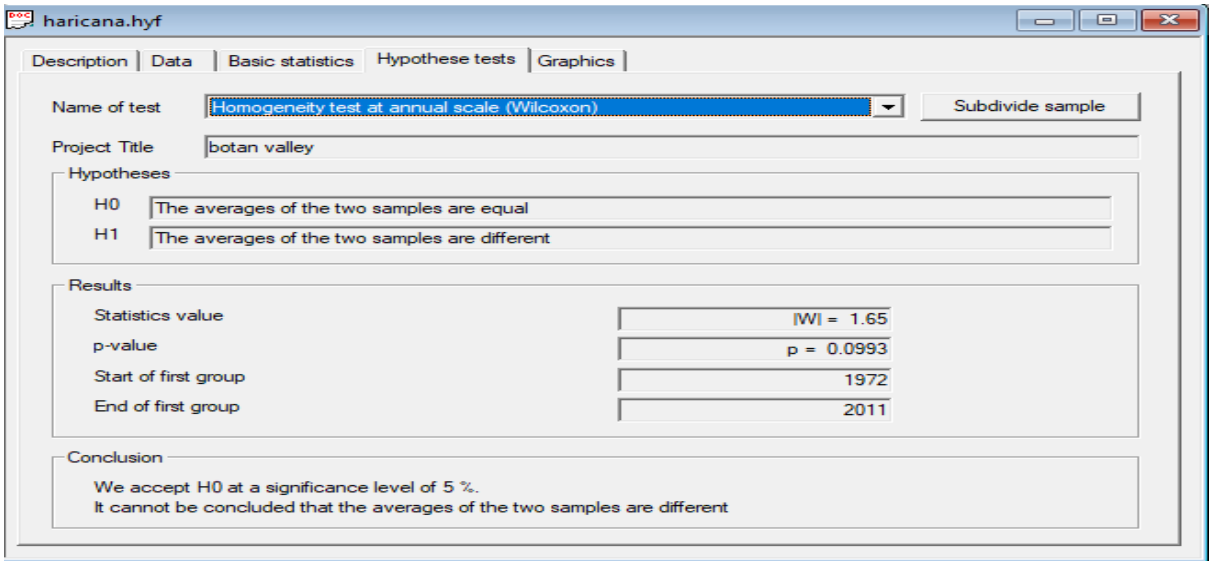


Figure 25 Result of homogeneity test (Willcoxon) on HYFRAN.

II.4 Adjustment according to GUMBEL's law:

$$f(x) = e^{e^{-a(x-x_0)}}$$

With:
F(x): Frequency of exceeding the value of x;
α, x0: Adjustment coefficients;
x0 is the position (mode) parameter;
α is the positive non-zero scaling parameter also called "gradex" when in 1/α form.
By a change of variable y = α (x-x0); Gumbel's law is written:

$$f(x) = e^{e^{y}}$$

y = α (x-x0) is the Gumbel reduced variable. The advantage of using the reduced variable is that
that the expression of a quantile is then linear.
And the equation of the Gumbel line is **x = (1/α) y +x0.**
Experimental frequency using Hazen's formula, which applies for normal and quasi-normal:

$$f(x) = \frac{m - 0,5}{n} * 100$$

m : rank in the data series ordered by growing values ;
n : sample size ;
Gumbel variable for each observed value ;
y= $[\ln(-\ln f(x))]$

II.4.1 Adjustment result :

The adjustment result are shown the figure below :

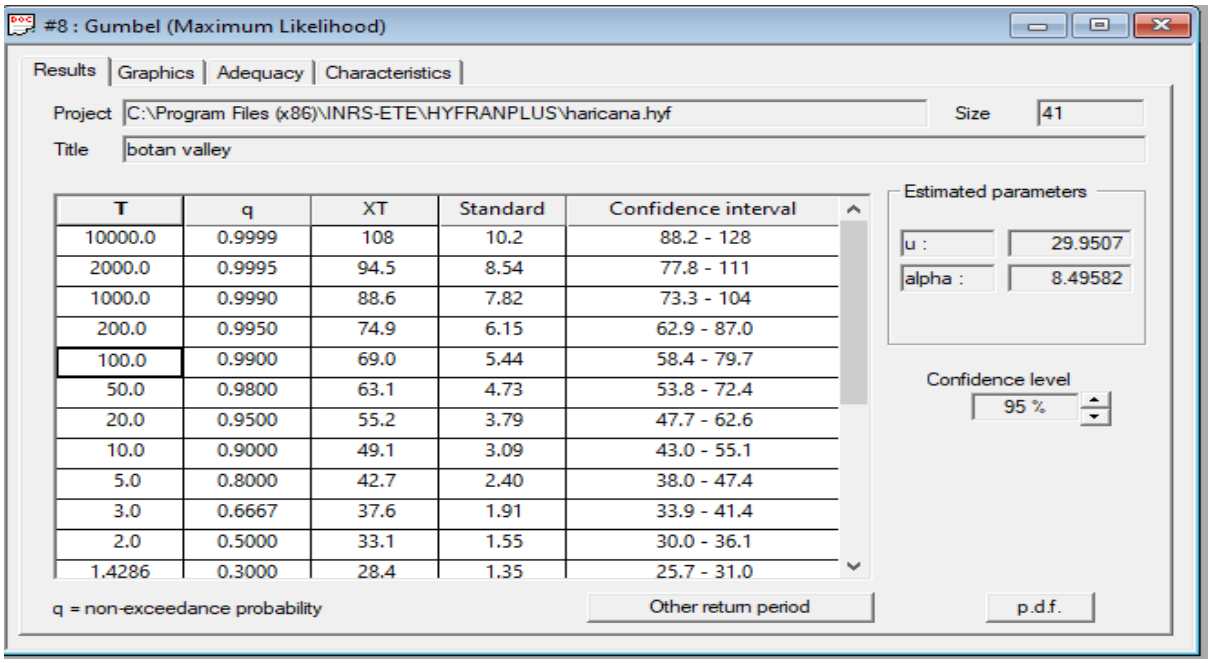


Figure 26 gumble results for ababbsa hydrometric station

Table 15 Result of the GUMBEL adjustment.

T	q	XT	Standard deviation	Confidence interval (95%)	
100	0.99	69	5.44	58.4	79.7
50	0.98	63.1	4.73	53.8	72.4
20	0.95	55.2	3.79	47.7	62.6
10	0.9	49.1	3.09	43	55.1
5	0.8	42.7	2.4	38	47.4

T : return period
q : Probability of frequency
XT : maximum daily railfall
The comparative characteristics of the Gumble distribution and the sample are shown in the following table:

Table 16 Comparison of gumble and sample characteristics.

Parameter	Charac. of the distribution function	Charac. of the sample
Minimum	None	16.1
Maximum	None	63.7
Mean	34.9	34.8
Standard deviation	10.9	10.2
Median	33.1	33.5
Coefficient of variation (Cv)	0.313	0.295
Skewness coefficient (Cs)	1.14	0.679
Kurtosis coefficient (Ck)	2.4	2.98

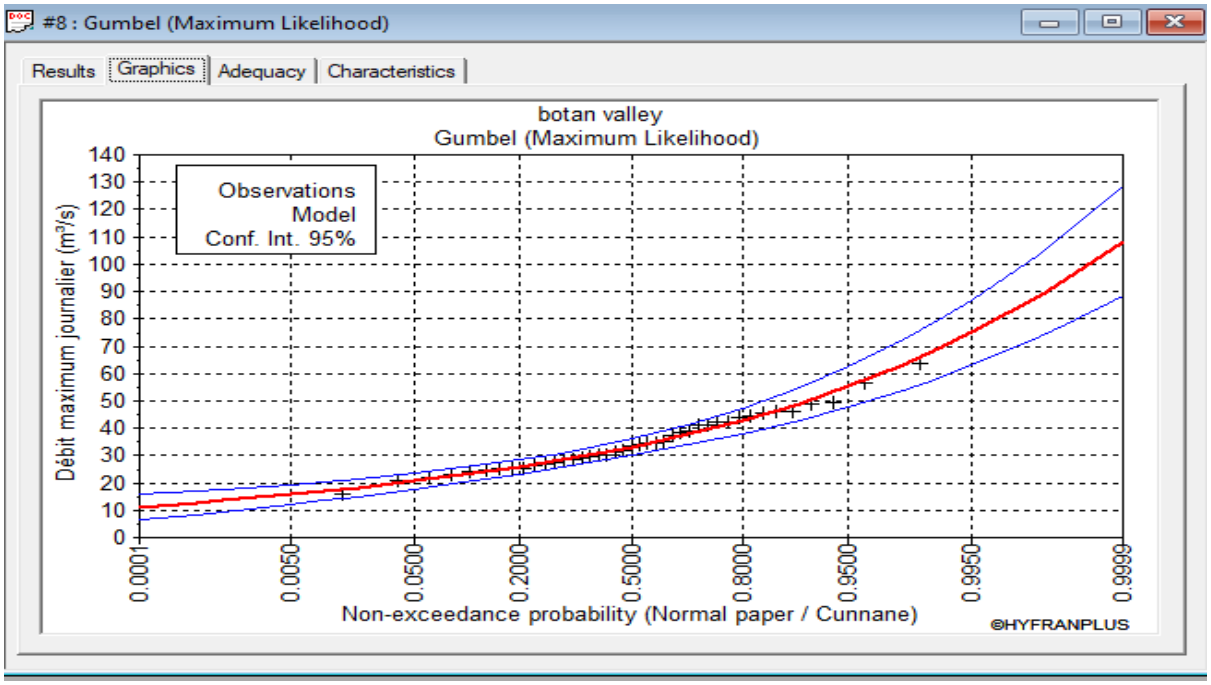


Figure 27 Graphical representation of the gumble distribution for the ababbsa station

II.5 Adjustment according to LOGNORMAL law

A Random Variable x is said to have a log normal distribution when: v = ln x is normal. Galton's law results from the normal law but is made asymmetrical by a change of variable.

The series was also fitted to the Log-Normal law using Hyfran software

Table 17 log normal fitting results

T	q	XT	Standard deviation	Confidence interval (95%)	
100	0.99	65.9	5.86	54.4	77.4
50	0.98	60.8	4.95	51.1	70.6
20	0.95	54	3.81	46.5	61.5
10	0.9	48.5	3.01	42.6	54.4

T: return period

q: Probability of frequency

XT: maximum daily rainfall

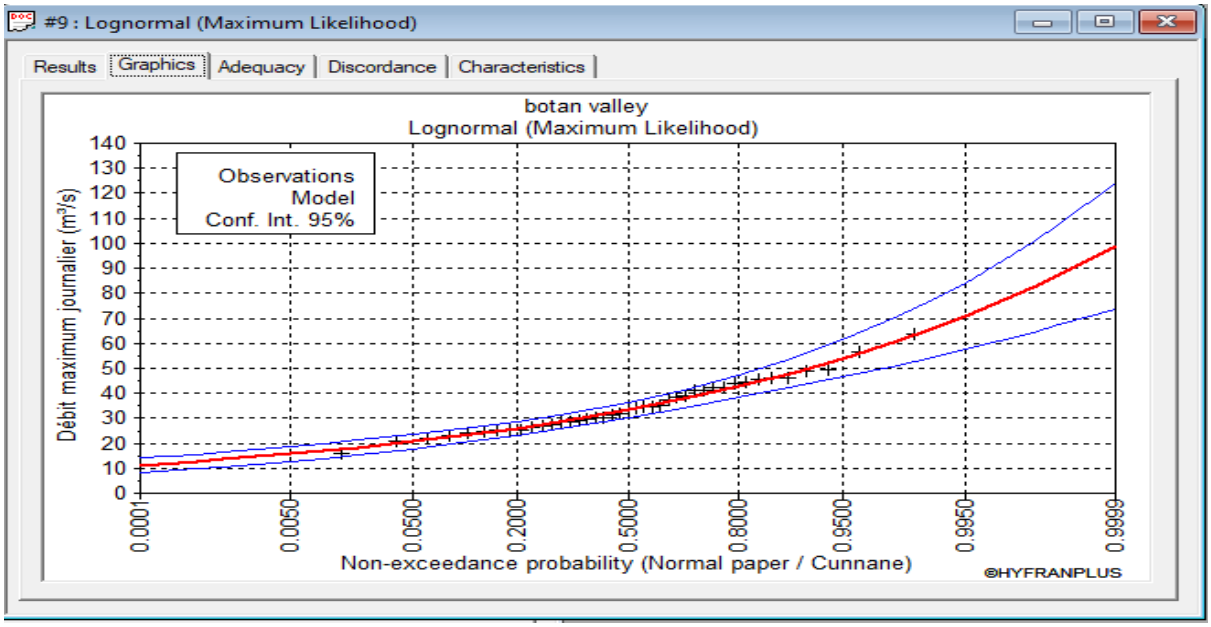


Figure 28 Graphical representation of the log normal distribution for the ababbsa station

The comparative characteristics of the Log Normal distribution and the sample are shown in the following table:

Table 18 Comparison of lognormal and sample characteristics

Prameter	Charac. of the distribution function	Charac. of the sample
Minimum	0	16.1
Maximum	None	63.7
Mean	34.8	34.8
Standard deviation	10.4	10.2
Median	33.3	33.5
Coefficient of variation (Cv)	0.299	0.295
Skewness coefficient (Cs)	0.925	0.679
Kurtosis coefficient (Ck)	4.56	2.98

II.6 Choice of the adjustment law :

There are always gaps between the experimental frequencies of observed values and the frequencies of the same values calculated from any distribution function.

Graphical adjustment is the first step, but it is not sufficient for the definitive choice of the theoretical law. The statistical goodness-of-fit test consists in comparing the goodness-of-fit of several laws in order to adopt the least bad fit(Touaibia, 2015).

The most widely used test is the χ2 test.

II.6.1 Visual graphic adjustment (visual method) :

The figures present graphs of the results obtained. They represent the empirical and theoretical probabilities of the Gumbel and Log Normal distributions using Hyfran-Plus software.

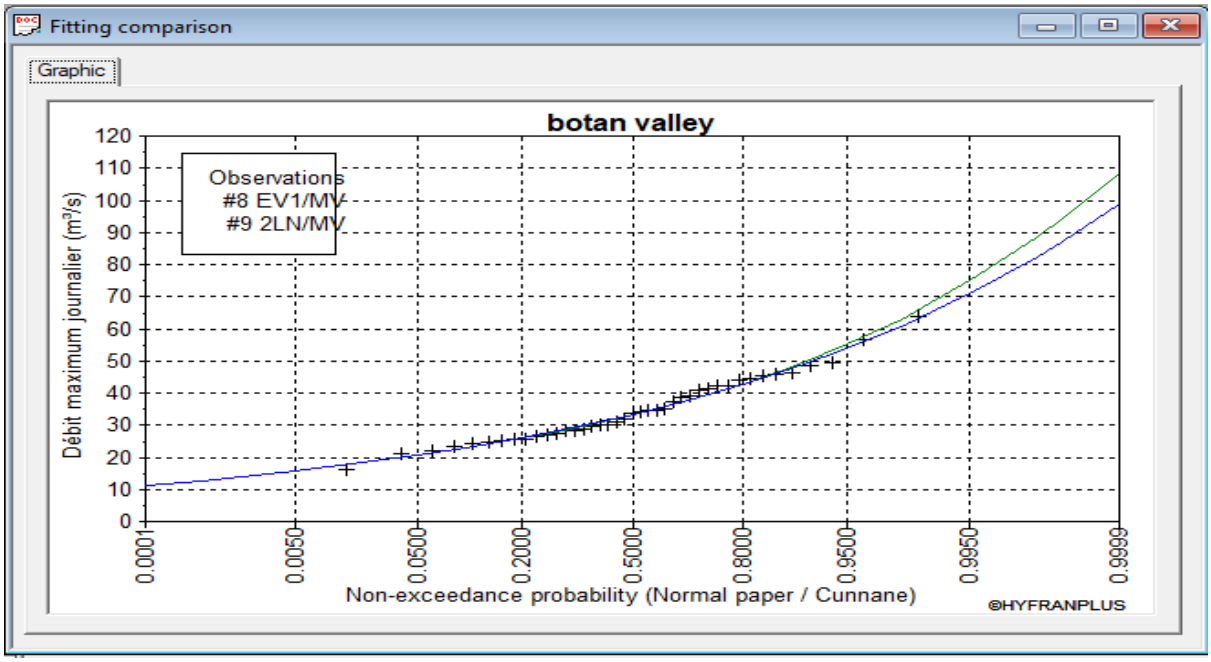


Figure 29 fitting comparison between lognormal and gumble low

#8 : GUMBLE line graph

#9 : log normal linegragh

Visually, we are unable to choose the most accurate fit, which is why we proceed with statistical analysis.

II.6.2 The test of adequacy of χ2:

The χ^2 (chi-square) goodness-of-fit test is a statistical test used to determine whether an observed distribution of data corresponds to an expected theoretical distribution. It is often used to test the fit of a model to observed data, or to assess the independence of two categorical variables.

The results obtained by the chi-square test were performed by Hyfran-plus software and are shown in the table

Table 19 χ^2 Test results

Statistical laws	Degree of freedom γ	χ^2 calculated	χ^2theoretical	Observation	Result
Gumbel	5	6.02	11.07	χ^2 calculated < χ^2 theoretical	**Valid**
lognormal	5	7.59	11.07	χ^2 calculated < χ^2 theoretical	**Valid**

III Estimation of river flood flows:

The GRADEX method is a statistical approach used in hydrology to estimate rare flood events (those with long return periods) based on data from more frequent floods. The name "GRADEX" is a contraction of "GRAdient EXtrapolation."

Principle of the GRADEX Method

a Observation of Frequent Floods:

The method starts by analyzing floods for which reliable data is available, typically those with shorter return periods (e.g., 10 or 20 years).

b Gradient Extrapolation:

The core idea is that, as the return period increases, the rate of increase in flood discharge (flow rate) tends to decrease in a nearly linear manner when plotted on a logarithmic scale. In other words, the gradient of the increase in discharge diminishes as the flood becomes rarer.

c Extrapolation for Rare Floods:

By using the observed gradients from more frequent floods, the method extrapolates these gradients to estimate the discharges of rarer floods (e.g., floods with return periods of 100 years or more).

d Steps of the GRADEX Method

Determining the Gradient: The gradient between the discharges of floods for shorter return periods is determined based on observed data.

Linear Extrapolation: This gradient is then extrapolated to longer return periods, assuming that the gradient decreases approximately linearly on a logarithmic scale.

Estimating Rare Flood Discharges: Using this extrapolation, estimates are made for the discharges of floods with longer return periods (i.e., rarer floods).

III.2 How it done

Choose the time step n hours (generally equal to the average of the base times of the available flood hydrographs. For ease of calculation, use a very rounded value, e.g. 2, 4, 6 ... 48 hours).
Adjust maximum daily rainfall using Gumbel's law.
Calculate precipitation Gradex “a” (slope of Gumbel line).

$p(mm) = a\mu + b$

: Reduced Gumbel variable.

Fit the observed flow series to Gumbel's law and determine the ten-year flow rate

(pivot point of flow extrapolation).

Express the ten-year flow in equivalent water level using the formula

$$\mathbf{R(mm)} = \frac{\mathbf{Q(m3\ /s)}}{\mathbf{S(Km2\ )}} \times (\mathbf{3.6} \times \mathbf{n(h)}\ )$$

Extrapolate the flow distribution beyond 0.9 (T=10 years) by a straight line with a slope equal to the rainfall Gradex.

$$Q_{(\mu\%)} = a * \mu + b'$$

a: Gradex of rainfall;

µ: Reduced Gumbel variable.

$$\mu = -\ln(-\ln(F))$$

$$F = 1/1 - T$$

For T=10 years

$$b' = Q_{10yrs} - a\mu$$

Draw the straight line of equation (%) = $a * \mu + b'$ on the same graph as the fit of Pdmax.

Next draw the Qs for each return period (in mm). Then express these flows in m3/s using the formula :

$$Q\left(m3/s\right) = S(Km2\ ) \times \frac{Q(mm)}{3.6 \times n(h)}$$

III.2.1 Calculation of peak flow :

Calculate the “CP” “peak coefficient” ratio on the hydrographs of the observed floods

ratio:

$$Cp = \frac{Qmax}{Qmed}$$

($m3/s$) = $Cp * (m3/s)$

a a briefing :

If no flood records are available for the basin under study, the base time and decennial discharge are estimated by analogy with other neighboring basins of the same size. Baseline time and decennial discharge.

III.2.2 Application of method:

Table 20 DAILY MAX PRICIPITAION DATA FOR KHEMISS MILLIANA STATION

	Year	Dpmax	Year	Dpmax
11717	1998	64.8	1972	47.5
	1999	30.65	1973	60.3
	2000	24.22	1974	33
	2001	24.3	1975	42.2
	2002	33.2	1976	36.4
	2003	59.6	1977	24.7
	2004	42.3	1978	63.6
	2005	40.5	1979	20.6
	2006	25	1980	44.1
	2007	43	1981	31.1
	2008	26.6	1982	41.7
	2009	22.6	1983	20.3
	2010	24.6	1984	49.3
	2011	37.1	1985	57.3
	2012	34.7	1986	22.1
	2013	42.3	1987	27.8
	2014	27.7	1988	31.7
	2015	44.9	1989	34.3
	2016	26.2	1990	37.3
	2017	73.7	1991	30.7
	2018	82.81	1992	56.7
	2019	23.67	1993	50.1
	2020	24.16	1994	31.8
	2021	78.89	1995	33.2
	2022	33.12	1996	
	2023	31.43	1997	32.5
	2024	30.79		

Table 21 HYDROMETRIC DAILY MAX DATA FOR ABABBSA STATION

	Year	DpMAX	Year	DpMAX
11715	1972	38.5	1993	30
	1973	44	1994	26.5
	1974	22.2	1995	16.1
	1975	31.8	1996	24.2
	1976	33.5	1997	41.2
	1977	39	1998	25.4
	1978	34.7	1999	35.1
	1979	48.6	2000	24.7
	1980	37.5	2001	28.4
	1981	46.1	2002	23.2
	1982	45.5	2003	42.4
	1983	63.7	2004	28.4
	1984	29.6	2005	34.7
	1985	49.3	2006	25.4
	1986	28.9	2007	41
	1987	31.2	2008	46
	1988	34.1	2009	25.2
	1989	30.2	2010	44.6
	1990	42.1	2011	27.5
	1991	27.1	2012	56.5
	1992	21		

III.2.3 Fitting the series to Gumbel's law :

The equations of the Gumbel line for each rainfall station and hydromertic station using the Hyfran-Plus software are given below:

a **The ababbsa station:**

P(mm) = 10.8u+31.1

So Gradex a = 10.8

b **Khemiss milliana station**

P(mm) = 12.8+29.9

So Gradex a= 12.83

c **Sidilakhdar station :**

P(mm) = 13.3+29.1

So Gradex a= 13.3

III.2.4 Choice of time interval:

a we estimated the base time at n=24h.

There were no flood data recordded in the study area, so by analogy with the ababbsa valley watershed, we estimate the same magnitude of base time and decennial discharge, such that :

$$\frac{Q}{S} = \frac{Q'}{S'}$$

Q'$_{10}$ yrs=82m^3/s

Q'$_{100}$ ans=124m^3/s

S'= 120.4 km^2

$$\boldsymbol{Q = S * \frac{Q'}{S'}}$$

Q$_{10\ yrs}$=14 m^3/s.

Q$_{100\ yrs}$=20 m^3/s

b The ten-year flow rate is expressed as the equivalent water level:

There were no flood data recorded in the basin studied, so by analogy with the ababbsa valley watershed, we estimate the same magnitude of base time and decennial discharge, such as :

$$\mathrm{R(mm)} = \frac{\mathrm{Q(m3\ /s)}}{\mathrm{S(Km2\ )}} \times (3.6 \times \mathrm{n(h)}\ )$$

$$\mathrm{R(mm)} = \frac{14}{20.18} \times (3.6 \times 24\mathrm{(h)}\ )$$

$$\mathbf{R(mm) = 56\ mm/24h}$$

c Extrapolate from the flow distribution beyond 0.9 (T=10 years) by a straight line with a slope equal to the rainfall Grade

station	R$_{10}$yrs	a	b'
11717	56	12.8	27.25
11715		10.8	31.58
11711		13.3	29

Ababbsa station :

$$Q_{\mu\%} = 10.8 * \mu\% + 31.58$$

Khemiss milliana station :

$$Q_{\mu\%} = 12.8 * \mu\% + 27.25$$

Sidi lakhdar station :

$$Q_{\mu\%} = 13.3 * \mu_{\%} + 29$$

Rainfall adjustment graph and discharge extrapolation line

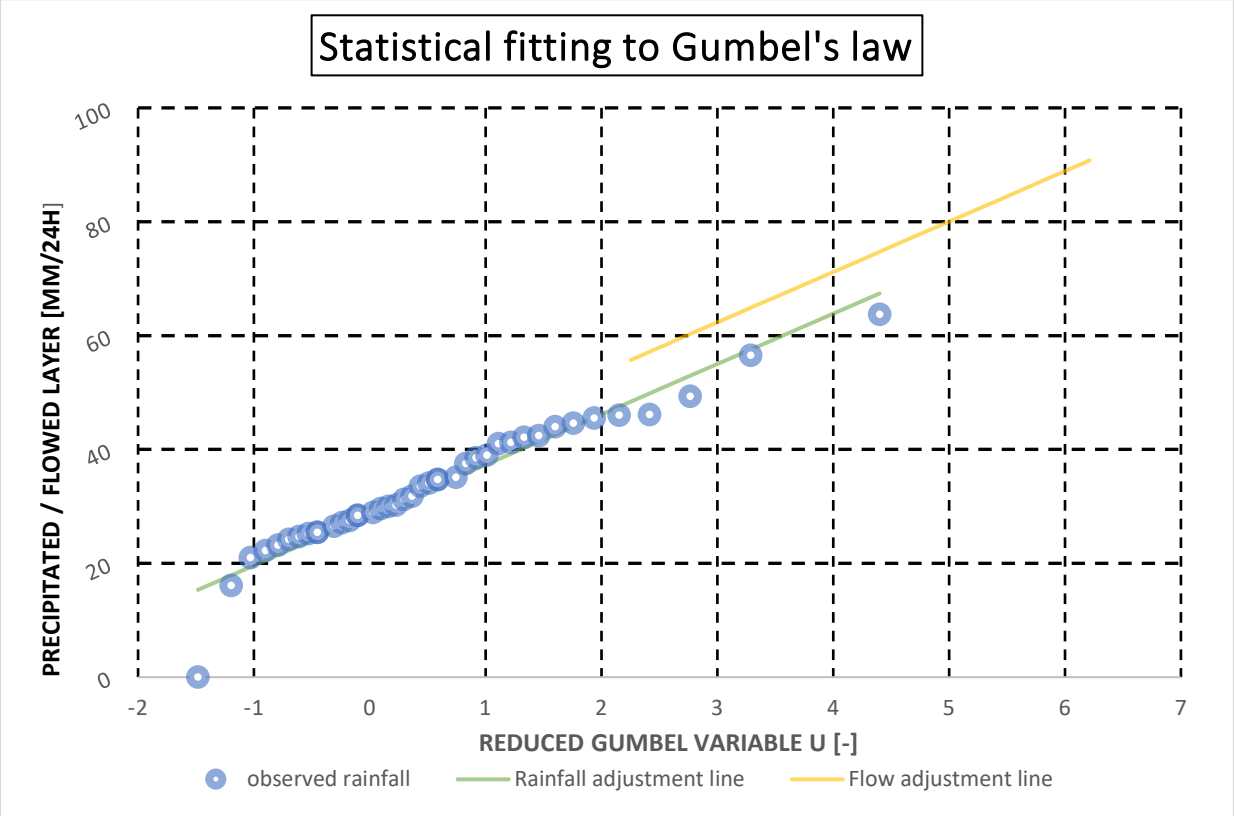


Figure 30 Rainfall adjustment graph and discharge extrapolation line

III.2.5 Calculation of peak flows:

We assume peak coefficient Cp=1.5

The adjustment results for the different return periods are summarized in Table

Table 22 The adjustment results for the different return periods

Station		Khemiss milliana			Ababbsa			Sidi lakhdar		
Return period	Gumbel reduced variable	R (mm/24h)	Q(mm/h)	Q(m/s)	R (mm/24h)	Q(mm/h)	Q(m/s)	R (mm/24h)	Q(mm/h)	Q(m/s)
10	2.25	58.7	56.1	13	55.3	55.9	14	59	58.93	13.8
20	2.97	67.9	65.3	15	63.1	63.7	16	68.6	68.5	16
50	3.9	79.8	77.2	18	73.1	73.7	19	81	80.9	18.9
100	4.6	88.8	86.1	20	80.7	81.3	20	90.3	90.18	21.1

Table 23 Adjustment results for stations taken.

Return period T	Hydrometric station ababbsa	Rainfall stations	
		Sidi lakhdar	Khemiss milliana
10	21	20.7	19.5
20	24	24	22.5
50	29	28.35	27
100	**30**	**31.65**	**30**

As a result, we confirm the discharge value of sidi lakhdar due to its extreme value.

III.3 Flood hydrograph:

It's a curve representing the evolution of flows as a function of time during the flood, it allows us to estimate some characteristics relating to the flood such as, shape, volume, rise time and base time, for the tracing of the hydrograph, we use the SOKOLOVSKY method (Touaibia, 2015).

$$Q(t) = Q_{max}\left(\frac{t}{t_m}\right)^m$$

The flood phase branch is expressed as

$$Q(t) = Q_{max}\left(\frac{t_d - 1}{t_d}\right)^n$$

With :

Qtr. : Instantaneous flow (m3/s).

M and n : Curvature coefficient (m=2; n=3).

Tm: Time taken for flood to rise (SOKOLOVSKY).

Tm=tc (h).

Td: Time of down welling.

Td=δ.tm= δ.tc

δ : Coefficient dépendant de la capacité de régulation

Table 24 Flood hydrographe Shape coefficient "**δ**".

Stream description	Value of "δ"
Small streams and valleys in bare, low-permeability watersheds.	2,0 – 2,5
Small streams and valleys in broken or permeable catchments, medium-sized streams with normal major bed terraces.	3,0 – 4,0
arge and medium-sized rivers with extensive overflow terraces.	4,0 – 7,0

Table 25 Flood discharge for different return periods

Time (h)	Return period		
	10	50	100
0.1	0.213382	0.320073	0.502972
0.2	0.853528	1.280293	2.011888
0.3	1.920439	2.880658	4.526749
0.4	3.414114	5.121171	8.047554
0.5	5.334553	8.001829	12.5743
0.6	7.681756	11.52263	18.107
0.7	10.45572	15.68358	24.64563
0.81	14	21	33
0.9	11.7939	20.21811	27.7999
1	9.62922	16.50723	22.69745
1.1	7.747078	13.2807	18.26097
1.2	6.127712	10.50465	14.44389
1.3	4.751364	8.145196	11.19964
1.4	3.598278	6.168476	8.481654
1.5	2.648694	4.540619	6.243351
1.6	1.882857	3.227754	4.438162
1.7	1.281007	2.196012	3.019517
1.8	0.823388	1.411523	1.940844
1.9	0.490242	0.840415	1.155571
2	0.261811	0.448819	0.617127
2.1	0.118338	0.202865	0.27894
2.2	0.040065	0.068683	0.094439

Using excel we draw the graph

III.3.1 Floods hydrograph

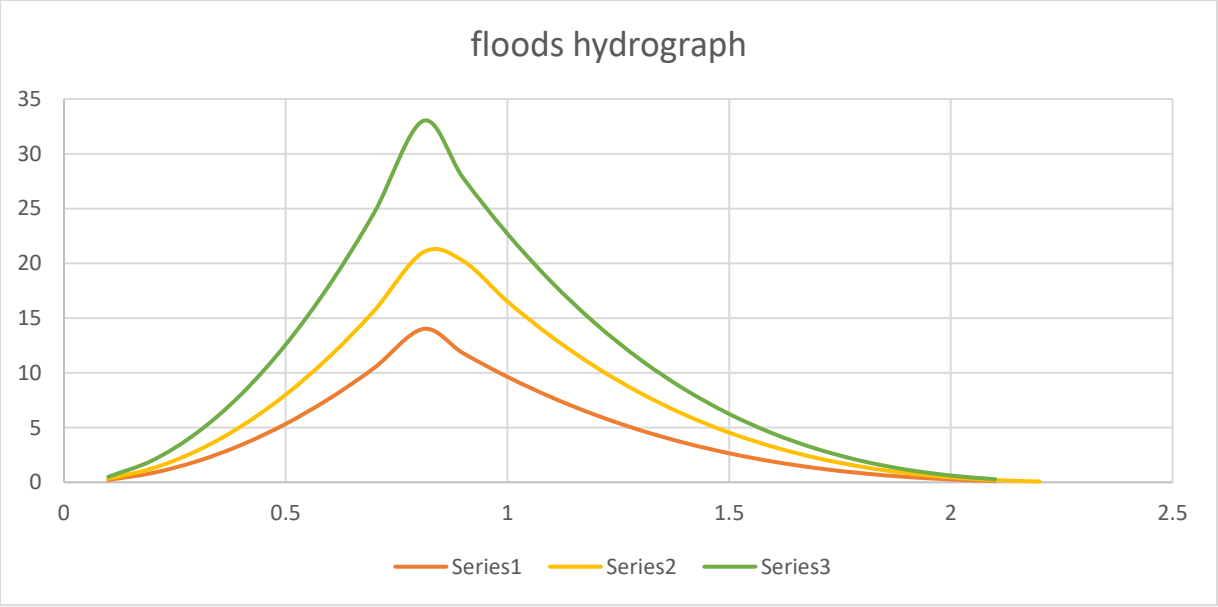


Figure 31 Flood hydrograph

III.4 Solid transportation study

The movement of suspended solids in water is a big issue that has led countries to work hard to prevent problems like the loss of farmland, the filling up of dams with sediment, and the damaging effects of floods and desertification (De Ploey et al., 1991, in Bouguerra et al., 2016).

In Algeria, the amount of solids carried by rivers is very high. However, it's not well measured in some rivers because there isn't enough data, especially on fine particles, and there aren't enough gauging stations (Bouchelkia & Remini, 2003). Therefore,

III.4.1 Estimation method in northern Algeria

$$D_s = 328.624Q^{-0.234}S^{-0.197}$$

With :

Ds: solid transport in (T/Km2/year) ;

Q: Maximum flow (m2/s);

S: Catchment area (Km^2);

Ds= 80.8 (T/Km2/year)

Conclusion:

In this part of the study, we looked at the shape and features of the watershed, which we'll use to calculate the project's water flow.

In the next part, we studied the rainfall, adjusted it to find out how much rain happens over certain periods, estimated the flood levels using the gradex method, and then created a flood graph at the end

CHAPTER FOUR

SIMULATION OF HYDRAULIC FLOWS AND CARTOGRAPHY OF AT-RISK FLOOD ZONES

I İntroduction :

Hydraulic engineering is a critical step in any development project, particularly in the context of flood prevention. This scientific and technical discipline is devoted to the in-depth analysis of flows in various water systems, whether artificial channels or natural watercourses, under free-surface or loaded conditions.

Flood risk management is a complex challenge, particularly in situations involving high water levels and high flow velocities. Traditionally, the design of flood protection structures has focused more on controlling water levels than on erosion problems.

To better understand and anticipate these phenomena, hydraulic modeling has become an essential tool. The aim of this approach is to numerically simulate the evolution in time and space of hydraulic parameters during a flood, such as flows, velocities and water heights in flood-prone areas. In particular, these simulations enable us to identify the areas likely to be flooded, to estimate the duration of submersion and to predict the speed at which water rises during the event. It is important to note that a model is a simplified representation of a real system, offering a useful but not exhaustive approximation of reality.

I.1 General information :

I.1.1 The physics of a hydraulic model :

Hydraulic models for the study of lowland flooding mainly use the Barré de Saint-Venant equations. These equations are a simplified version of the Navier-Stokes equations, adapted to free-surface flows by integrating water level variables. This approach effectively models flooding phenomena, while reducing the mathematical complexity of the problem.

✵ Mass conservation equation :

$$\frac{\partial Q}{\partial t} + \frac{\partial Q}{\partial x} = q_L$$

✵Equation of conservation of momentum :

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{S}\right) + gS\left(\frac{\partial Z}{\partial x} + J\right) = K_L \cdot q_L \cdot V$$

With :

S : wetted surface, meaning the cross-sectional area occupied by the fluid (m^2)

Q : flow rate (m^3/s) ;

q_L : flow rate per unit length (m^2/s) of supply ($qL \geq 0$) or waste ($qL < 0$)

g : acceleration of gravity (m/s^2)

Z : free surface elevation (m)

J : the slope of the energy line (m/m), also known as the linear pressure drop

K_L : a coefficient such that :

$$KL=\begin{cases}1 \text{ si } qL < 0\\ 0 \text{ si } qL \geq 0\end{cases}$$

V : average speed in a cross-section (m/s) ;

X : curvilinear abscissa (m) ;

T : time (s).

I.1.2 Definition of free-surface flow :

A free-surface flow is a liquid flow whose upper surface is in direct contact with the atmosphere, subject to the pressure of the ambient air.

I.1.3 Definition of steady (permanent) flow :

Flow is considered permanent when the flow conditions at each point remain constant over time (∂v/∂t = 0 ; ∂h/∂t = 0, etc.).

I.1.4 Definition of non-stationary (non-permanent) flow :

Flow is said to be non-stationary when the flow characteristics at each point vary as a function of time (∂v/∂t ≠ 0 ; ∂h/∂t ≠ 0, etc.).

I.1.5 Channel dimensioning :

For free-surface flow and the uniform regime, the mean flow velocity is given by the Chézy formula :

$$V = C\sqrt{RH.I}$$

We have :

Q=V.S

This gives :

$$Q = C.S.\sqrt{RH.I}$$

With :

C: Chézy's coefficient, its unit is (m0.5/s) ;

R_H: Hydraulic radius (m) ;

I: Hydraulic gradient or head loss per unit length; in the case of uniform flow, I is equal to the slope of the channel invert (bottom).

I.1.6 Determining the Chézy coefficient :

Several formulas are available for calculating the Chézy coefficient. Of these, the most commonly used are discussed below.

I.1.7 Manning's formula (1891) :

Manning gives the following formula :

$$C = \frac{1}{n}. R_H⅙$$

Where n is the roughness coefficient and RH is the hydraulic radius. Blench (1939) considers the coefficient C as a variable that depends not only on n but also on RH, and whose exponent in turn depends on n and RH. depends in turn on n and RH. This is known as Pavlovski's formula.

I.1.8 Pavlovski formula (1940) :

$$C = \frac{1}{n} R_H^y$$

With :

n : is the roughness coefficient

R_H : is the hydraulic radius.

y : is an exponent determined either according to the complete equation :

$$y = 2.5\sqrt{n} - 0.13 - 0.75\sqrt{RH}(n - 0.1)$$

I.1.9 Agroskine formula :

The Agroskine formula for calculating the Chézy coefficient is as follows:

$$C = 4\sqrt{2.g(K + \log RH)}$$

Where **k :** is the Poli parameter.

Given that Agroskin's formula is semi-empirical and the quantities in its second term are expressed solely in length units (meters), we suggest employing the following formula :

$$C = \frac{1}{n} + 17.72. log R_H$$

I.1.10 Bazin's formula (1897) :

Bazin considers that the value of Chézy's coefficient C depends on the hydraulic radius RH but not on the slope I of the channel. but does not depend on the slope I of the channel.

The coefficient C can then be determined by the expression :

$$C = \frac{87}{1 + \frac{m}{\sqrt{RH}}}$$

m: is the roughness coefficient depending on the nature of the material making up the channel

considered

I.2 Diagnosis and simulation of the watercourse without management

I.2.1 Extent of study area

The study start from the train bridge in jardin city and ends in the south of the Botan district

I.2.2 Network description

A deep inspection of the line was made, and a report detailing the hydraulic situation was drawn up during the visit. Part of this report is presented below.

After 2 kilometers from the top of the Zakkar Mountains, passing through the city of Melliana between the mountains, the valley of Botan begins in the north of Khemais Melliana. This valley was once used by locals and colonizers for fishing, watering, drinking, and boating, and was a militarily guarded area by the colonialists. However, after population expansion, the area of the basin decreased and became polluted by the waste products of the population. The water level rises in winter due to the springs that originate from the Zakkar Mountains, most of which flow into the valley of Botan. This water is used by some farmers in the south of the city for irrigation and water storage.

I.2.3 Down stream town :

On the down side of the city, the valley passes through a popular neighborhood called Botan, where the local grain storage facility is located. The condition of the valley in this area is very poor, and the last flood occurred in 2017.



I.3 Introducing HEC-RAS software

HEC-RAS (Hydrologic Engineering Center's River Analysis System) is an advanced computer program developed by the Hydrologic Engineering Center of the United States Army Corps of Engineers. This software is designed to model and analyze

water and hydraulic systems in rivers and streams. HEC-RAS is widely used by hydraulic engineers and planners to evaluate and design projects related to water resource management.

I.3.1 Key Features of HEC-RAS:

a Water Flow Analysis

the program can perform detailed analyses of water flow in rivers and streams, including steady flow and unsteady flow conditions.

It analyzes the impact of various factors such as dams, bridges, and channels on water flow.

b Flood Modeling

HEC-RAS is used to model and study floods and predict their impacts, helping in planning and implementing flood management strategies to reduce damages.

c Groundwater Management

it can model the interaction between surface water and groundwater, aiding in a comprehensive understanding of the water system dynamics.

d Water Quality Analysis

HEC-RAS also enables the analysis of water quality, including the study of pollutant distribution and concentration in water systems.

I.3.2 Applications of HEC-RAS:

a Flood Planning and Management:

Used to identify flood-prone areas and design preventive measures.

b Infrastructure Design:

Supports the design of dams, bridges, and channels to ensure effective and safe performance.

c Water Resource Management

Helps in developing effective strategies for managing water resources, such as allocating water for agricultural and urban uses.

d Environmental Impact Studies:

Used to assess the impact of engineering projects on the surrounding environment.

HEC-RAS is an essential tool for hydraulic engineers, planners, and water resource management professionals, providing accurate and in-depth analysis of various water systems.

I.3.3 Detailed Features of HEC-RAS:

a Hydraulic Modeling:

1D and 2D Flow: HEC-RAS supports both one-dimensional (1D) and two-dimensional (2D) flow modeling, allowing for detailed simulations of complex hydraulic conditions.

Mixed Flow Regimes: It can handle mixed flow regimes, including subcritical, supercritical, and mixed flow conditions, which is crucial for accurate hydraulic modeling.

Sediment Transport: The software includes sediment transport modeling capabilities, allowing for the analysis of erosion and deposition processes in rivers and streams.

b User Interface and Usability:

Graphical User Interface (GUI): HEC-RAS features an intuitive GUI that makes it easier for users to set up models, input data, and visualize results.

Data Import and Export: It supports various data formats for importing and exporting data, enhancing compatibility with other tools and datasets.

Detailed Reporting: The software generates detailed reports and graphical outputs, providing comprehensive insights into the hydraulic performance of the modeled system.

c Advanced Computational Capabilities:

Parallel Processing: HEC-RAS utilizes parallel processing to enhance computational efficiency, especially for large and complex models.

Customizable Modules: Users can develop custom modules and scripts to extend the functionality of HEC-RAS, tailoring it to specific project needs.

d Integration with GIS:

HEC-RAS integrates seamlessly with Geographic Information Systems (GIS), allowing for spatial analysis and mapping of hydraulic and hydrologic data.

This integration facilitates the visualization of model results in a geospatial context, aiding in better decision-making and communication of findings.

I.3.4 Practical Applications and Case Studies:

a Urban Flood Management:

HEC-RAS is extensively used in urban areas to design and evaluate flood control measures, such as levees, floodwalls, and stormwater management systems.

Case studies often demonstrate its application in assessing flood risk and developing mitigation plans to protect communities.

b River Restoration Projects:

The software is employed in river restoration projects to model the hydrodynamics of restored channels and predict the outcomes of various restoration strategies.

It helps in designing structures like fish passages, weirs, and bank stabilizations to enhance the ecological health of rivers.

c Dam Break Analysis:

HEC-RAS is a crucial tool for dam safety evaluations, particularly in simulating potential dam break scenarios and their downstream impacts.

It aids in emergency planning and response by providing detailed inundation maps and time-of-travel analyses for flood waves.

d **Environmental Impact Assessments (EIA):**

The software is used to evaluate the hydrologic and hydraulic impacts of proposed infrastructure projects, such as highways, bridges, and pipelines.

It helps in identifying potential environmental impacts and developing mitigation strategies to minimize adverse effects.

e **Future Developments and Enhancements:**

HEC-RAS continues to evolve with advancements in computational technology and user needs. Future developments may include:

- **Enhanced 3D Modeling:**Expanding the capabilities for three-dimensional hydraulic modeling to capture more complex flow phenomena.
- **Improved User Experience:** Ongoing enhancements to the user interface and data handling capabilities to streamline model setup and analysis.
- **Integration with Emerging Technologies:** Incorporating advancements in remote sensing, machine learning, and artificial intelligence to improve model accuracy and predictive capabilities.
- **Cloud Computing:** Leveraging cloud computing to provide scalable and accessible modeling solutions, enabling collaboration and sharing of models and results.

f **The operation of HEC-RAS**

HEC-RAS is capable of modeling a wide range of flow conditions in extreme detail. The control center, the centerpiece of HEC-RAS, enables different types of data to be managed and combined:

Geometry

Flows and boundary conditions

Calculation conditions

Results (Idrici, 2017).

II Application of HEC-RAS on the vally :

II.1 Data bank required to apply the HEC-RAS model:

To apply the HEC-RAS model it is necessary to have a database concerning the study area:

A series of distance-altitude pairs for all cross-sections;

The distance between two successive sections (banks and canal axis);

Contraction and expansion coefficients;

Flow data and boundary conditions (Jabbour, 2006).

II.2 Geometric data:

The geometric data required, consists of establishing connectivity information for the river system (river system diagram), cross-section data, and existing or planned hydraulic structure data (bridges, levees, lateral structures, weirs, etc.) (Idrici, 2017).

II.3 Downloaded of the DEM :

Digital Elevation Models (DEMs) are a key component in hydraulic modeling and analysis, including their use in HEC-RAS. Here's a detailed overview of what a DEM is, how it's created, and its importance in hydraulic modeling.

II.3.1 What is a DEM?

A Digital Elevation Model (DEM) is a 3D representation of a terrain's surface, typically stored as a grid of elevation values. DEMs are used to represent the topography of the Earth's surface and are essential for various types of spatial analysis, including hydraulic modeling.

II.3.2 Applications of DEMs in HEC-RAS

River Channel Definition: DEMs help in defining the geometry of river channels, including their shape, slope, and cross-sectional profiles.

Flood Simulation: DEMs are used to simulate how water will spread across the terrain during different flood scenarios, aiding in the development of flood management plans.

Hydraulic Structure Analysis: By integrating DEMs with hydraulic models, the impact of structures like bridges, culverts, and weirs on water flow can be accurately assessed.

II.3.3 Importing the DEM

The DEM is imported into HEC-RAS, where it forms the basis for the geometric representation of the river system.

II.3.4 Creating Cross-Sections

Cross-sections of the river are created using the elevation data from the DEM. These cross-sections are critical for modeling the flow of water through the river.

II.3.5 Running Simulations

With the DEM and cross-sections in place, HEC-RAS can simulate different flow conditions, such as normal flow, flood events, and the impact of proposed infrastructure changes.

II.3.6 Analyzing Results

The results of the simulation are analyzed to understand water surface elevations, flow velocities, and inundation areas. These results are often visualized as maps and charts.

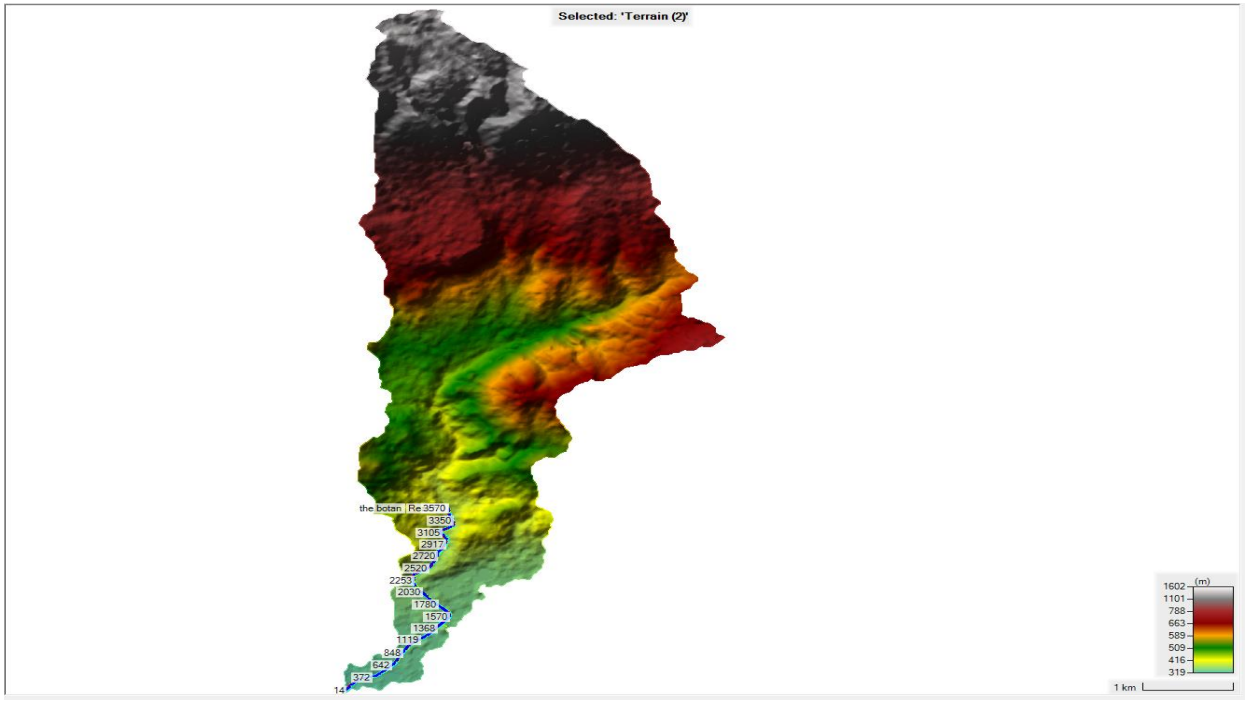


Figure 32 dem of study area

Once the DEM has been built, we export the ESRI projection file (extension file.Prj) containing information about a specific coordinate system for our study area, which we have downloaded from the "Spatial Reference" website to the HEC-RAS software so that RASMAPPER can simulate it.

And with the use of Topographic survey . we manged to combain between the DEM data and AUTOCAD file to draw the valley cross-sections from AutoCAD and HECRAS

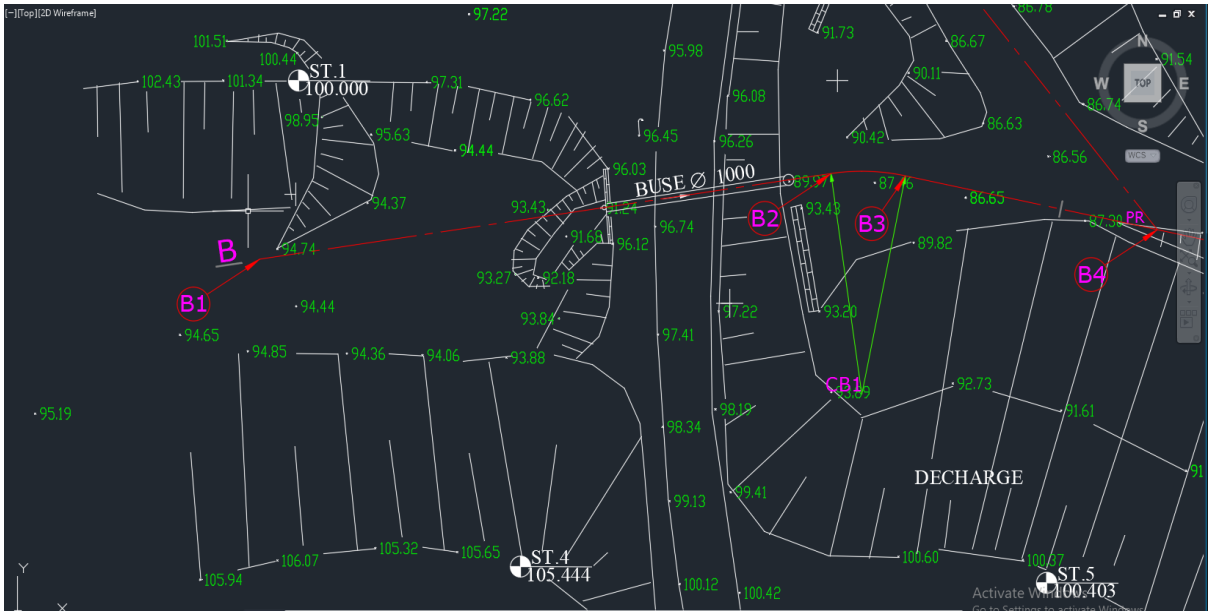


Figure 33 autocad Topographic survey for botan valley

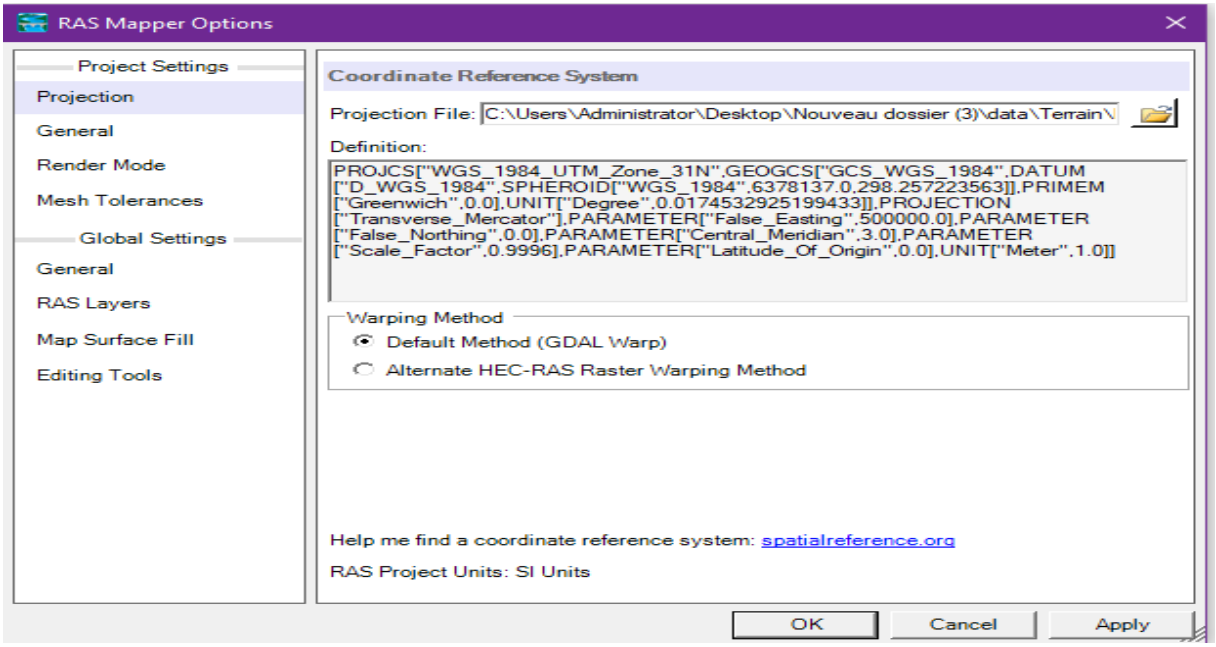


Figure 34 projection system

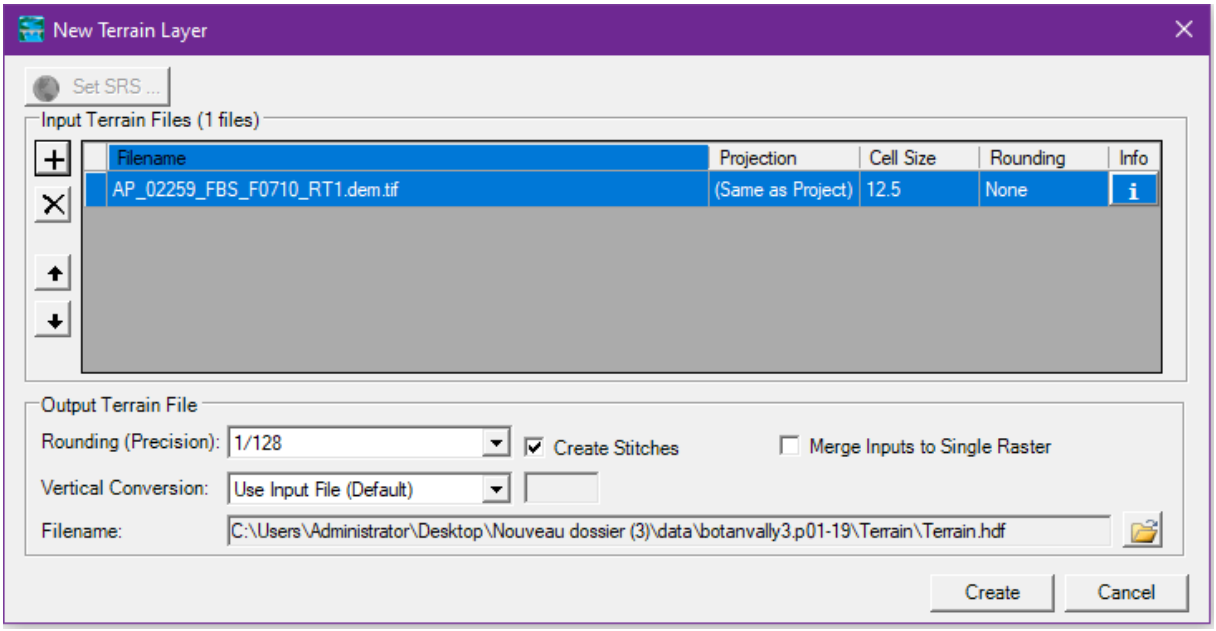


Figure 35 uploading DEM

III Simulation result :

The numerical values of the hydraulic values for the 100-year return period are presented in a table, while the visual results of the post-flood simulation showing the long and cross-sectional profiles are shown in the following figures:

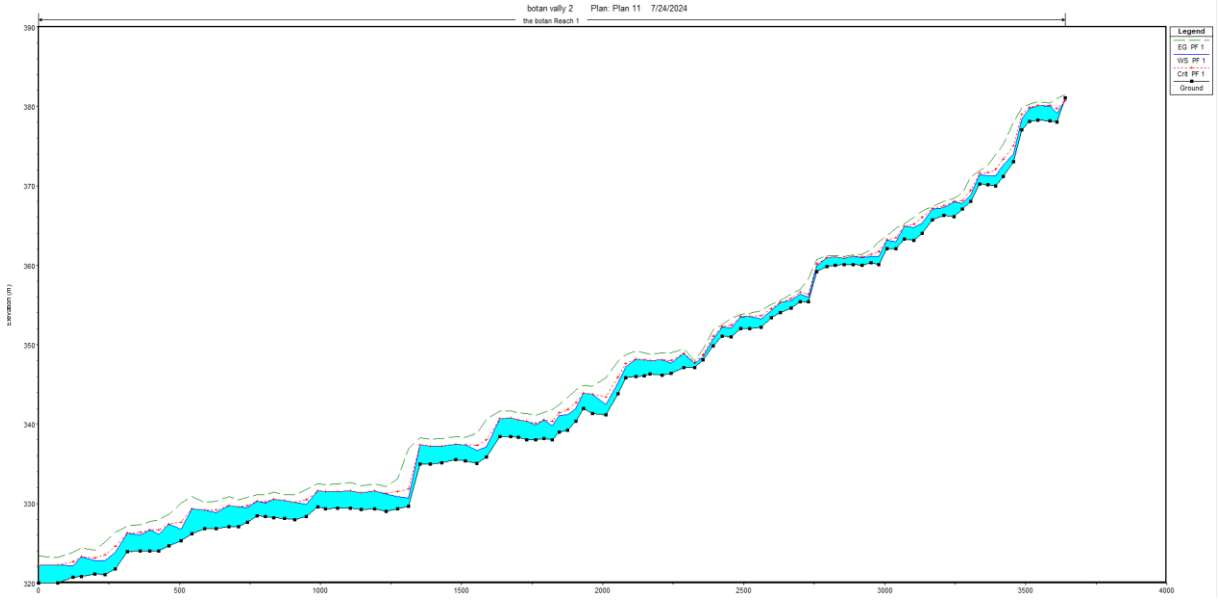


Figure 36 profile plote Natural case

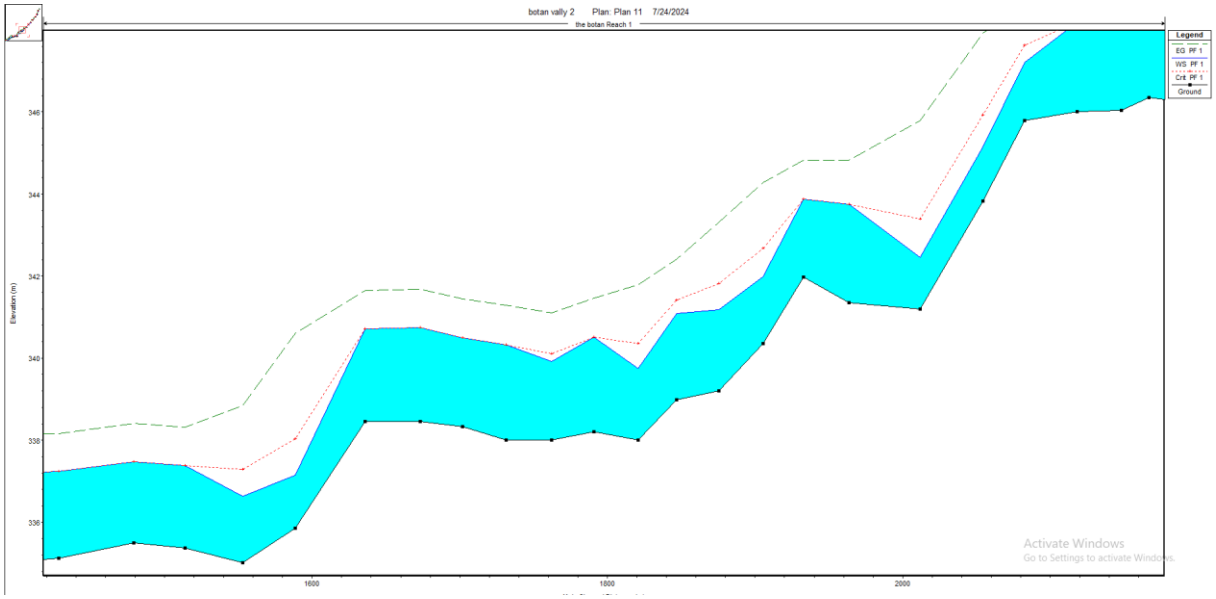


Figure 37 profil plote Natural case zoome

III.1 Cross sections :

Some of the simulations cross-sections from HEC-RAS for the botan valley in its natural condition :

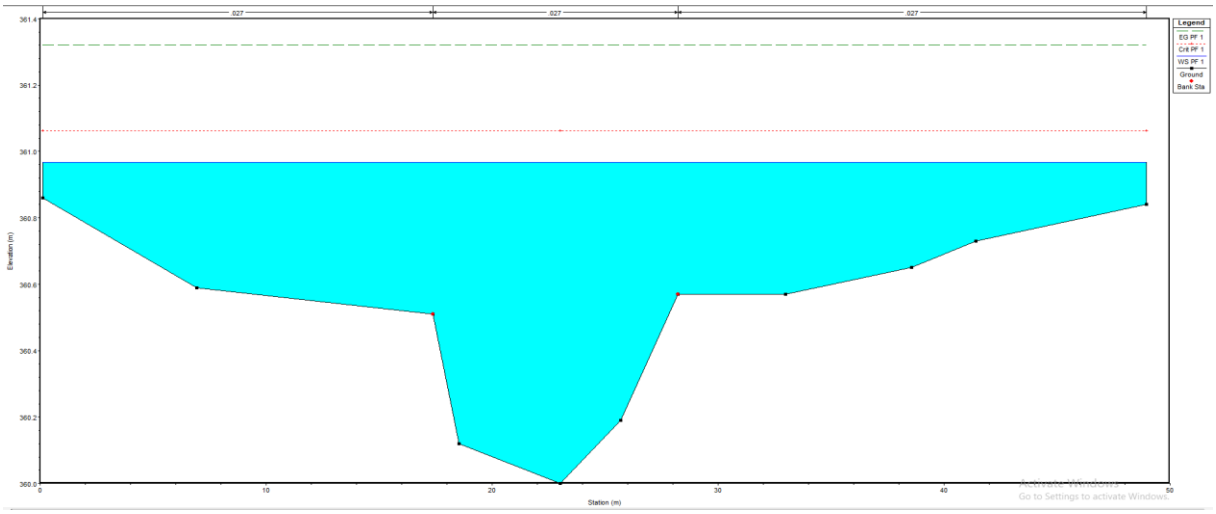


Figure 38 cross section for botan valley

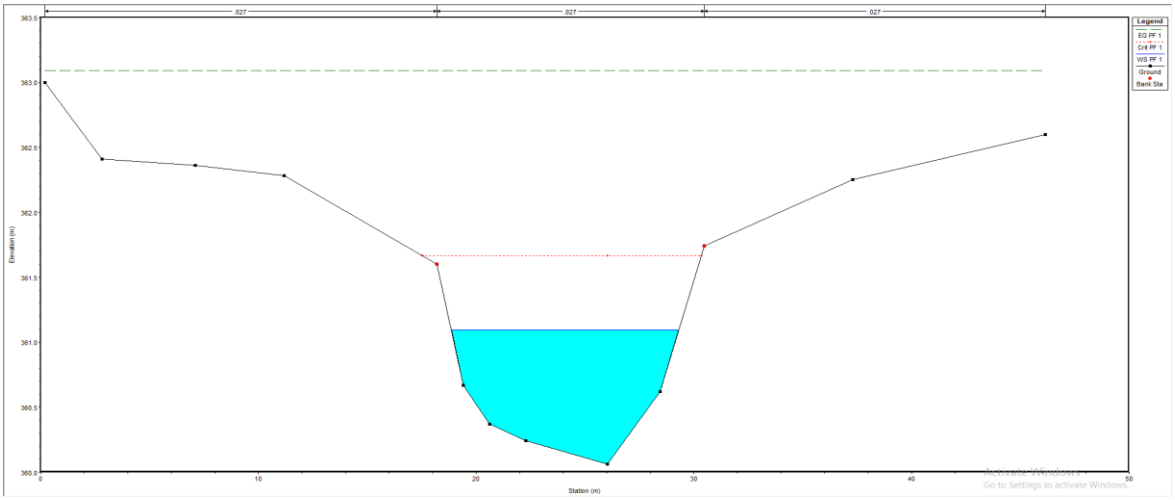


Figure 39 cross section for botan valley

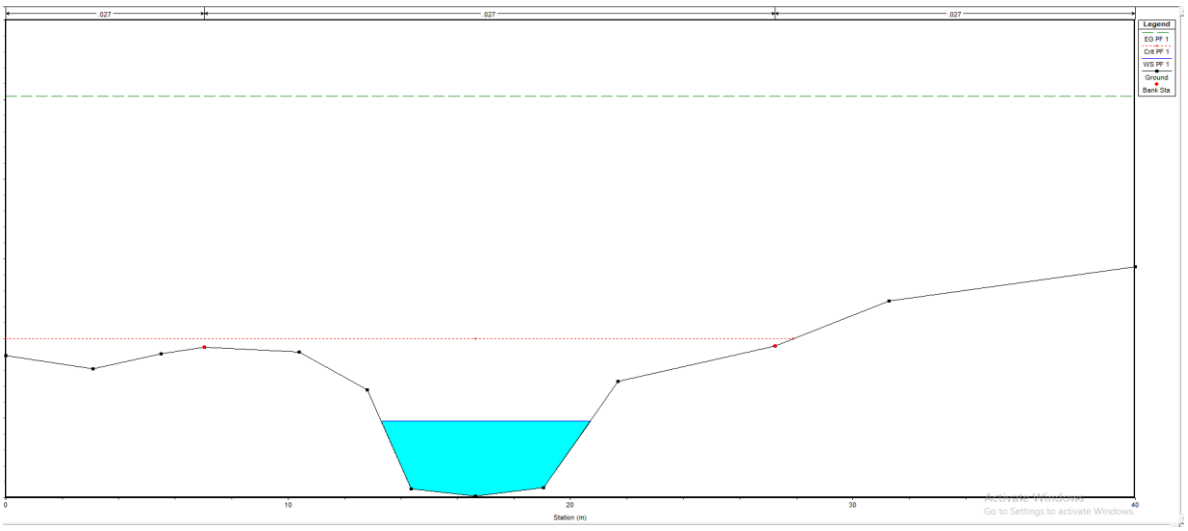


Figure 40 cross section for botan valley

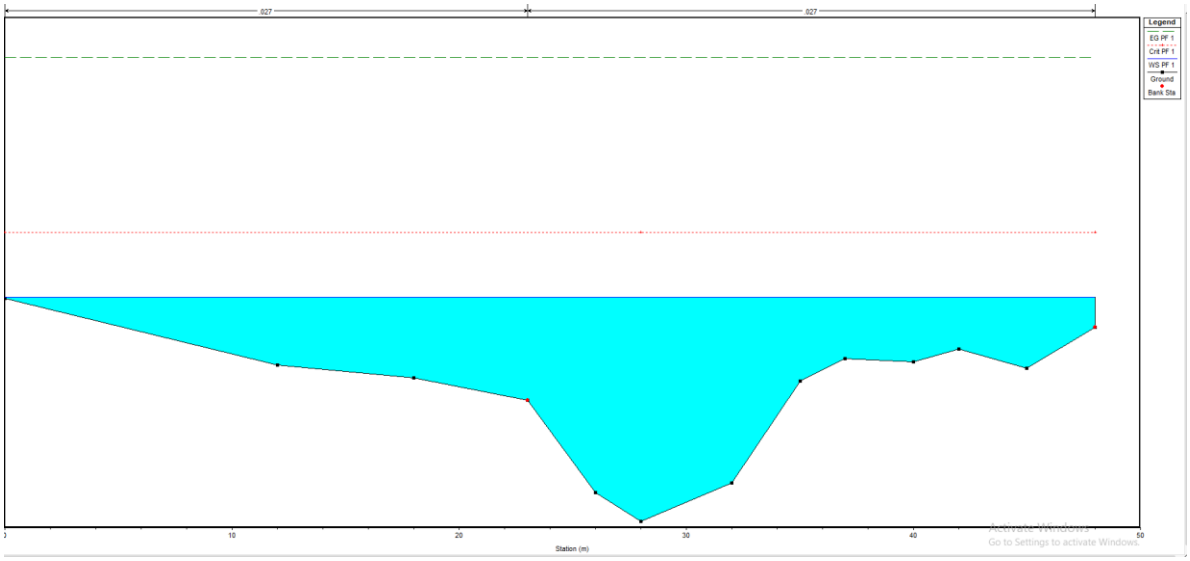


Figure 41 cross section for botan valley

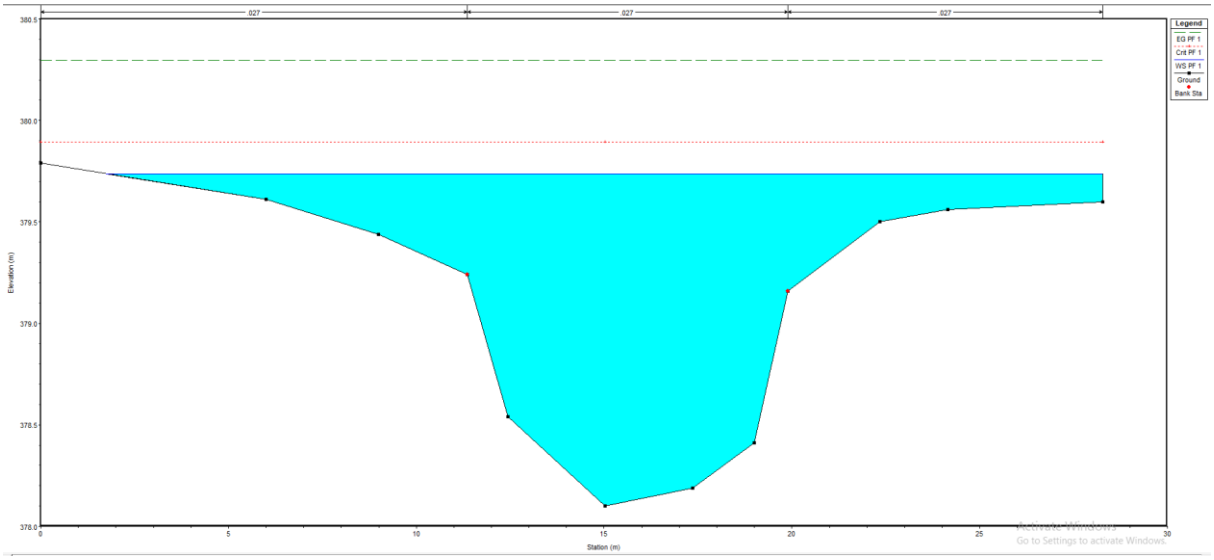


Figure 42 cross section for botan valley

Table 26 Results of simulation of VALLEY OF BOTAN in its natural state on HEC-RAS

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Reach 1	3533	PF 1	32	381.1	380.72	380.72	381.49	0.007345		12.35	8.13	0
Reach 1	3503	PF 1	32	378	379.13	379.7	380.99	0.031686	6.04	7.94	8.04	1.94
Reach 1	3477	PF 1	32	378.14	380.02	380.09	380.41	0.004586	3.01	20.65	33.96	0.82
Reach 1	3435	PF 1	32	378.28	380.12	380.12	380.56	0.007697	2.93	16.38	18.65	0.99
Reach 1	3406	PF 1	32	378.1	379.74	379.89	380.3	0.009759	3.36	15.4	26.54	1.12
Reach 1	3380	PF 1	32	377.08	378.42	378.96	379.8	0.029595	5.19	9.25	12.24	1.9
Reach 1	3350	PF 1	32	373.02	373.97	375	378.04	0.098	8.94	5.37	7.42	3.36
Reach 1	3314	PF 1	32	371.19	372.65	373.37	375.19	0.048299	7.06	6.8	7.73	2.41
Reach 1	3287	PF 1	32	370	371.21	372.05	373.92	0.044922	7.38	6.77	8.58	2.39
Reach 1	3260	PF 1	32	370.1	371.29	371.65	372.6	0.024833	5.23	10.68	27.71	1.79
Reach 1	3232	PF 1	32	370.21	371.42	371.57	371.9	0.010062	3.24	18.1	47.16	1.14
Reach 1	3200	PF 1	32	368	368.81	369.37	371.07	0.064668	6.66	7.21	12.11	2.73
Reach 1	3172	PF 1	32	367.09	367.77	368.14	369.1	0.05524	5.46	10.39	34.74	2.45
Reach 1	3141	PF 1	32	366.08	367.96	368	368.46	0.006318	3.16	16.09	20.63	0.93
Reach 1	3105	PF 1	32	366.28	367.19	367.48	368.03	0.023878	4.27	11.89	19.66	1.65
Reach 1	3065	PF 1	32	365.69	367.09	367.15	367.42	0.006453	2.62	20.61	38.64	0.91
Reach 1	3028	PF 1	32	364.05	365.32	366.04	366.86	0.028255	5.5	8.72	10.03	1.88
Reach 1	3001	PF 1	32	363.12	364.7	365.15	365.99	0.025513	5.15	10.25	19.27	1.79
Reach 1	2967	PF 1	32	363.25	364.92	364.92	365.24	0.008294	2.51	19.18	31.34	0.99
Reach 1	2941	PF 1	32	362.06	362.96	363.45	364.64	0.040728	5.73	8.38	12.12	2.2
Reach 1	2917	PF 1	32	362.45	363.4	363.41	363.75	0.008579	2.88	18.71	28.65	1.05
Reach 1	2893	PF 1	32	360.06	361.09	361.67	363.09	0.045145	6.26	7.67	10.43	2.33
Reach 1	2864	PF 1	32	360	360.98	361.29	361.91	0.021299	4.54	12.73	30.84	1.64
Reach 1	2836	PF 1	32	360	360.97	361.06	361.32	0.009901	3.15	20.74	48.84	1.13
Reach 1	2803	PF 1	32	360.03	361.08	361.08	361.27	0.005023	2.31	27.72	60.88	0.81
Reach 1	2772	PF 1	32	360.08	360.91	360.91	361.1	0.006734	2.19	27.1	68.61	0.89

Reach 1	2746	PF 1	32	360.02	361.02	361.02	361.21	0.0049	2.19	28.5	68.61	0.79
Reach 1	2720	PF 1	32	359.82	360.92	360.92	361.16	0.005569	2.32	24.88	65.62	0.84
Reach 1	2693	PF 1	32	359.22	359.92	360.13	360.68	0.048782	4.13	13.15	48	2.2
Reach 1	2666	PF 1	32	355.41	355.95	356.4	358.31	0.122663	6.81	7.05	18.5	3.52
Reach 1	2640	PF 1	32	355.44	356.38	356.61	356.93	0.012053	3.33	15.35	32.98	1.23
Reach 1	2613	PF 1	32	354.61	355.54	355.8	356.42	0.022607	4.42	13.75	46.45	1.67
Reach 1	2588	PF 1	32	352.34	353.51	354.09	355.24	0.033985	5.82	8.24	9.95	2.04
Reach 1	2565	PF 1	32	352.16	353.24	353.51	354.15	0.020875	4.24	11.32	15.78	1.6
Reach 1	2544	PF 1	32	352.22	353.65	353.65	353.9	0.003549	2.41	26.21	56.36	0.71
Reach 1	2520	PF 1	32	352.07	353.55	353.55	353.96	0.005126	2.91	18.74	28.19	0.86
Reach 1	2494	PF 1	32	352.05	353.46	353.52	353.76	0.005294	2.71	23.37	49.56	0.86

Reach 1	2460	PF 1	32	349.13	350.45	351.2	353.12	0.052549	7.24	6.63	7.62	2.48
Reach 1	2428	PF 1	32	349.17	350.96	351.17	351.91	0.01221	4.32	11.11	9.23	1.26
Reach 1	2396	PF 1	32	349.88	350.94	351.05	351.32	0.014083	2.79	18.4	47.47	1.25
Reach 1	2360	PF 1	32	347.12	347.38	347.75	349.75	0.290863	6.82	7.04	35.29	4.87
Reach 1	2337	PF 1	32	347.11	347.68	347.73	347.96	0.014434	2.35	20.47	56.62	1.21

III.2 OVERVIEW

Variations in flow regime along the VALLEY. This is confirmed by Froude number values ranging from 0.71 to 4.87.

The average flow velocity in the valley is between 2.19 and 10.96 m/s, due to steep slopes and the presence of counter-slopes.

The depth varies between 0.8 m and 1.8 m, and the top width varies from 5 to 68.61 m, indicating that the valley bed is not well defined in some sections.

III.3 Flood risk mapping

Having established the flood profiles using HEC-RAS software, our next step is to delimit and map the at-risk flood zones. To do this, we need to know the water levels in different parts of the vally .

III.3.1 Depth map :

Flooding is mainly characterized by its extent and depth. Its determination requires the use of hydraulic models where the topography of minor and major river beds is digitally reproduced (Graguid, 2011). ▪ As a result, three categories of submersion are distinguished according to their depths:

Low submergence: with a depth of less than 0.5 meters

Medium submergence: with a depth of between 0.5 and 1 meter;

High submergence: depths exceeding 1 meter (Graguid, 2011).



Figure 43 Water depth map for the 100-year return period.

From the water depth map obtained, we can see that the water height varies between 0.6 and 5.4 m. The areas at greatest risk of flooding are near the north of the city and the downtown

III.3.2 Velocity map :

Water flow velocities are classified into three classes:

Low velocity: less than 0.2 m/s;

Moderate velocity: between 0.2 m/s and 0.5 m/s;

High velocity: over 0.5 m/s.

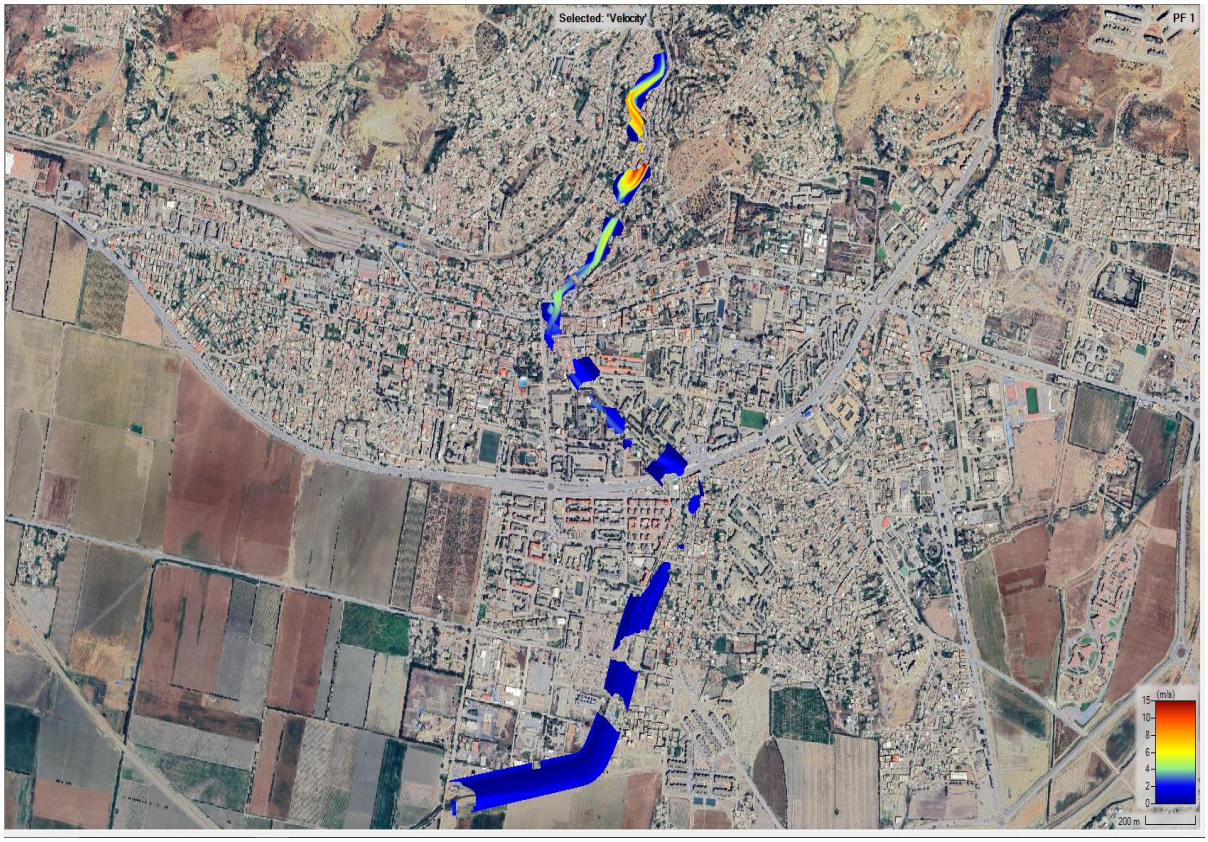


Figure 44 Water velocity map for the 100-year return period.

In the north the velocity reached 9 m/s due to the slope and in the south it holed to 2.3 m/s

III.3.3 Hazard map

A hazard rating is commonly used to describe the direct risk to people exposed to

flood waters. This combines the effect of flood depth and flood velocity with a debris factor. The Hazard Rating formula is given as:

$$HR = d \times (v + n) + DF$$

where

HR = Hazard Rating

d = depth of flooding (m)

v = velocity of floodwaters (m/s)

DF = Debris Facto

rn = 0.5 (constant)

Table 27 Flood Hazard Thresholds

Threshold for Flood Hazard Rating	Degree of Flood Hazard	Description
< 0.75	Low	**Caution** – "Flood zone with shallow flowing water or deep standing water"
0.75 – 1.25	Moderate	**Dangerous for some** – "Danger: Flood zone with deep or fast flowing water"
1.25 – 2.0	Significant	**Dangerous for most** – "Danger: Flood zone with deep fast flowing water"
> 2.0	Extreme	**Dangerous for all** – "Extreme danger: Flood zone with deep fast flowing water"

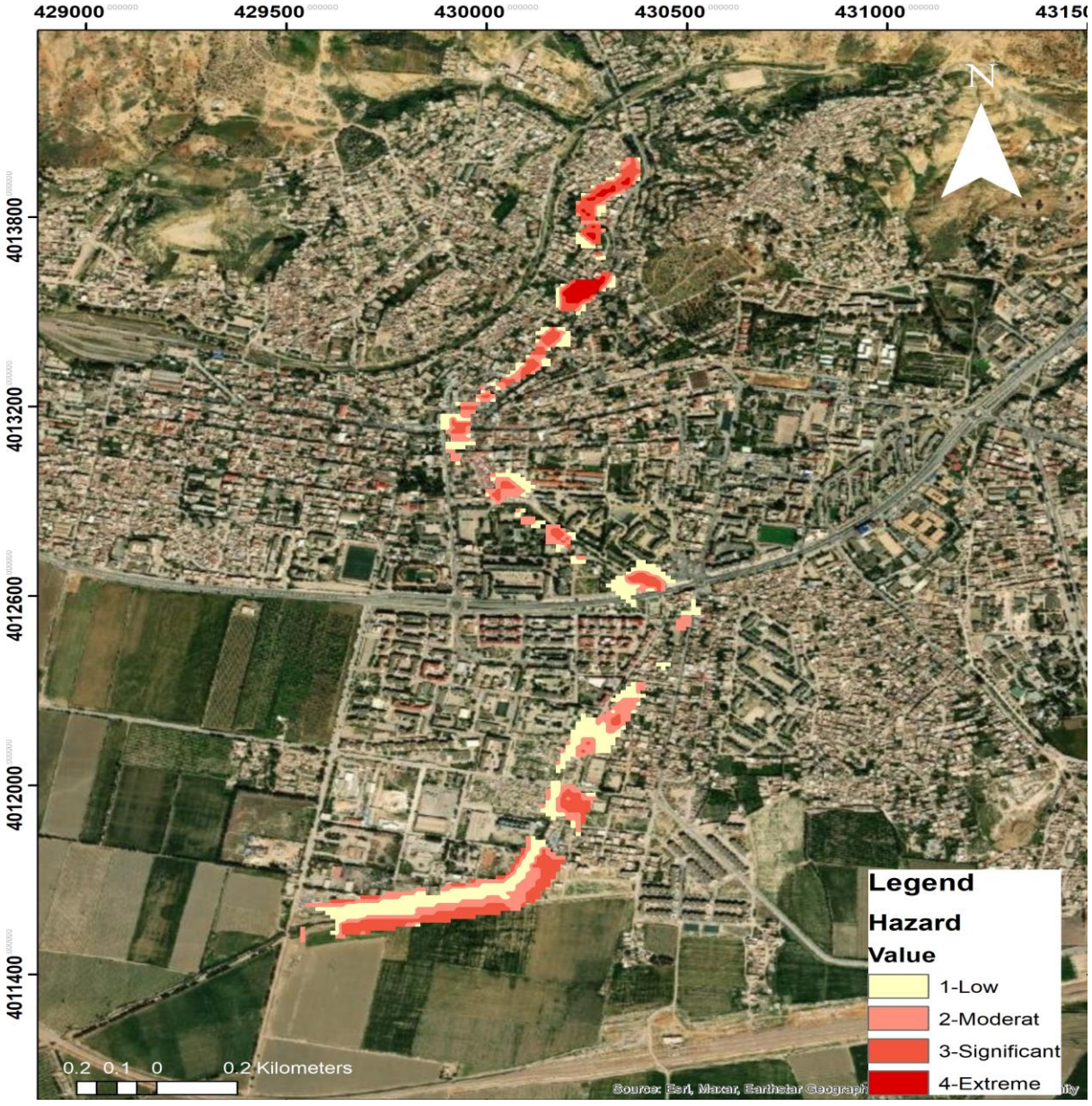


Figure 45 Hazard map

High-risk areas are mainly located along watercourses, mainly in the south and also the north

III.3.4 Vulnerability mapping

Spatial management in areas at risk of flooding aims to integrate risk management into land-use planning. It is therefore necessary to accurately determine the dynamics of risk as a function of urban dynamics. Risk varies greatly according to the type of land use (Guigo et al., 2002).

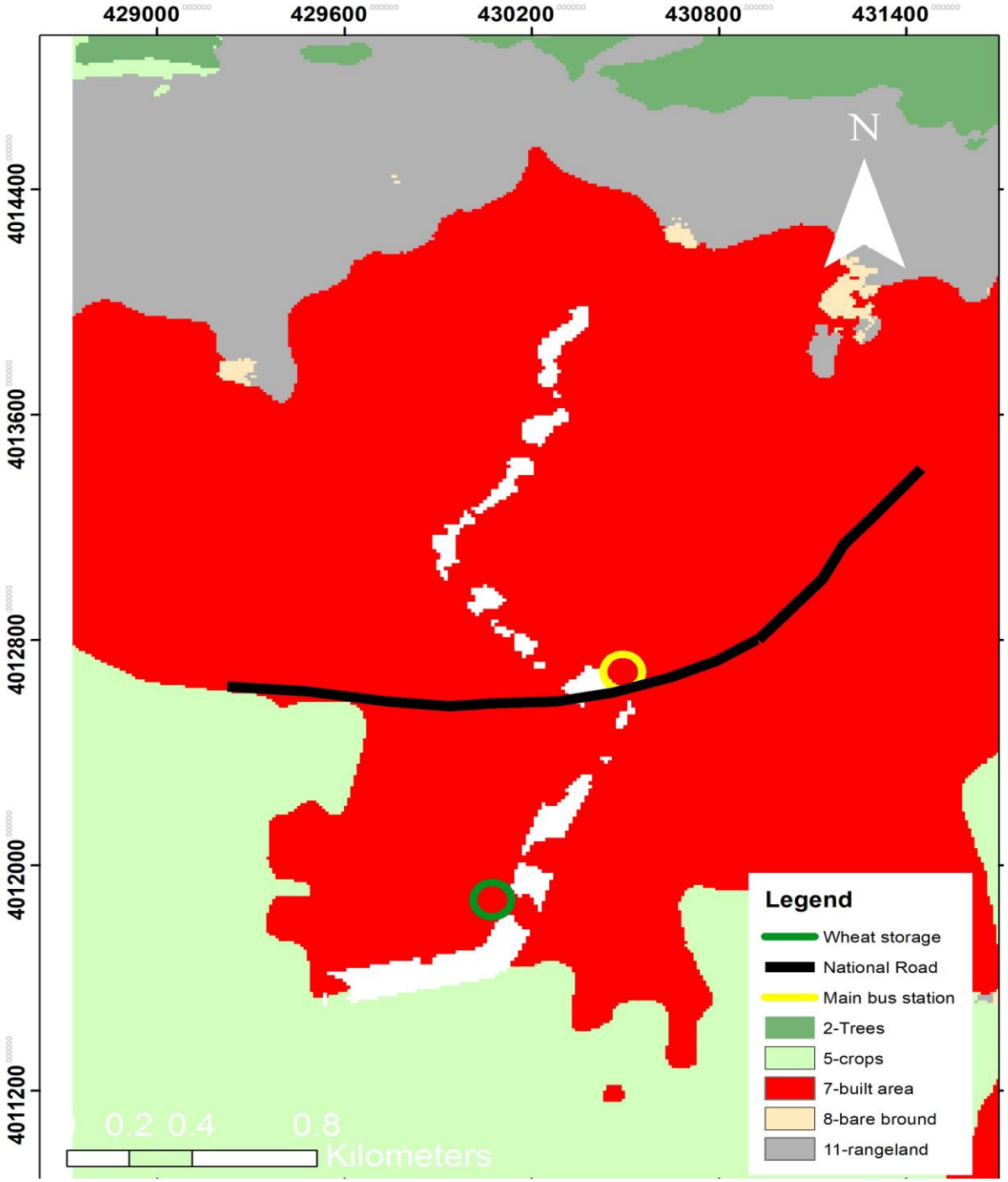


Figure 46 Vulnerability map of the study area.

III.3.5 Risk map

In order to map risk, we need to multiply vulnerability with hazard

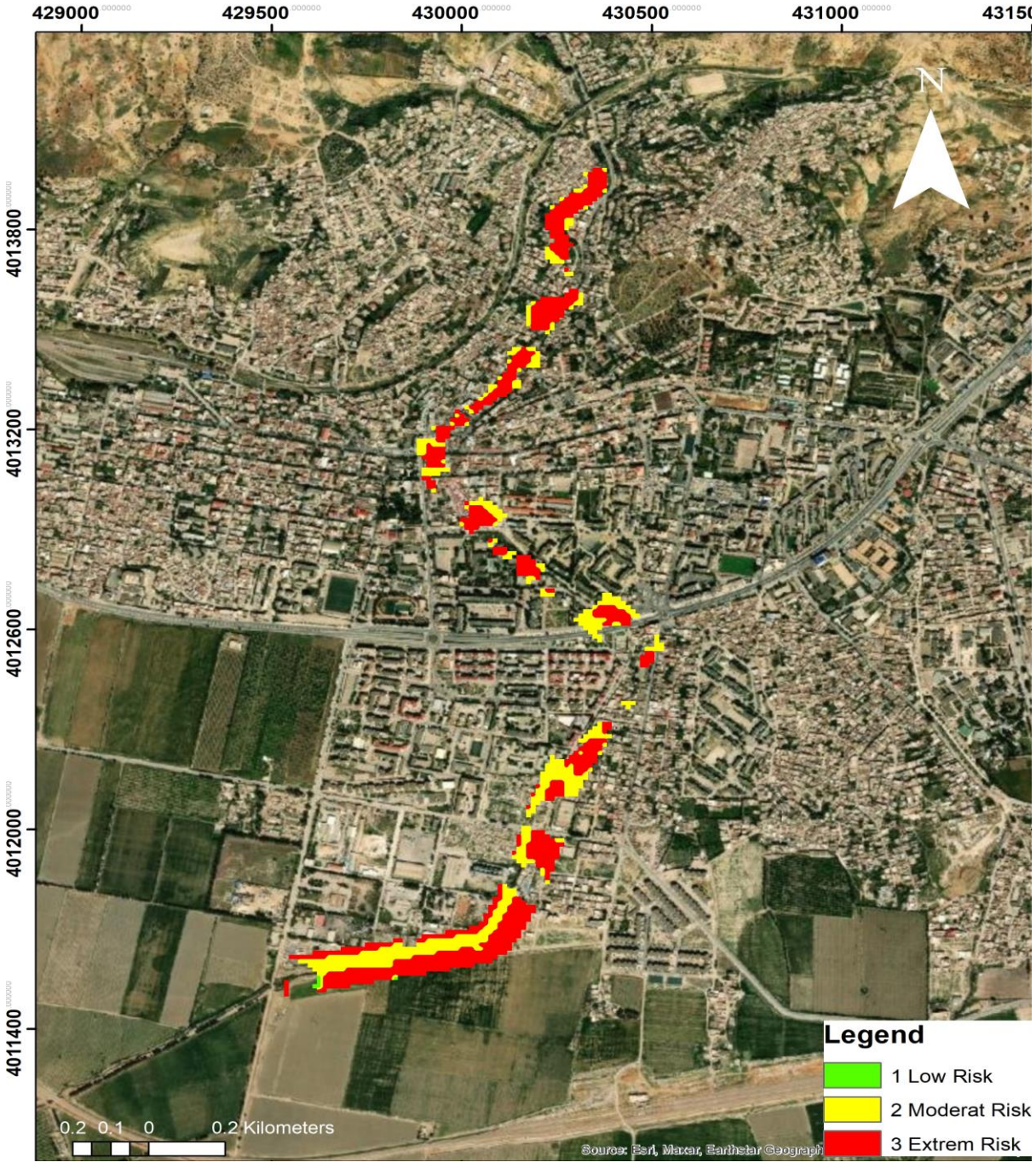


Figure 47 Flood risk map

The flood risk map presents a global overview of areas exposed to high levels of vulnerability in the study region. The results of this map offer crucial insights for risk management and urban planning, facilitating a proactive approach to potential flood-related challenges.

Conclusion

his chapter has enabled us to model the water flow along Botan Valley and understand its behavior during a 100-year flood. Additionally, we have identified the areas affected by flooding and gathered information on various hydraulic parameters.

We have observed that most areas near the watercourses are at risk of flooding during a 100-year flood, either due to the overflow of water from the minor bed

Chapter Five

STUDY OF DEVELOPMENT VARIANTS

I Introduction :

The objective of this study is to provide effective flood protection for the towns located along the Botan valley. This involves selecting the most suitable development solutions based on the options examined in the previous chapters, while taking into account the specific natural characteristics of our study area.

The solutions selected will aim to ensure full protection of the towns bordering the Boutan valley by channeling floodwaters to appropriate outlets. This will involve taking into account key factors such as flow requirements, bank stability and the environmental impact of the proposed developments. The selection process will take place in several distinct stages to identify the most effective and sustainable options for managing flood risk in the region.

Development principles

I.1 The different types of possible developments :

I.1.1 Curage :

This method attempts to optimize water circulation by removing obstacles and sediments that impede its passage through the riverbed. The aim is double : to reduce resistance to flow and increase the volume of water that can be evacuated.

I.1.2 Recalibration :

This method consists in increasing the dimensions of the riverbed, both in width and in depth, in order to increase the possible flow and ensure a sufficient surface area in contact with the water (wetted section) to achieve the desired level of protection against flooding.

I.1.3 Channel realization:

The purpose of this method is to re-establish the river's original course. It is crucial in cases where buildings or roads have been built to trespass on the river's natural bed and flow zone.

I.1.4 Bank protection:

These measures include all constructions designed to maintain the integrity of the land in the face of the effects of water. Riverbanks are sensitive to turbulence caused by rising water levels, while land is at risk of subsidence due to water seeping in after receding. Bank consolidation is particularly important in the vicinity of certain facilities.

I.1.5 Creation of derivation channels:

This method consists in redirecting the flow of a watercourse towards other valleys, thus keeping it away from areas requiring protection. This detour can be total or partial, and its main aim is to reduce the risk of flooding in exposed areas.

I.1.6 Channel sizing formulas:

The formula used for dimensioning is that of Manning Strickler, given by the following formula :

$$Q = \frac{1}{n} R_h^{\frac{2}{3}} . S_m . \sqrt{1}$$

Where the various parameters are :

Q: dimensioning flow rate (m³/s).

n: channel roughness.

Sm: wetted channel section in (m²).

I: slope of stream section (bottom slope) in (m／m).

Rh: hydraulic radius in (m) such that :

$$R_h = \frac{S_m}{P_m}$$

I.2 Naturel slope :

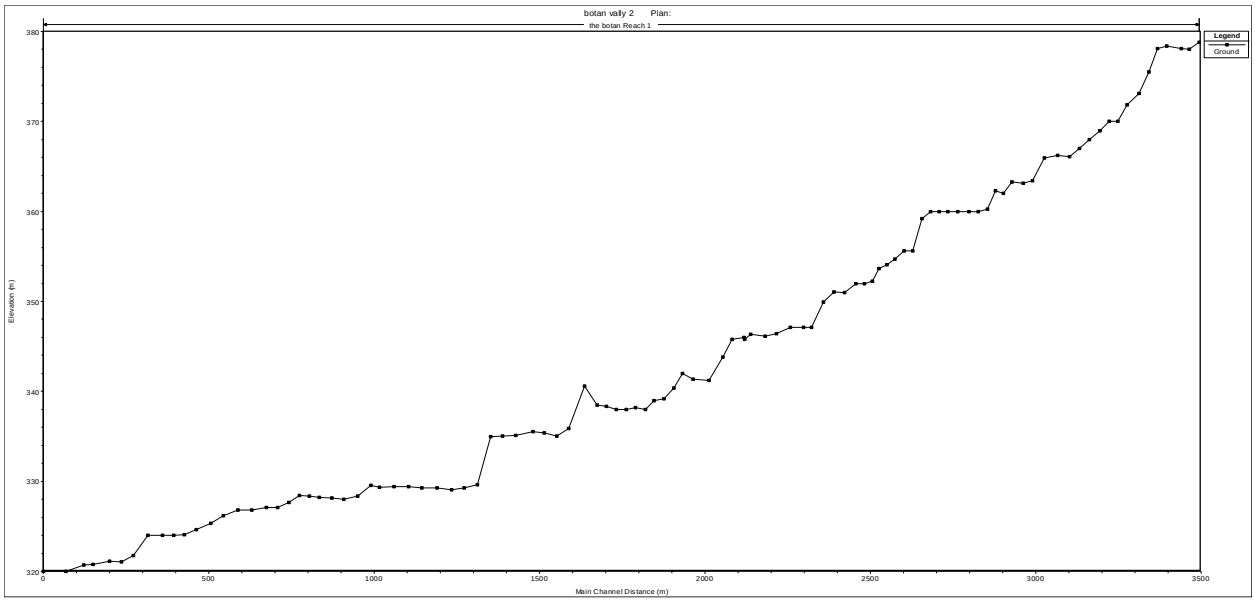


Figure 48 valley natural slope

II Multivraint suggestionsgs

We proposed three variants based on security, ease of operation, and pricing

II.1 Trapeziodal Concrete Channel

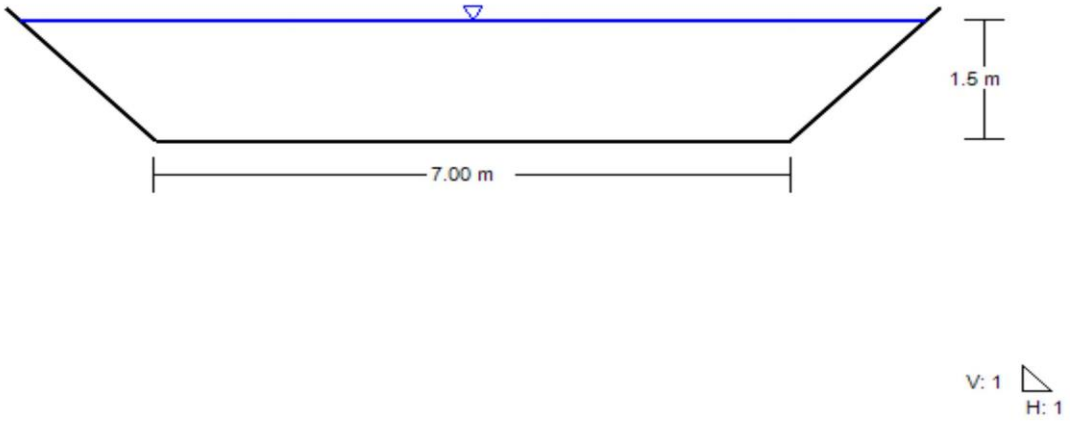
II.1.1 Dimensions :

Channel characteristics are determined using Flow-Master software; The results of the hydraulic calculation for the trapezoidal flume are shown below

Cross Section for Trapezoidal Channel - 1

Project Description	
Friction Method	Manning Formula
Solve For	Discharge

Input Data	
Roughness Coefficient	0.013
Channel Slope	0.001
Normal Depth	1.5
Left Side Slope	1.000
Right Side Slope	1.000
Bottom Width	7.00
Discharge	33.73



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Bentley Systems, Inc. Haestad Methods Solution Center
27 Siemon Company Drive Suite 200 W
Watertown, CT 06795 USA +1-203-755-1666

FlowMaster
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Page 1 of 1

Figure 49 concret channel for botan valley dimentios using flowmaster

II.1.1 Flow parameters

The result of the simulation are shown in the table below :

Table 28 RESULTS OF SIMULTION FOR CONCRET CHANNEL OF BOTAN VALLEY

Reach	River Sta	Profile	Q	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude
				(m)	(m)	(m)	(m)	0	0	(m2)	(m)	-
Reach 1	3533	PF 1	32	378.8	380.3	380.3	381.0	0.009	5.18	6.18	9.57	2.25
Reach 1	3503	PF 1	32	378.0	379.0	379.5	380.8	0.029	7.42	4.31	9.02	3.85
Reach 1	3477	PF 1	32	377.5	378.4	379.0	380.5	0.037	7.95	4.03	8.85	4.27
Reach 1	3435	PF 1	32	376.5	377.3	378.0	380.0	0.012	5.74	5.57	8.69	2.62
Reach 1	3406	PF 1	32	375.4	376.2	377.0	379.49	0.018	6.46	4.95	8.55	3.13
Reach 1	3380	PF 1	32	374	374.6	375.5	378.81	0.030	7.48	4.28	8.39	3.90
Reach 1	3350	PF 1	32	373	373.	374.5	377.95	0.032	7.65	4.18	8.37	4.03
Reach 1	3314	PF 1	32	371	371.6	372.5	376.7	0.046	8.47	3.78	8.26	4.70
Reach 1	3287	PF 1	32	370.2	370.8	371.8	375.66	0.041	8.22	3.89	8.29	4.49
Reach 1	3260	PF 1	32	369.8	370.4	371.4	374.61	0.030	7.49	4.27	8.39	3.91
Reach 1	3232	PF 1	32	369.5	370.2	371.2	373.75	0.022	6.79	4.71	8.49	3.37
Reach 1	3200	PF 1	32	368.5	369.0	369.5	372.84	0.038	8.02	3.99	28.3	4.33
Reach 1	3172	PF 1	32	366.7	367.3	368.1	371.82	0.035	7.84	4.08	8.34	4.19
Reach 1	3141	PF 1	32	366	366.69	367.5	370.83	0.030	7.5	4.27	8.39	3.92
Reach 1	3105	PF 1	32	365	365.6	366.5	369.85	0.031	7.53	4.25	8.38	3.94
Reach 1	3065	PF 1	32	364.5	365.2	366.0	368.68	0.021	6.7	4.78	8.51	3.31
Reach 1	3028	PF 1	32	364	364.7	365.6	367.88	0.017	6.28	5.10	8.58	3.00
Reach 1	3001	PF 1	32	363	363.7	364.6	367.31	0.022	6.86	4.66	8.48	3.43
Reach 1	2967	PF 1	32	362.2	362.9	363.7	366.56	0.023	6.93	4.62	8.47	3.48
Reach 1	2941	PF 1	32	361	361.6	362.5	365.86	0.031	7.54	4.24	8.38	3.95
Reach 1	2917	PF 1	32	360.2	360.8	361.7	365.17	0.033	7.67	4.17	8.36	4.05
Reach 1	2893	PF 1	32	359.8	360.51	361.35	364.41	0.02	7.24	4.42	8.42	3.71
Reach 1	2864	PF 1	32	359.3	360.04	361.01	363.64	0.02	6.91	4.63	8.48	3.46
Reach 1	2836	PF 1	32	359.1	359.9	360.89	362.92	0.02	7.19	4.45	8.6	3.68
Reach 1	2803	PF 1	32	359	359.89	360.89	362.26	0.02	7.32	4.37	8.78	3.78
Reach 1	2772	PF 1	32	359	360.01	360.73	361.79	0.02	7.41	4.32	9.03	3.85
Reach 1	2746	PF 1	32	358.8	359.81	360.35	361.59	0.02	7.41	4.32	9.03	3.85
Reach 1	2720	PF 1	32	358.5	359.49	360.05	361.37	0.03	7.58	4.22	8.98	3.98
Reach 1	2693	PF 1	32	356.5	357.09	357.98	360.81	0.02	7.05	4.54	10.17	3.57
Reach 1	2666	PF 1	32	355	355.68	356.43	359.97	0.03	7.67	4.17	8.36	4.05
Reach 1	2640	PF 1	32	354.5	355.21	356.27	359.17	0.02	7.32	4.37	8.41	3.78
Reach 1	2613	PF 1	32	354	354.73	355.74	358.42	0.02	7.01	4.56	8.46	3.54
Reach 1	2588	PF 1	32	353.5	354.24	355.31	357.82	0.02	6.89	4.64	8.48	3.45
Reach 1	2565	PF 1	32	353	353.74	354.52	357.32	0.02	6.89	4.64	8.48	3.45
Reach 1	2544	PF 1	32	352.2	352.94	353.73	356.55	0.02	6.91	4.63	8.47	3.46
Reach 1	2520	PF 1	32	351.8	352.6	353.43	355.59	0.01	6.15	5.20	8.61	2.91
Reach 1	2494	PF 1	32	351.6	352.47	353.34	354.97	0.01	5.51	5.81	8.74	2.47
Reach 1	2460	PF 1	32	351	351.85	352.5	354.5	0.01	5.72	5.59	8.69	2.61
Reach 1	2428	PF 1	32	350.8	351.7	352.21	354.01	0.04	8.23	3.89	8.81	4.50
Reach 1	2396	PF 1	32	349.3	350.06	351.04	353.42	0.02	6.62	4.83	8.52	3.25
Reach 1	2360	PF 1	32	347.5	348.18	348.82	352.47	0.03	7.68	4.17	8.36	4.06

Reach 1	2337	PF 1	32	347.11	347.38	347.74	349.87	0.04	8.49	3.77	35.89	4.72
Reach 1	2297	PF 1	32	346.8	347.75	347.93	348.58	0.01	6.42	4.98	31.66	3.10
Reach 1	2253	PF 1	32	346.34	347.73	347.91	348.34	0.02	7.19	4.45	44	3.68
Reach 1	2220	PF 1	32	346.15	347.7	347.7	348.37	0.017	6.32	5.06	10.11	3.03
Reach 1	2176	PF 1	32	346.1	346.98	347.37	348.17	0.016	6.18	5.18	18.79	2.93
Reach 1	2136	PF 1	32	346	347.55	347.55	348.22	0.006	4.78	6.69	10.11	1.99
Reach 1	2101	PF 1	32	345.79	347.09	347.34	348.1	0.02	6.95	4.60	9.6	3.49
Reach 1	2073	PF 1	32	343.82	344.61	345.37	347.71	0.02	7.32	4.37	8.58	3.78
Reach 1	2030	PF 1	32	341.27	341.93	342.82	346.56	0.03	7.98	4.01	8.32	4.30
Reach 1	1981	PF 1	32	340.9	341.67	342.45	344.96	0.018	6.41	4.99	8.54	3.09
Reach 1	1950	PF 1	32	340.55	341.36	342.1	344.31	0.015	6.07	5.27	8.62	2.85
Reach 1	1923	PF 1	32	340.2	341.03	341.75	343.83	0.013	5.88	5.44	8.66	2.72
Reach 1	1893	PF 1	32	339.23	340	340.78	343.28	0.019	6.5	4.92	8.54	3.16
Reach 1	1864	PF 1	32	338.69	339.46	340.24	342.72	0.018	6.48	4.94	8.55	3.15
Reach 1	1838	PF 1	32	338.1	338.86	339.65	342.21	0.01	5.58	5.73	8.53	2.51
Reach 1	1808	PF 1	32	338	338.85	339.55	341.5	0.02	6.71	4.77	8.69	3.31
Reach 1	1780	PF 1	32	338	338.95	339.55	341	0.03	7.83	4.09	8.91	4.18
Reach 1	1749	PF 1	32	338	339.08	339.55	340.61	0.02	6.95	4.60	9.17	3.49
Reach 1	1720	PF 1	32	338	339.26	339.55	340.35	0.015	6.1	5.25	9.51	2.87
Reach 1	1691	PF 1	32	338	339.42	339.55	340.24	0.012	5.78	5.54	9.84	2.65
Reach 1	1653	PF 1	32	338	339.39	339.55	340.25	0.009	5.27	6.07	9.78	2.31
Reach 1	1606	PF 1	32	335	336.64	337.4	339.77	0.03	7.73	4.14	8.57	4.10
Reach 1	1570	PF 1	32	335	335.77	336.55	339.08	0.02	7.13	4.49	8.53	3.63

Reach 1	1531	PF 1	32	335	335.9	336.55	338.21	0.04	8.3	3.86	8.81	4.56
Reach 1	1496	PF 1	32	335	336.04	336.55	337.72	0.025	7.09	4.51	9.08	3.60
Reach 1	1445	PF 1	32	335	336.35	336.55	337.28	0.014	5.95	5.38	9.69	2.77
Reach 1	1404	PF 1	32	335	336.55	336.55	337.22	0.006	4.79	6.68	10.11	2.00
Reach 1	1368	PF 1	32	334.9	336.49	336.5	337.17	0.009	5.2	6.15	10.08	2.26
Reach 1	1327	PF 1	32	329.5	330.11	331.09	336.4	0.046	8.48	3.77	8.14	4.71
Reach 1	1287	PF 1	32	329.2	329.95	330.82	334.3	0.028	7.36	4.35	8.35	3.81
Reach 1	1248	PF 1	32	329	329.77	330.55	333.06	0.014	6	5.33	8.54	2.80
Reach 1	1205	PF 1	32	329	329.92	330.55	332.14	0.035	7.68	4.17	8.84	4.06
Reach 1	1158	PF 1	32	329	330.11	330.55	331.56	0.020	6.45	4.96	9.22	3.12
Reach 1	1119	PF 1	32	329	330.4	330.55	331.24	0.011	5.52	5.80	9.86	2.47
Reach 1	1074	PF 1	32	329	330.5	330.55	331.22	0.013	5.67	5.64	10.11	2.57
Reach 1	1030	PF 1	32	329	330.5	330.55	331.22	0.009	5.11	6.26	10.11	2.20
Reach 1	1005	PF 1	32	329	330.5	330.55	331.22	0.009	5.2	6.15	10.1	2.26
Reach 1	963	PF 1	32	328.2	329.2	329.85	330.97	0.031	7.37	4.34	9.04	3.81
Reach 1	922	PF 1	32	328	329.0	329.55	330.63	0.019	6.4	5.00	9.15	3.09
Reach 1	887	PF 1	32	328	329.2	329.55	330.32	0.012	5.61	5.70	9.57	2.53
Reach 1	848	PF 1	32	328	329.3	329.55	330.26	0.006	4.49	7.13	9.77	1.81
Reach 1	817	PF 1	32	328	329.3	329.55	330.26	0.007	4.81	6.65	9.75	2.01
Reach 1	787	PF 1	32	328	329.3	329.55	330.26	0.005	4.38	7.31	9.77	1.75
Reach 1	753	PF 1	32	327.6	328.8	329.24	330.1	0.017	6.16	5.19	9.4	2.91
Reach 1	721	PF 1	32	327.1	328.1	328.66	329.87	0.031	7.35	4.35	9.05	3.80
Reach 1	686	PF 1	32	327.1	328.3	328.66	329.52	0.011	5.52	5.80	9.4	2.47
Reach 1	642	PF 1	32	326.7	327.9	328.32	329.3	0.019	6.35	5.04	9.25	3.05
Reach 1	601	PF 1	32	326.7	328.2	328.3	328.98	0.005	4.48	7.14	9.91	1.81
Reach 1	556	PF 1	32	326.2	327.3	327.75	328.76	0.019	6.36	5.03	9.22	3.06

Reach 1	517	PF 1	32	325.4	326.3	326.96	328.42	0.035	7.66	4.18	8.9	4.04
Reach 1	474	PF 1	32	324.6	325.5	326.19	327.93	0.036	7.74	4.13	8.77	4.11
Reach 1	438	PF 1	32	324.0	324.9	325.61	327.47	0.041	8.04	3.98	8.73	4.35
Reah 1	406	PF 1	32	324	324.9	325.55	326.96	0.009	5.2	6.15	8.93	2.26
Reach 1	372	PF 1	32	324	325.1	325.55	326.56	0.007	4.73	6.77	9.22	1.96

Reach 1	327	PF 1	32	323.9	325.43	325.53	326.21	0.0083	4.95	6.46	9.9	2.10
Reach 1	284	PF 1	32	321.7	322.57	323.34	325.76	0.065	9.21	3.47	8.56	5.33
Reach 1	249	PF 1	32	321.0	321.85	322.63	325.1	0.068	9.34	3.43	8.55	5.44
Reach 1	213	PF 1	32	320.8	321.64	322.35	324.34	0.0536	8.67	3.69	8.68	4.87
Reach 1	164	PF 1	32	320.8	321.82	322.35	323.56	0.0297	7.26	4.41	9.05	3.73
Reach 1	136	PF 1	32	320.6	321.77	322.24	323.32	0.0274	7.08	4.52	9.16	3.59
Reach 1	82	PF 1	32	319.9	320.91	321.49	322.88	0.0274	7.08	4.52	8.94	3.59
Reach 1	14	PF 1	32	319.9	321.18	321.46	322.24	0.0069	4.69	6.82	9.55	1.94

II.1.2 Crosssections

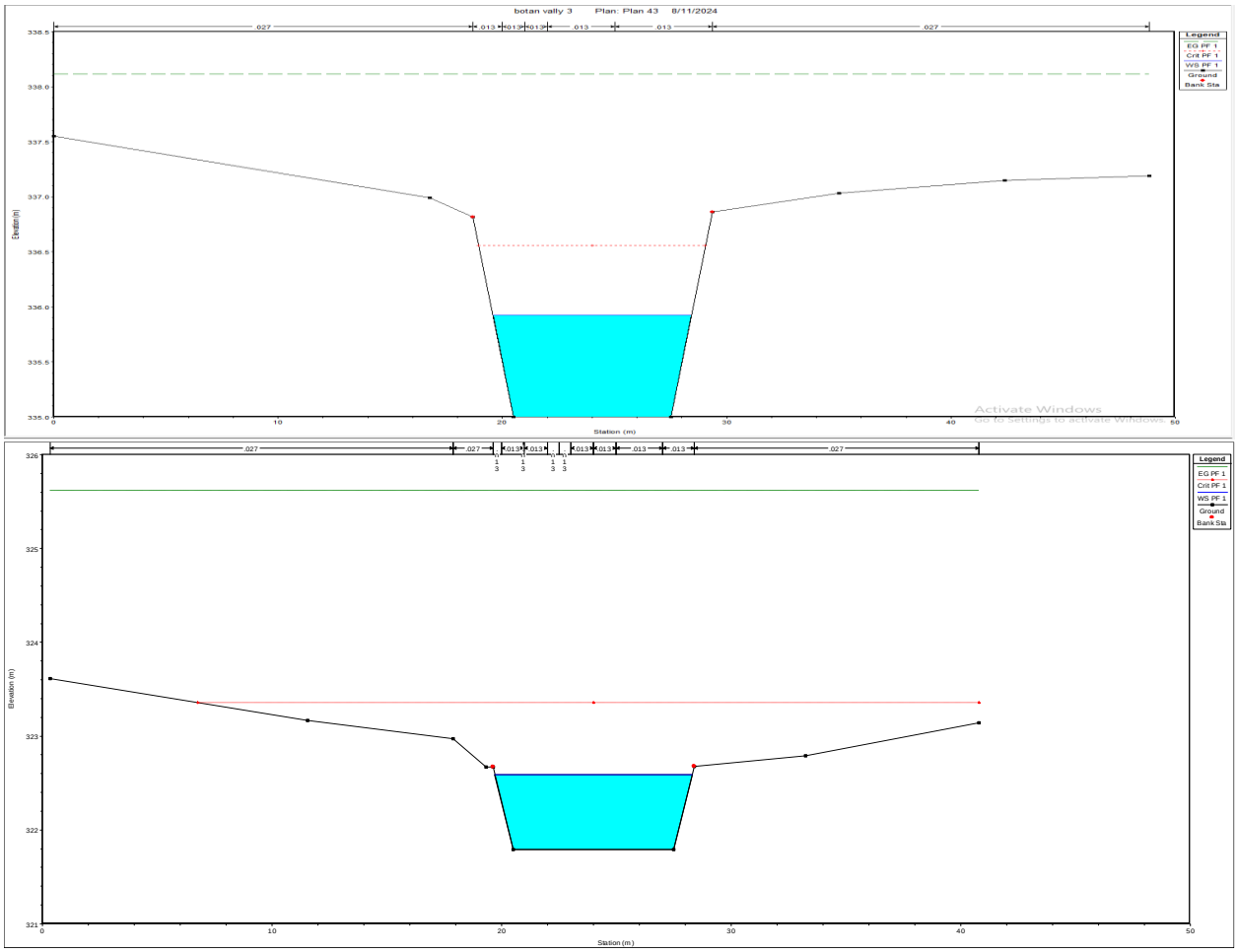


Figure 50 cross sction n 248 from the valley after the simulation

II.1.3 Plot profile :

The plot profile is attached below

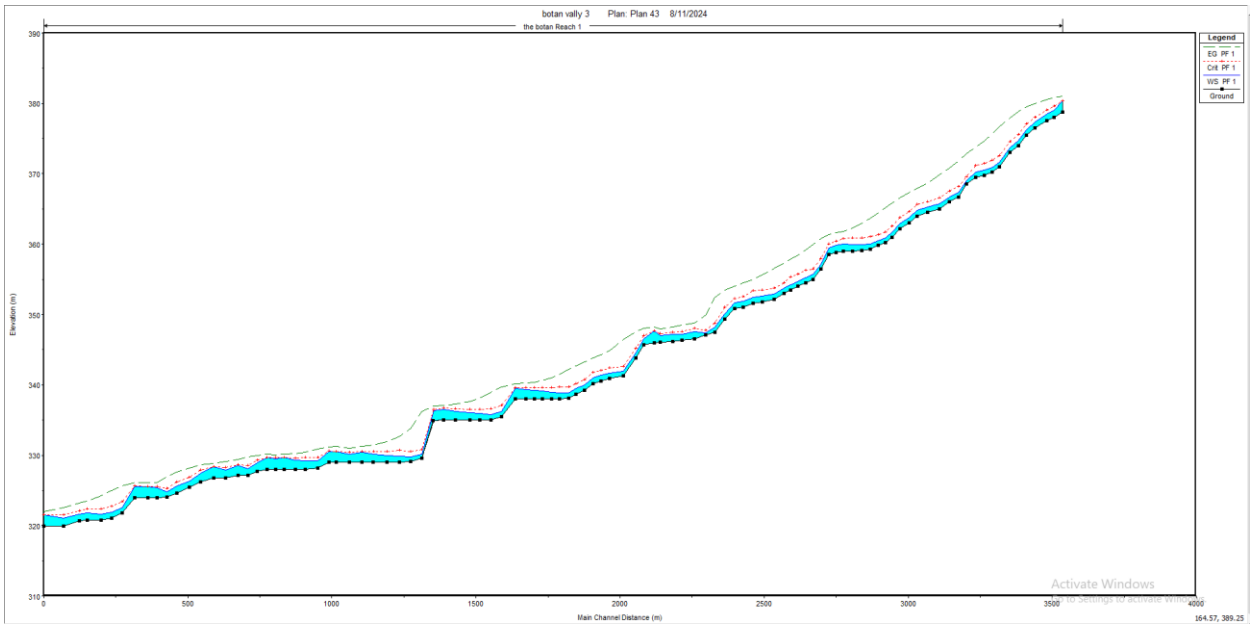


Figure 51 the plot after the simulation

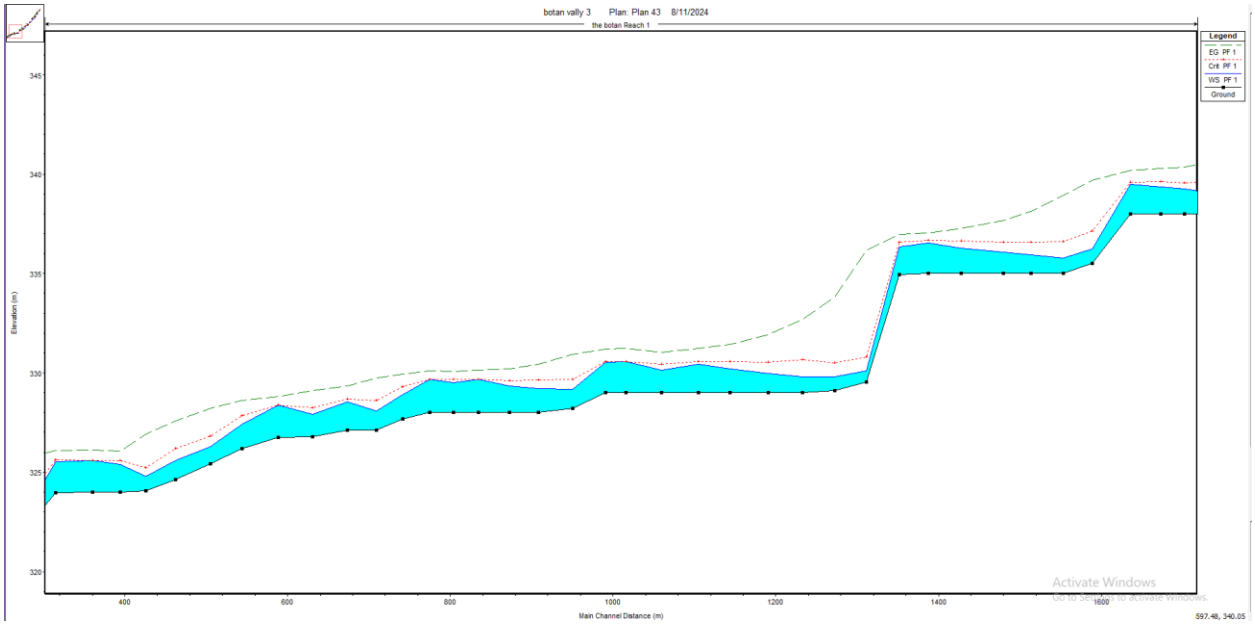


Figure 52 zoomed plot of the valley after the simulation

II.1.4 Comment

The simulation results indicate the following:

- **Water Heights**: 0.4 meters to 1.4 meters

- **Velocities**: 3.43 meters per second to 8.5 meters per second

These conditions are still within the admissible limits for reinforced concrete.

II.1.5 Variant cost estimate

Table 29 Cost estimate for the concret Channel variant for BOTAN VALLEY

Work Description	Unit	volume	unit price	price
			(DA)	(DA)
Earthworks				
Excavated soil of all kinds	**m3**	23044.5	320	7374240
Compacted soil	**m3**	2733.6	2600	7107360
Civil engineering				
Clean concrete	**m3**	2630	7900	20777000
Reinforced concrete	**m3**	5260	34000	178840000
TOTAL HT				199617000
TVA 19%				37927230
TOTAL TTC				**237544230**

II.2 Gabion Baskets

Gabion mattresses are mainly used fozr the construction of revetments and erosion protection devices. They are available in a variety of sizes, the most common of which are 2.0 m long by 1.0 m wide and 0.5 m high, and 2.0 m long by 1.0 m wide and 1.0 m high. Gabion channels are installed in a special way, where the bags are arranged to form a staircase, promoting bank stability.

The advantages of gabions include:

Flexibility: Gabions are flexible, enabling them to adapt to deformations in the terrain.

Ease of installation.

Cost-efficiency: Gabion structures are an economical alternative to their concrete counterparts.

specifications	formula
Wetted cross-section	$\frac{1}{2}\,k(k-1)+bk$
Wetted perimeter	$b+3k-1$
Hydraulic radius	$\frac{0.5k(k-1)+bk}{b+3k-1}$

With:

K: number of cages

B: bed width. .

The gabion baskets design.

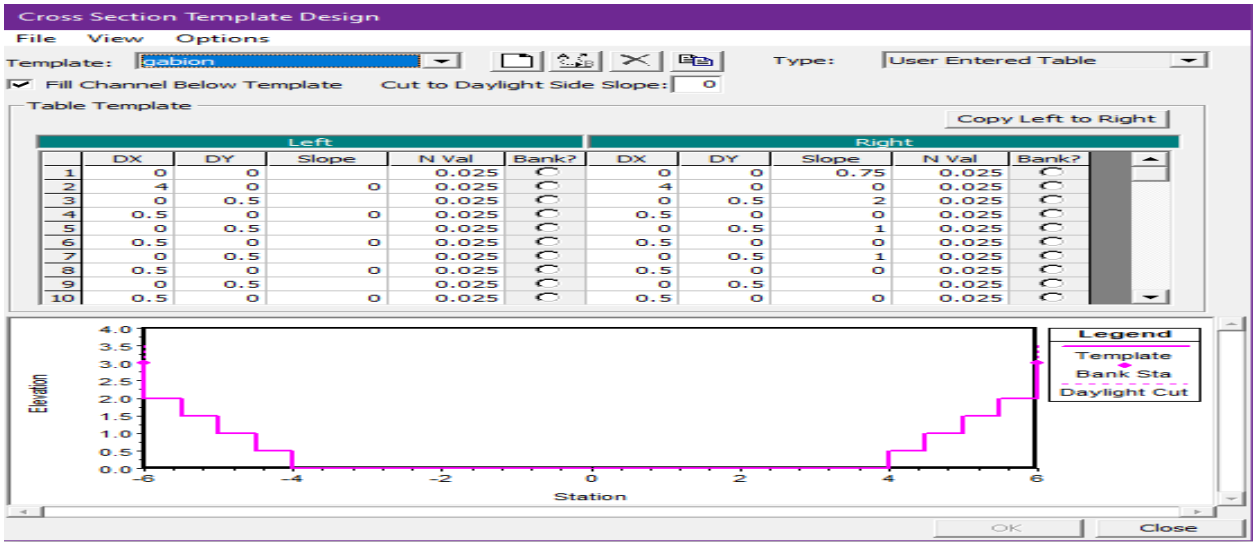


Figure 53 the gabion basket dimensions from HEC RAS

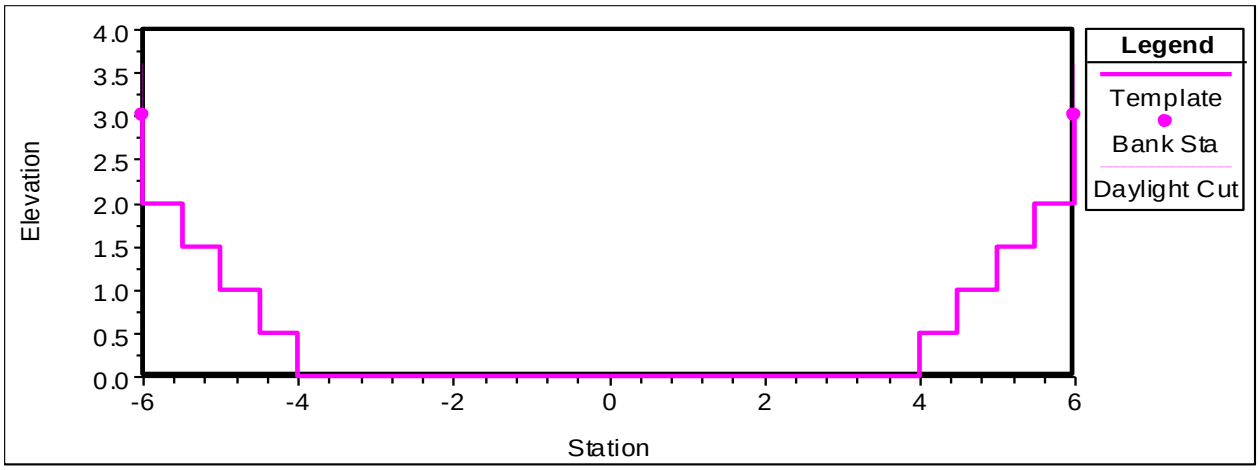


Figure 54 the gabion baskets design.

The gabion baskets design.

II.2.1 Flow parameters

The simulation results are shown in the table below:

Table 30 the simulation results for gabion channel

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Reach 1	3533	PF 1	32	378.8	380.4	380.3	381	0.01	3.74	12.82	9.1	1.01
Reach 1	3503	PF 1	32	378.02	379.0	379.5	381	0.03	5.5	8.72	10	1.88
Reach 1	3477	PF 1	32	378	379.5	379.4	380	0.01	3.61	13.29	10.65	1
Reach 1	3435	PF 1	32	377.5	378.8	378.9	379	0.01	4.24	11.31	10	1.27
Reach 1	3406	PF 1	32	377.5	379.0	379	380	0.01	3.51	13.67	11	1.01
Reach 1	3380	PF 1	32	376.5	377.5	378.1	379	0.03	5.74	8.36	9	1.9
Reach 1	3350	PF 1	32	372.5	373.2	374	377	0.12	9.04	5.31	9	3.76
Reach 1	3314	PF 1	32	371	371.9	372.5	374	0.05	6.7	7.17	9	2.4
Reach 1	3287	PF 1	32	369.5	370.3	371	373	0.05	6.92	6.93	9	2.52

Reach 1	**3260**	**PF 1**	32	369.3	370.5	370.8	372	0.02	4.69	10.24	10	1.48
Reach 1	**3232**	**PF 1**	32	369	370.5	370.5	371	0.01	3.62	13.24	10	1.01
Reach 1	**3200**	**PF 1**	32	367	367.8	368.5	370	0.06	7.16	6.71	9	2.65
Reach 1	**3172**	**PF 1**	32	366	366.9	367.7	369	0.04	6.23	7.71	9	2.15
Reach 1	**3141**	**PF 1**	32	365.5	366.6	367	368	0.02	4.83	9.95	10	1.55
Reach 1	**3105**	**PF 1**	32	364.5	365.6	366	367	0.03	5.35	8.98	10	1.8
Reach 1	**3065**	**PF 1**	32	364.5	366.0	366	367	0.01	3.51	13.67	11	1.01
Reach 1	**3028**	**PF 1**	32	363.5	364.5	365	366	0.03	5.45	8.81	10	1.86
Reach 1	**3001**	**PF 1**	32	362.8	363.9	364.3	365	0.03	5.28	9.08	10	1.77
Reach 1	**2967**	**PF 1**	32	362	363.1	363.5	364	0.02	5.11	9.39	10	1.68
Reach 1	**2941**	**PF 1**	32	361.5	362.7	363	364	0.02	4.82	9.95	10	1.54
Reach 1	**2917**	**PF 1**	32	361.2	362.5	362.6	363	0.01	4.15	11.57	10	1.23
Reach 1	**2893**	**PF 1**	32	359	359.8	360.5	363	0.07	7.47	6.43	9	2.82
Reach 1	**2864**	**PF 1**	32	358	358.9	359.51	361	0.04	6.28	7.65	9	2.17
Reach 1	**2836**	**PF 1**	32	357.9	359.3	359.41	360	0.01	3.91	12.29	10	1.13
Reach 1	**2803**	**PF 1**	32	357.7	359.2	359.21	360	0.01	3.51	13.66	11	1.01
Reach 1	**2772**	**PF 1**	32	357.7	359.2	359.21	360	0.01	3.51	13.66	11	1.01
Reach 1	**2746**	**PF 1**	32	357.6	359.1	359.11	360	0.01	3.51	13.66	11	1.01
Reach 1	**2720**	**PF 1**	32	357.3	358.6	358.81	359	0.01	4.13	11.61	10	1.22
Reach 1	**2693**	**PF 1**	32	357.2	358.7	358.71	359	0.01	3.51	13.66	11	1.01
Reach 1	**2666**	**PF 1**	32	353.8	354.5	355.31	358	0.12	8.86	5.42	9	3.65
Reach 1	**2640**	**PF 1**	32	353.5	354.5	355.01	356	0.03	5.66	8.48	9	1.86
Reach 1	**2613**	**PF 1**	32	353.2	354.5	354.71	355	0.01	4.29	11.18	10	1.3
Reach 1	**2588**	**PF 1**	32	351	351.8	352.52	355	0.07	7.43	6.46	9	2.8
Reach 1	**2565**	**PF 1**	32	350.5	351.5	352.01	353	0.03	5.94	8.08	9	2
Reach 1	**2544**	**PF 1**	32	350.5	352.0	352.01	353	0.01	3.51	13.66	11	1.01
Reach 1	**2520**	**PF 1**	32	350.5	352.0	352.01	353	0.01	3.51	13.66	11	1.01
Reach 1	**2494**	**PF 1**	32	350.5	352.0	352.01	353	0.01	3.51	13.66	11	1.01
Reach 1	**2460**	**PF 1**	32	348.8	349.7	350.31	352	0.05	6.69	7.17	9	2.39
Reach 1	**2428**	**PF 1**	32	348.8	350.3	350.31	351	0.01	3.67	13.08	10	1.02

II.2.2 Cross sections for gabion baskets :

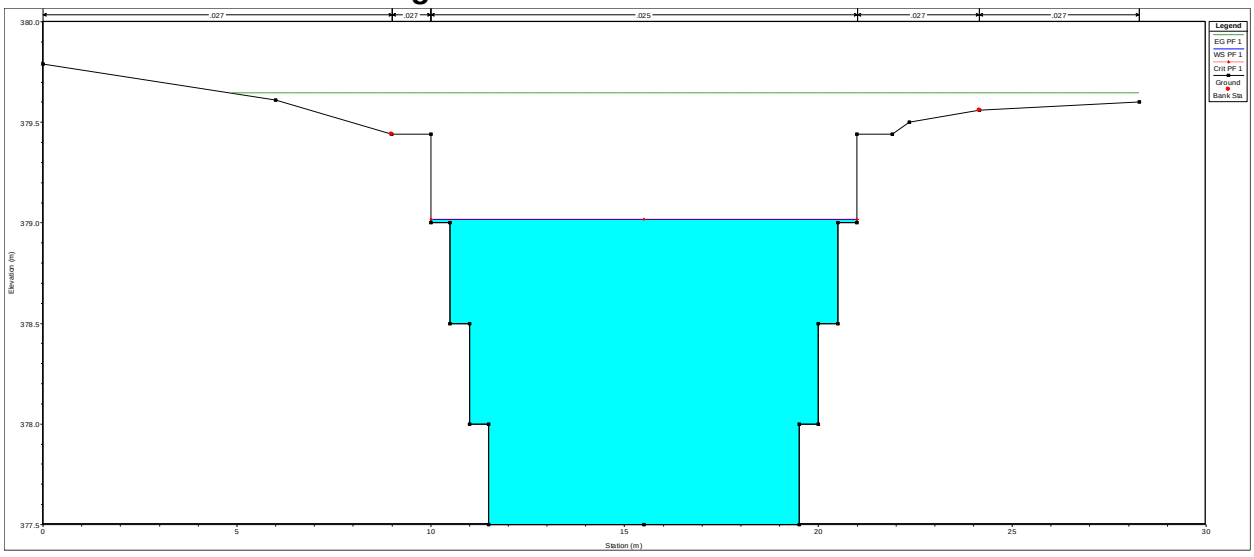


Figure 55 gabion baskets n 3406 for botan valley

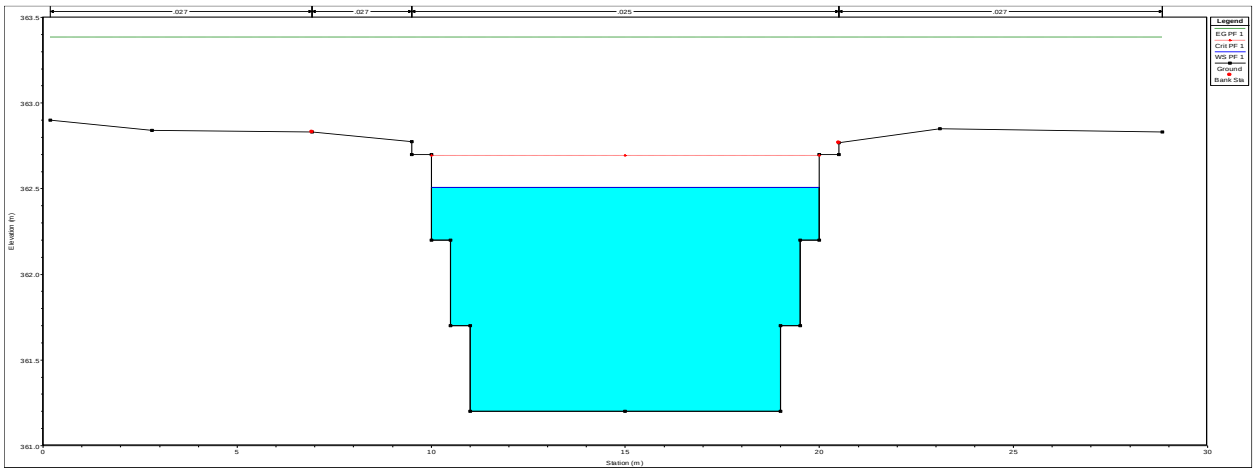


Figure 56 gabion basket n 2917 for botan valley

Comment

The simulation results indicate the following:

- **Water Heights**: 0.6 meters to 1.5 meters
- **Velocities**: 3.51 meters per second to 7.47 meters per second

These conditions are still within the admissible limits for gabion cages

II.2.3 Variant cost estimate

Table 31 Cost estimate for the gabions channel variant for BOTAN VALLEY

Work Description	Unit	volum	unit price	price
			(DA)	
Earthworks				
Excavated soil of all kinds	**m3**	23044.5	320	7374240
Compacted soil	**m3**	1020	850	867000
Civil engineering				
Gabion for embankments	**m3**	12530	5400	67662000
Reno mattress bed	**m3**	8370	3200	26784000
TOTAL HT				102687240
TVA 19%				19510575.6
TOTAL TTC				**122197815.6**

II.3 Hard rocks dimensions

The third proposal involves the creation of a trapezoidal rock channel. The characteristics of the channel are determined using Flow-Master software; below are the results of the hydraulic calculation for the trapezoidal channel

II.3.1 Dimensions

Channel characteristics are determined using Flow-Master software; The results of the hydraulic calculation for the trapezoidal hard rocks are shown below

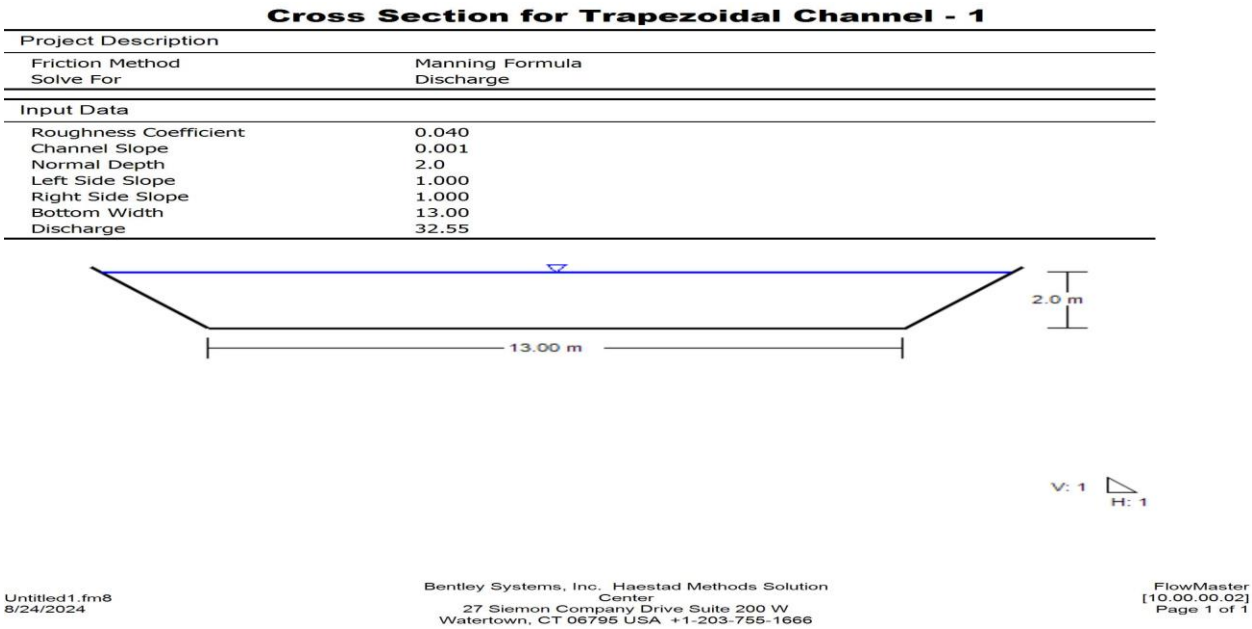


Figure 57 hard rocks dimensions by flow master

II.3.2 Flow parameters

The simulation results are shown in the table below:

Table 32 simulation results for hard rocks Channel

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
Reach 1	**3503**	**PF 1**	**32**	378	379	379	381	0.066	6.56	7.31	11.91	2.67
Reach 1	**3477**	**PF 1**	**32**	378	379	379	380	0.005	2.39	20.09	14.98	0.66
Reach 1	**3435**	**PF 1**	**32**	378	379		379	0.009	2.84	16.93	14.55	0.84
Reach 1	**3406**	**PF 1**	**32**	378	379	379	379	0.013	3.22	14.92	14.27	1
Reach 1	**3380**	**PF 1**	**32**	377	377	378	378	0.048	4.9	9.8	13.54	1.84
Reach 1	**3350**	**PF 1**	**32**	372	372	373	375	0.254	8.27	5.8	12.93	3.94
Reach 1	**3314**	**PF 1**	**32**	371	372	372	373	0.022	3.84	12.5	13.93	1.29
Reach 1	**3287**	**PF 1**	**32**	370	371	371	372	0.049	4.94	9.72	13.52	1.86
Reach 1	**3260**	**PF 1**	**32**	369	370	370	371	0.018	3.54	13.54	14.08	1.15
Reach 1	**3232**	**PF 1**	**32**	369	370	370	370	0.016	3.44	13.94	14.13	1.11
Reach 1	**3200**	**PF 1**	**32**	367	368	368	369	0.082	5.81	8.26	13.31	2.35
Reach 1	**3172**	**PF 1**	**32**	366	367	367	368	0.031	4.24	11.33	13.76	1.49
Reach 1	**3141**	**PF 1**	**32**	366	367	367	367	0.013	3.22	14.92	14.27	1

Reach 1	**3105**	**PF 1**	**32**	365	366	366	367	0.019	3.64	13.19	14.03	1.2
Reach 1	**3065**	**PF 1**	**32**	365	366	366	366	0.013	3.22	14.92	14.27	1
Reach 1	**3028**	**PF 1**	**32**	364	364	365	365	0.036	4.48	10.72	13.67	1.61
Reach 1	**3001**	**PF 1**	**32**	363	364	364	364	0.019	3.63	13.21	14.03	1.2
Reach 1	**2967**	**PF 1**	**32**	362	363	363	364	0.015	3.37	14.24	14.18	1.07
Reach 1	**2941**	**PF 1**	**32**	361	362	362	363	0.057	5.17	9.28	13.46	1.99
Reach 1	**2917**	**PF 1**	**32**	361	362	362	362	0.015	3.34	14.39	14.2	1.06
Reach 1	**2893**	**PF 1**	**32**	359	361	360	361	0.002	1.71	28.13	16.02	0.41
Reach 1	**2864**	**PF 1**	**32**	359	361		361	0.002	1.72	29.43	29.52	0.41
Reach 1	**2836**	**PF 1**	**32**	359	361		361	0.002	1.61	35.28	48.84	0.39
Reach 1	**2803**	**PF 1**	**32**	359	361		361	0.003	1.95	26.08	46.16	0.49
Reach 1	**2772**	**PF 1**	**32**	359	361		361	0.003	1.82	28.6	56.46	0.58
Reach 1	**2746**	**PF 1**	**32**	359	360	360	361	0.013	3.22	14.92	14.27	1
Reach 1	**2720**	**PF 1**	**32**	359	360	360	360	0.018	3.6	13.32	14.05	1.18
Reach 1	**2693**	**PF 1**	**32**	357	358	358	359	0.055	5.12	9.37	13.47	1.96
Reach 1	**2666**	**PF 1**	**32**	354	354	355	357	0.124	6.6	7.27	13.16	2.84
Reach 1	**2640**	**PF 1**	**32**	354	355	355	355	0.009	2.8	17.13	14.58	0.83
Reach 1	**2613**	**PF 1**	**32**	354	355	355	355	0.013	3.22	14.92	14.27	1
Reach 1	**2588**	**PF 1**	**32**	352	353	353	354	0.043	4.73	10.15	13.59	1.75
Reach 1	**2565**	**PF 1**	**32**	352	353	353	353	0.007	2.65	18.1	14.71	0.76
Reach 1	**2544**	**PF 1**	**32**	351	353		353	0.003	1.89	25.41	15.67	0.47
Reach 1	**2520**	**PF 1**	**32**	351	353		353	0.004	2.11	22.75	15.33	0.55
Reach 1	**2494**	**PF 1**	**32**	351	352	352	353	0.013	3.22	14.92	14.27	1
Reach 1	**2460**	**PF 1**	**32**	349	350	350	352	0.093	6.05	7.94	13.26	2.5
Reach 1	**2428**	**PF 1**	**32**	349	351	350	351	0.004	2.12	22.6	15.31	0.56
Reach 1	**2396**	**PF 1**	**32**	349	350	350	351	0.012	3.22	14.92	14.27	1

Cross-sections

Hard rocks variant simulation results using Hec-ras the cross-sections are shown below rock cross

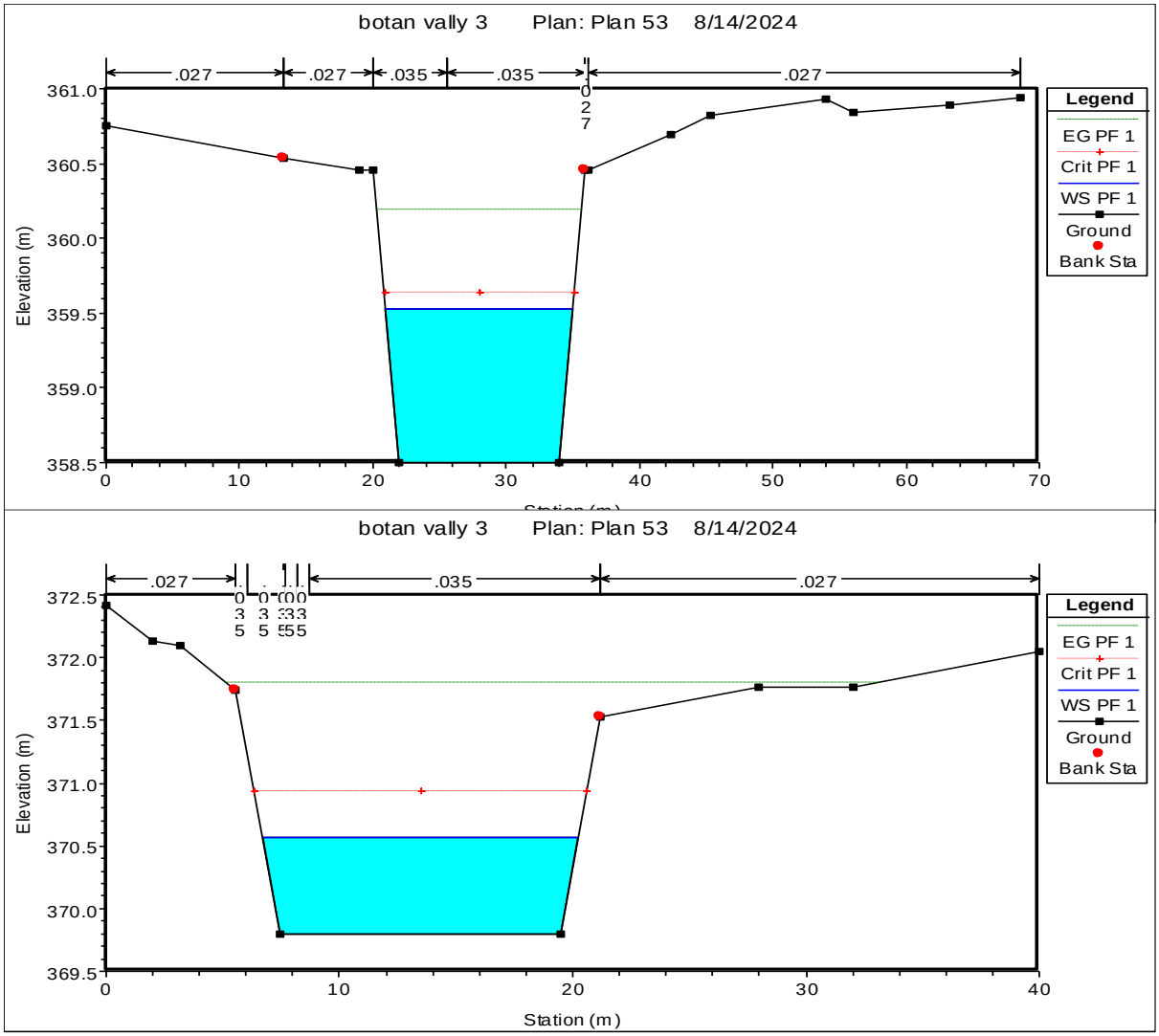


Figure 58 hard rocks cross section N 2720

II.3.3 Comment

The simulation results indicate the following:

- **Water Heights**: 0.6 meters to 1.5 meters
- **Velocities**: 1.61 meters per second to 5.81 meters per second

These conditions are still within the admissible limits for gabion cages

II.3.4 Variant cost estimate

Table 33 Cost estimate for the rockfill channel variant for BOTAN VALLEY

Work Description	Unit	volum	unit price	price
			(DA)	
Earthworks				
Excavated soil of all kinds	**m3**	13826.7	320	4424544
Compacted soil	**m3**	510	850	433500
Civil engineering				
Rocks	**m3**	4850	6400	31040000
TOTAL HT				35898044
TVA 19%				6820628.36
TOTAL TTC				**42718672.36**

II.4 Culvert and bridges

The valley crosses the road at two main points and two smaller ones, the smaller ones constructed in the 1980s using metal models. The larger crossings are extremely important due to their location and strategic value.
The first major crossing is located to the north of the city, where the natural slope of the terrain is very steep. This is the only bridge linking Jardin City to the N4B from the east.
The second major crossing carries the N4 National Road and lies near the bus station in the center of town.

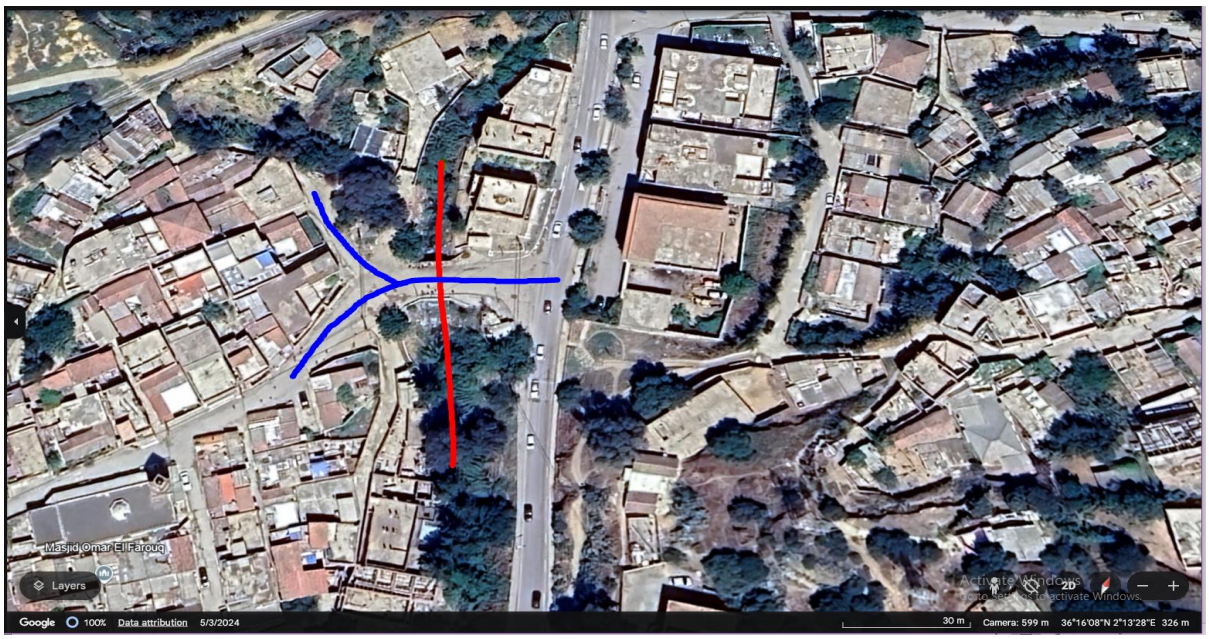


Figure 59 the jardine city culvert

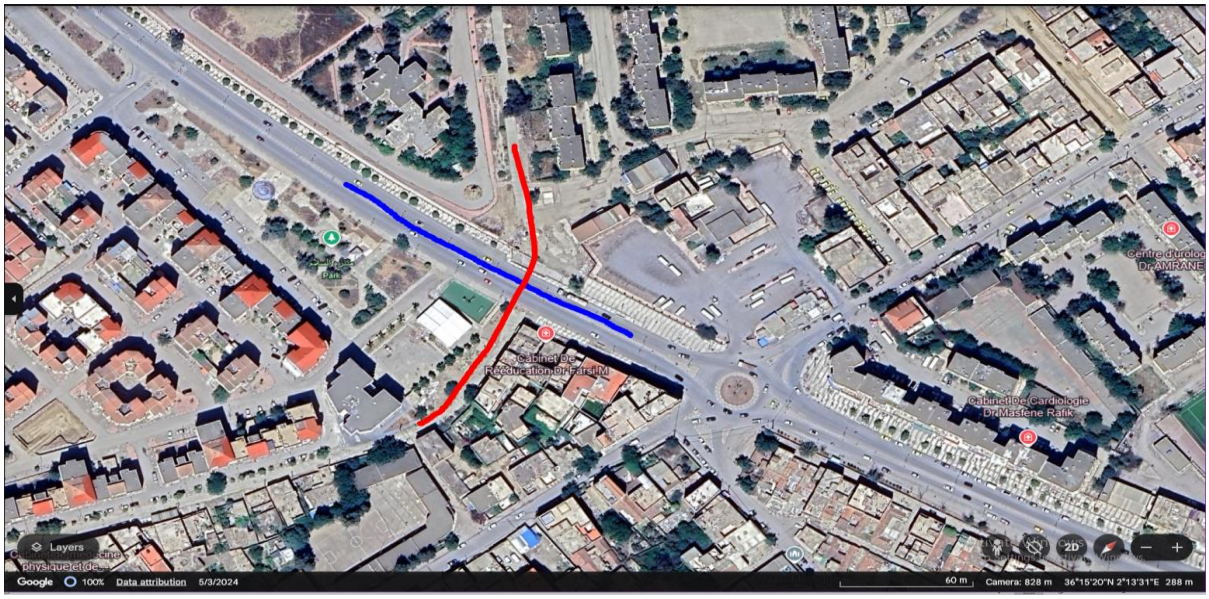


Figure 60 the national road N4 colvert

II.4.1 Culvert proposal and DIMENTIOS

Frames are reinforced concrete elements of rectangular sections generally consisting of inner gaskets at the junction of vertical (pedestrian) and horizontal (slabs) plans, as well as joints between elements.
Special items can be made upon request (dalot look, dalot with manhole...).
The Benefits: Installation on site very easy, decreasing labor time and costs.
Multiple uses: hydraulic works, lower passages, technical galleries, wells, gazebo
Laying under the road, under the railroad, under the sidewalk...
Covering from 0 to several meters (filling).
Areas of Application: Three main applications can be distinguished:
Hydraulic works: The elements are generally called rectangular sewers that can be laid at a low filling height.

Technical galleries: They allow for example the passage of cables and sewers in a hostile environment.
Works of art: The elements are then of large dimensions: they are used, for example, as a pedestrian crossing or as a crossing for animals.



Figure 61 rectangle concret culvert proposed for the study

II.4.2 DECK ROADWAY DIMENTIOS

With the geometric and flow data in place, you use the Bridge/Culvert tool in HEC-RAS to simulate how the structure interacts with the flow. This step involves:

a Selecting the Structure Type:

Choosing between bridge, culvert, or a combination of both, depending on the design.

b Entering Detailed Geometry:

For bridges, this includes deck elevation, pier shape and location, and the type of bridge (e.g., low chord, high chord). For culverts, it includes the number of barrels, shape (box, circular, etc.), length, slope, and entrance/exit loss coefficients.

c Computing Hydraulic Properties:

HEC-RAS calculates head losses due to contraction,

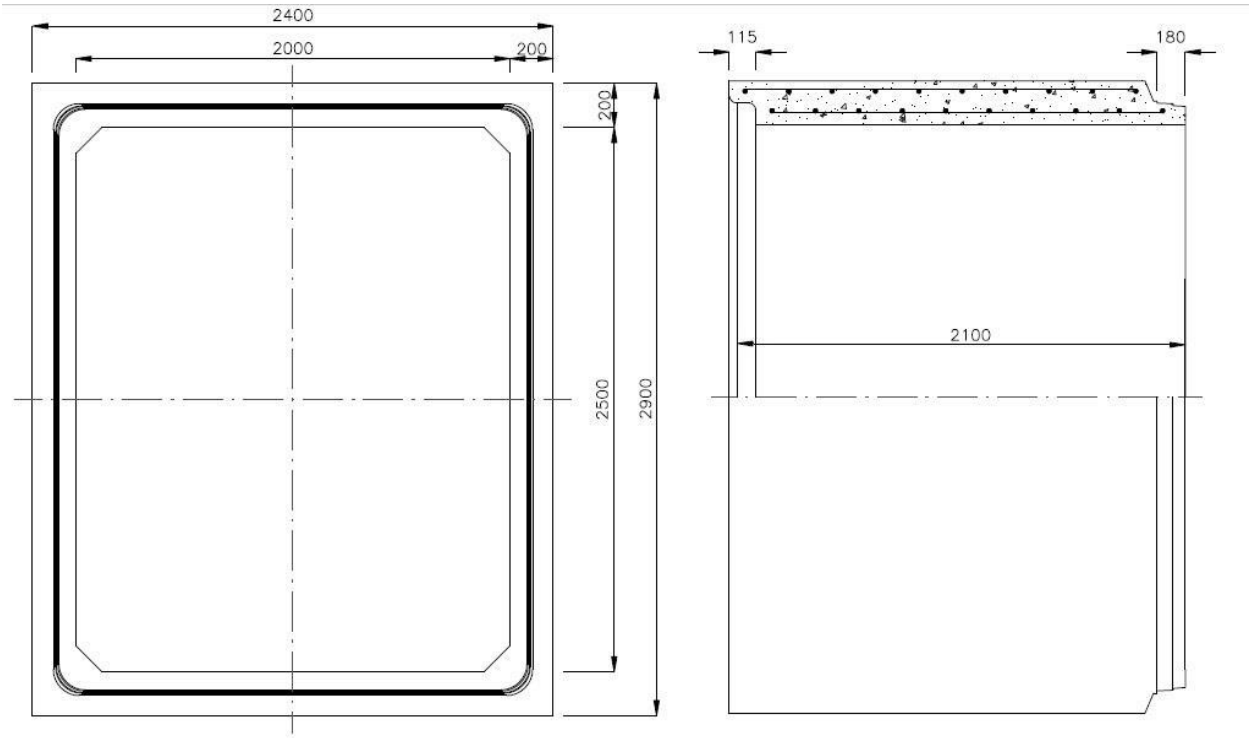


Figure 62 dimensions of the rectangular culvert

Table 34 gutters caractiristics

Caractiristics	Value
Height	2.5 m
width	2m
length	10 m
Number of gutters	4
Spacing	0.5 m
Manning	0.013
slop	0.006

II.4.3 Cross sections

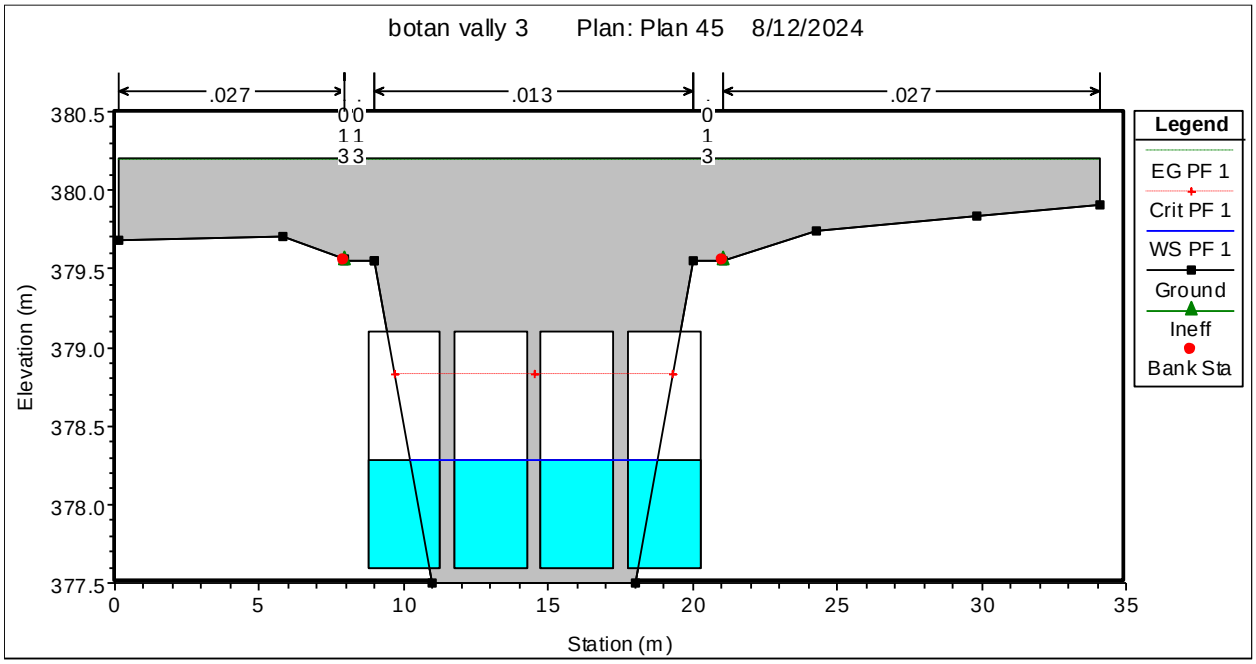


Figure 63 deck n 3477 on road n4b

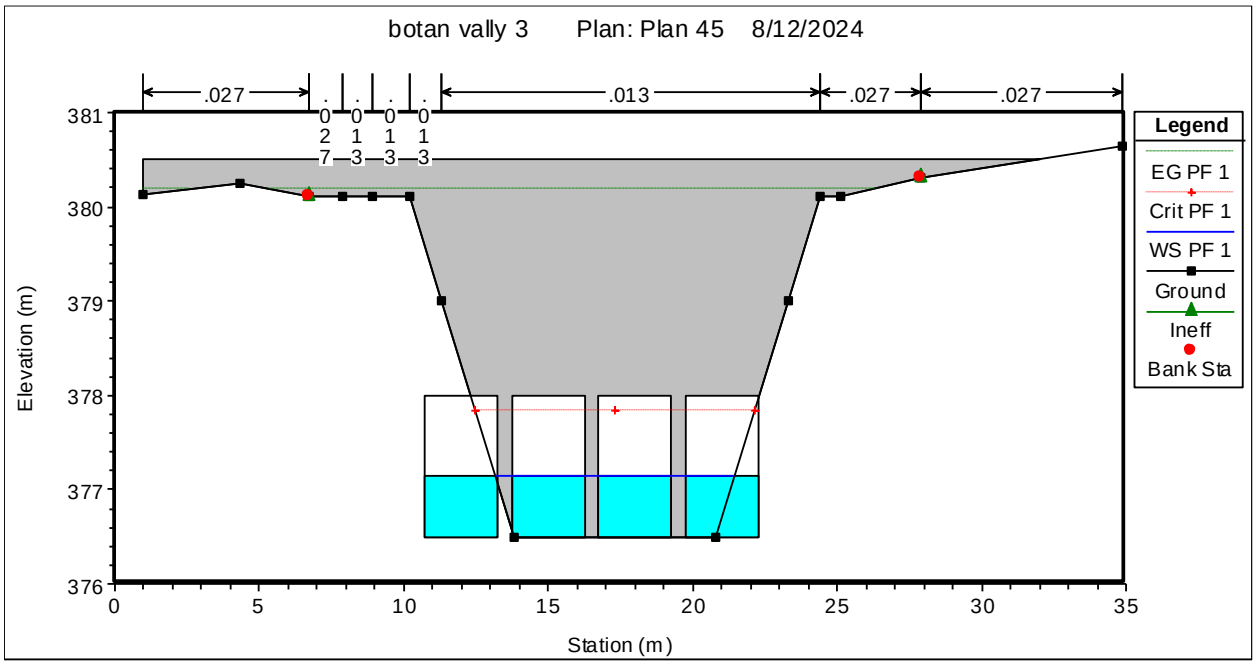


Figure 64 deck N 3450 on road N4B downstream

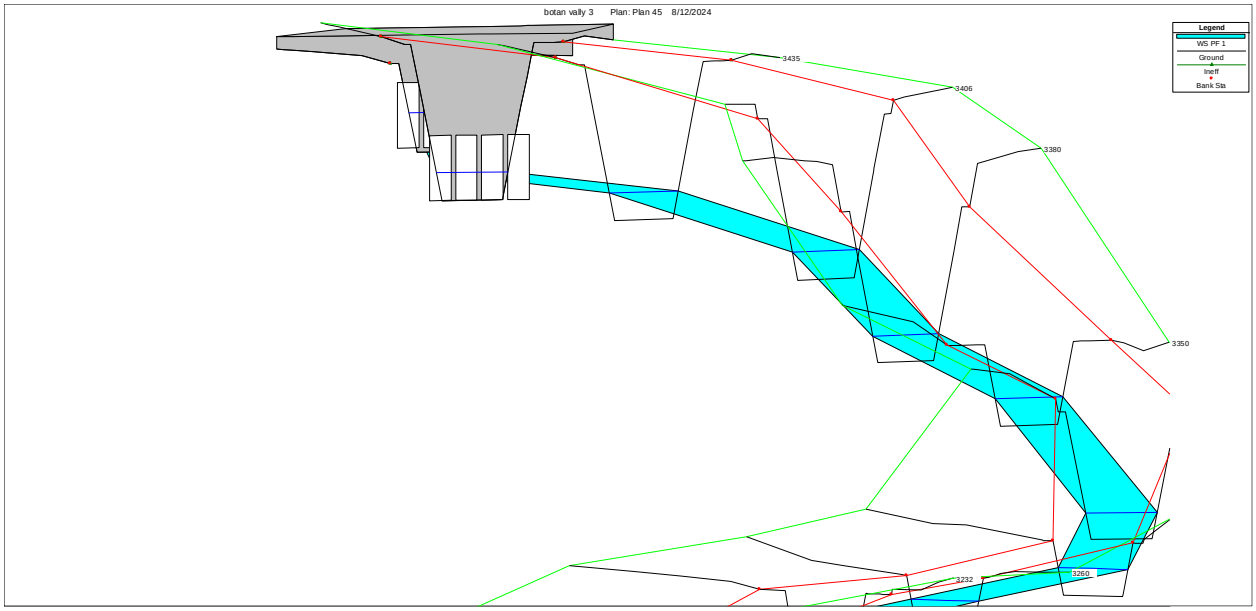


Figure 65 3d viewed the deck road from hec ras

II.4.4 Comment

The simulation indicates that the culvert successfully handled the 100-year flood without submersion, maintaining a maximum water depth of 0.4 meters and a flow velocity of 6.3 meters per second.

II.5 The second Deck road crossing the national road N4

This road is highly significant as it is National Road Number 4, connecting the western, northern, and eastern regions of the country

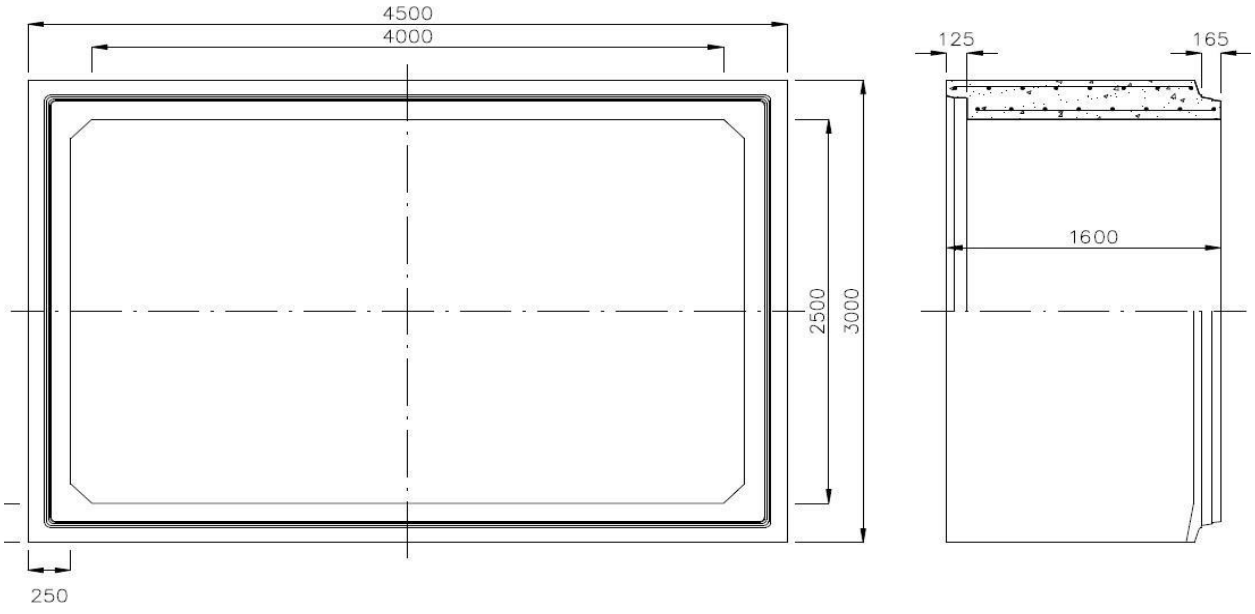


Figure 66 dimensions of the rectangular culvert for national road

In addition, here is a table of dimensions used for the simulation

Table 35 caractiristics for deck road crossing the national road 4N

Caractiristics	Value
Height	2.5 m
width	2*4 m
length	15 m
Number of gutters	2
Spacing	0.5 m
Manning	0.013
slop	0.0058

II.5.1 Cross sections

Cross section number 1560 upstream :

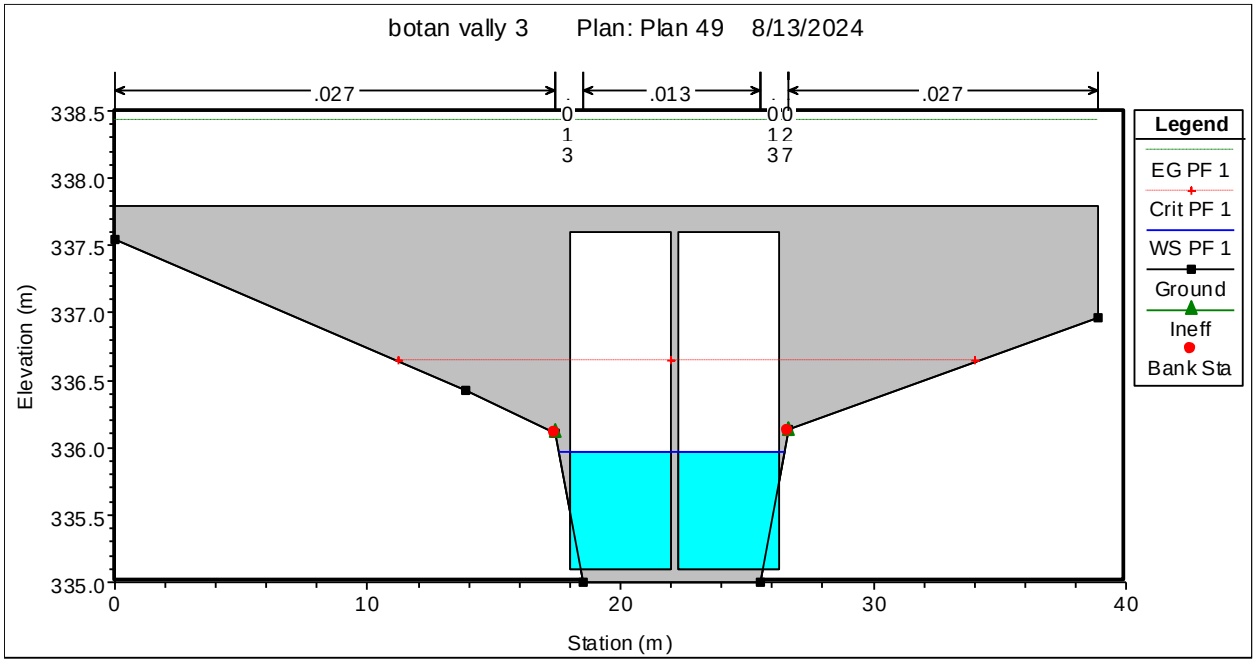


Figure 67 Road Deck crossing the national road N4

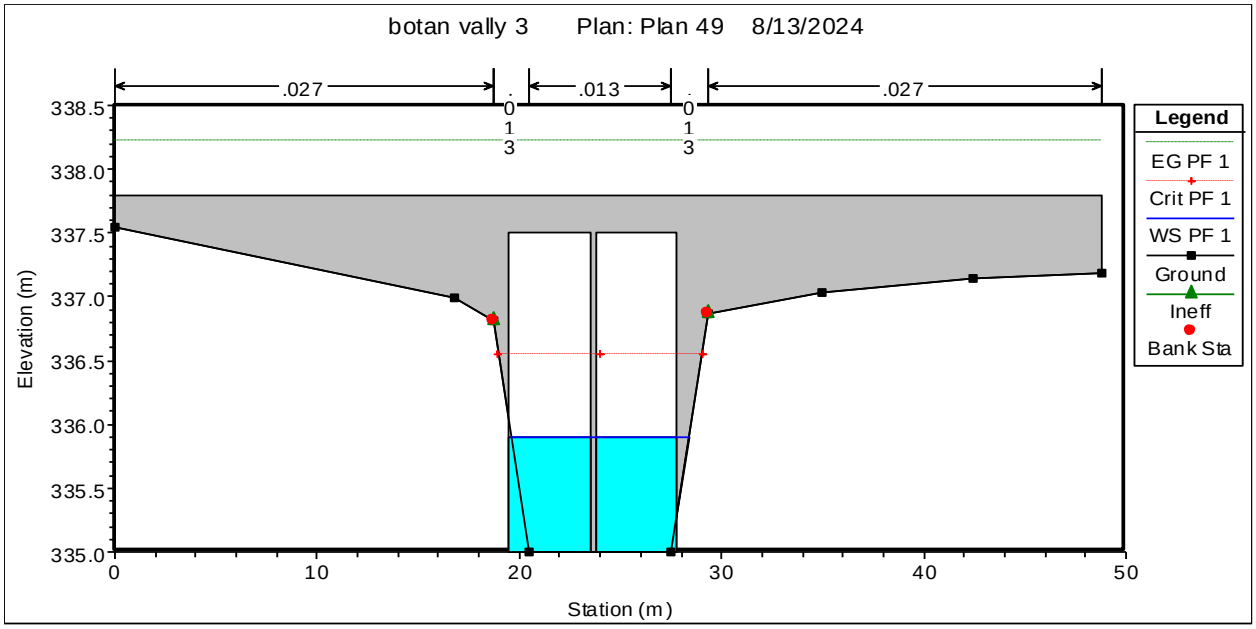


Figure 68 Down Stream the road Deck crossing the N4

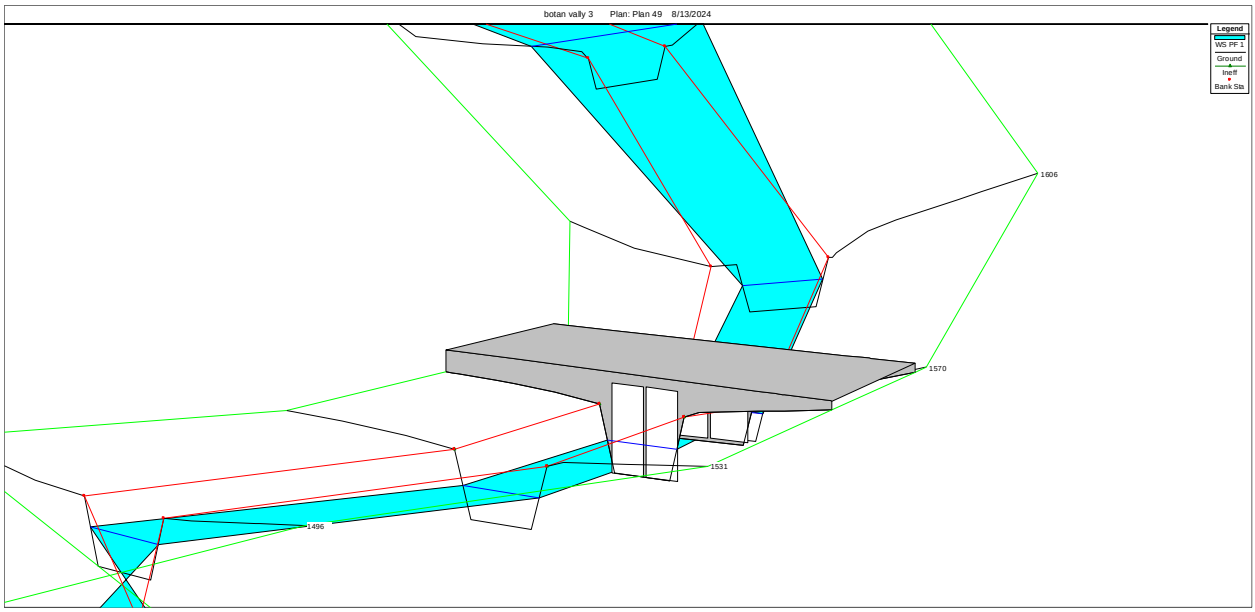


Figure 69 3d view of deck road on n4

II.5.2 Comment

The simulation indicates that the culvert successfully handled the 100-year flood without submersion, maintaining a maximum water depth of 0.8 meters and a flow velocity of 7.5 meters per second.

Table 36 bridges parameter

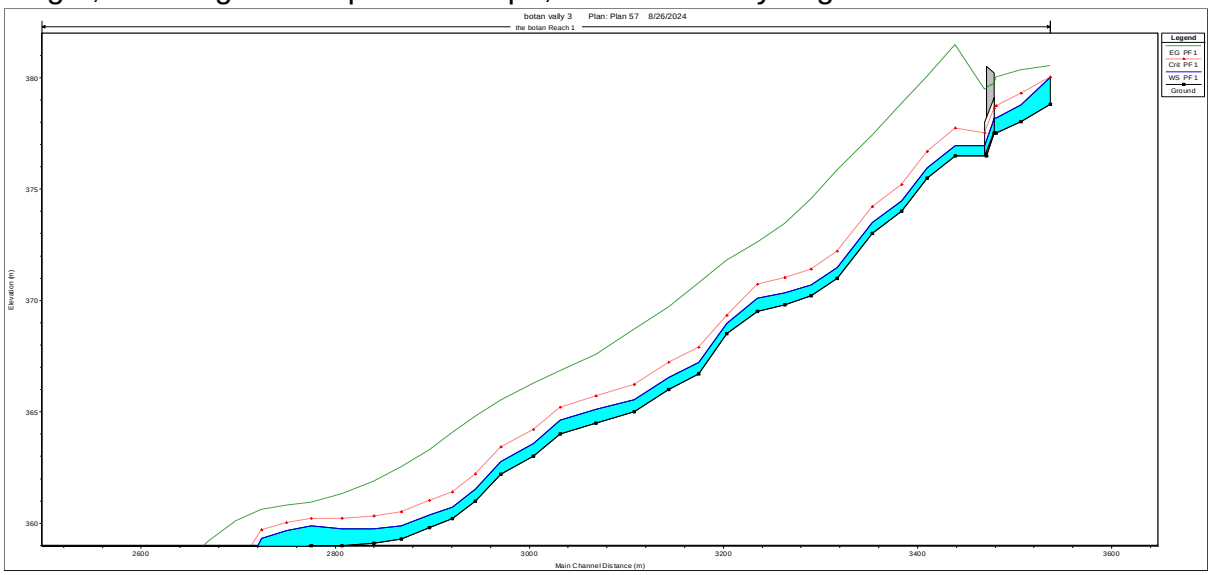
River Station	Dist Avail	Upstream Dist	Bridge Width	Downstream Dist
3450	42.3	2	8.00	32.3
1560	39.2	2	15.00	22.2

III Hydraulic constructions

The simulation results and the plot profile of the valley's natural state indicate several sections with very steep slopes. These steep slopes contribute to a significant rise in velocity, and the increasing Froude number could exacerbate safety risks in the future. To address these concerns, we are planning to implement a hydraulic construction to reduce the slope, break the velocity, and dissipate the excessive energy within the valley, thereby mitigating potential hazards

III.1 The highlighted sections :

The average drop in the natural ground surface is about 5 meters over a 25-meter length, creating a steep 20% slope, which is very high and crucial to assess.



The profile plot from HECRAS in the north of the city

Figure 70 the plot profile after the channel creation



Figure 71 image for the area were taken from a field inspection



Figure 72 the highlighted section from google earth

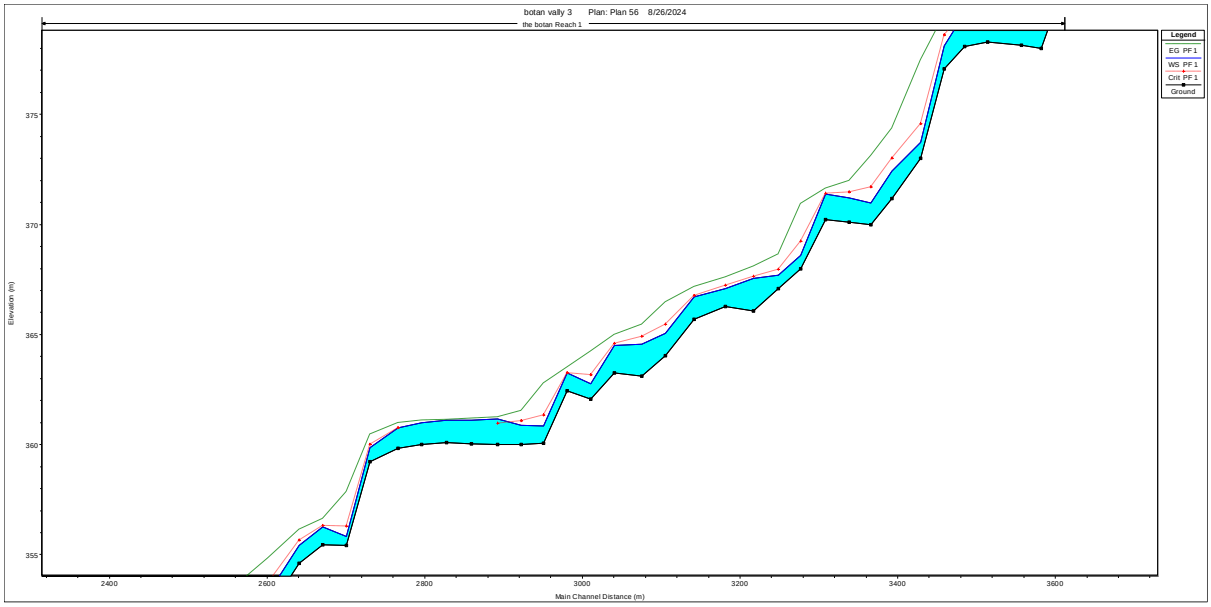


Figure 73 the narutel profile plote

The natural plot profile of the valley in its Natural state from AutoCAD :

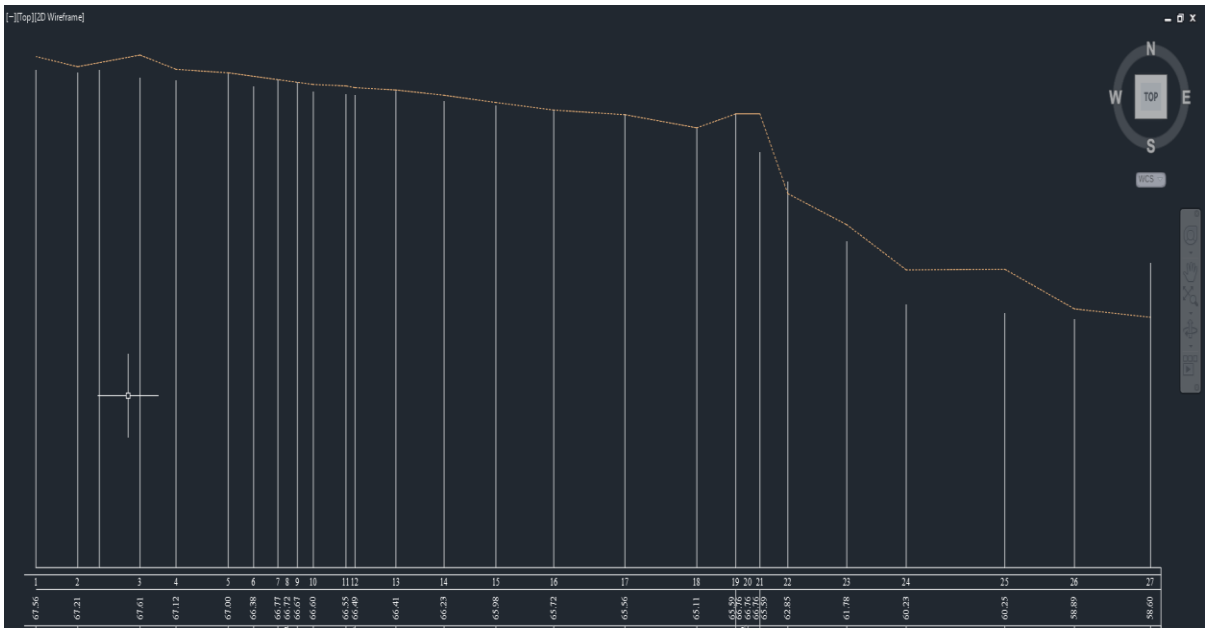


Figure 74 the natural ground surfacez in the north of the city plot profile

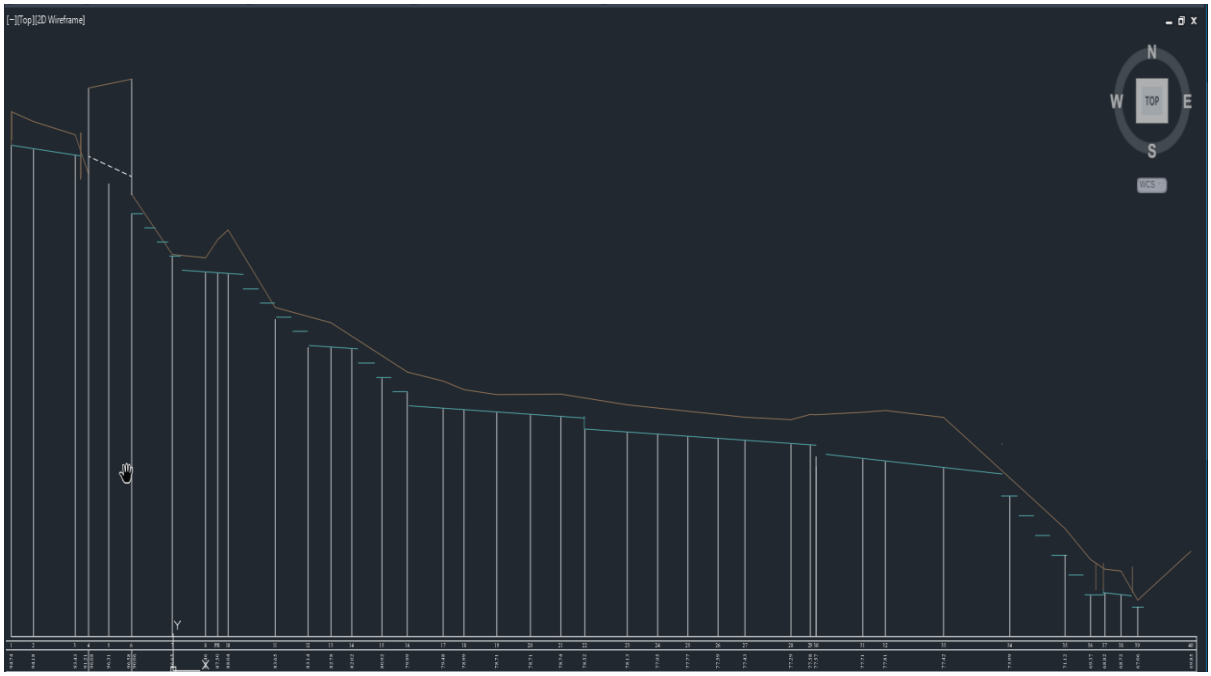


Figure 75 the natural grounde surafce in the north of the city plot profile

III.2 The proposed solutions :

Given the significant influence of the geology in the study area, the proposed hydraulic construction solutions have been carefully tailored to accommodate the specific geological conditions. The primary recommendations include the implementation of pooled cascades and a stepped spillway. These structures are particularly suited to areas with complex geological features, as they can effectively manage water flow while minimizing the risk of erosion and other geological impacts. The design of pooled cascades involves a series of small pools that dissipate energy and reduce the velocity of the water, making it an ideal choice for areas with uneven terrain. Similarly, the stepped spillway is designed to control the flow of water over steep slopes by breaking it into smaller, more manageable steps, which helps to prevent excessive wear on the surrounding rock and soil. Together, these hydraulic constructions offer a robust and efficient solution that takes full advantage of the geological characteristics of the study area.

III.2.1 briefing :

The flow conditions on a stepped chute are governed by the step height, step length, inclination of the chute with horizontal, and the unit discharge. Most investigators have developed empirical relationships with parameters (y/h) and (h/l), where y、 is critical depth, h is step height, and I the step length. The parame- ter (h/l) represents the chute slope.

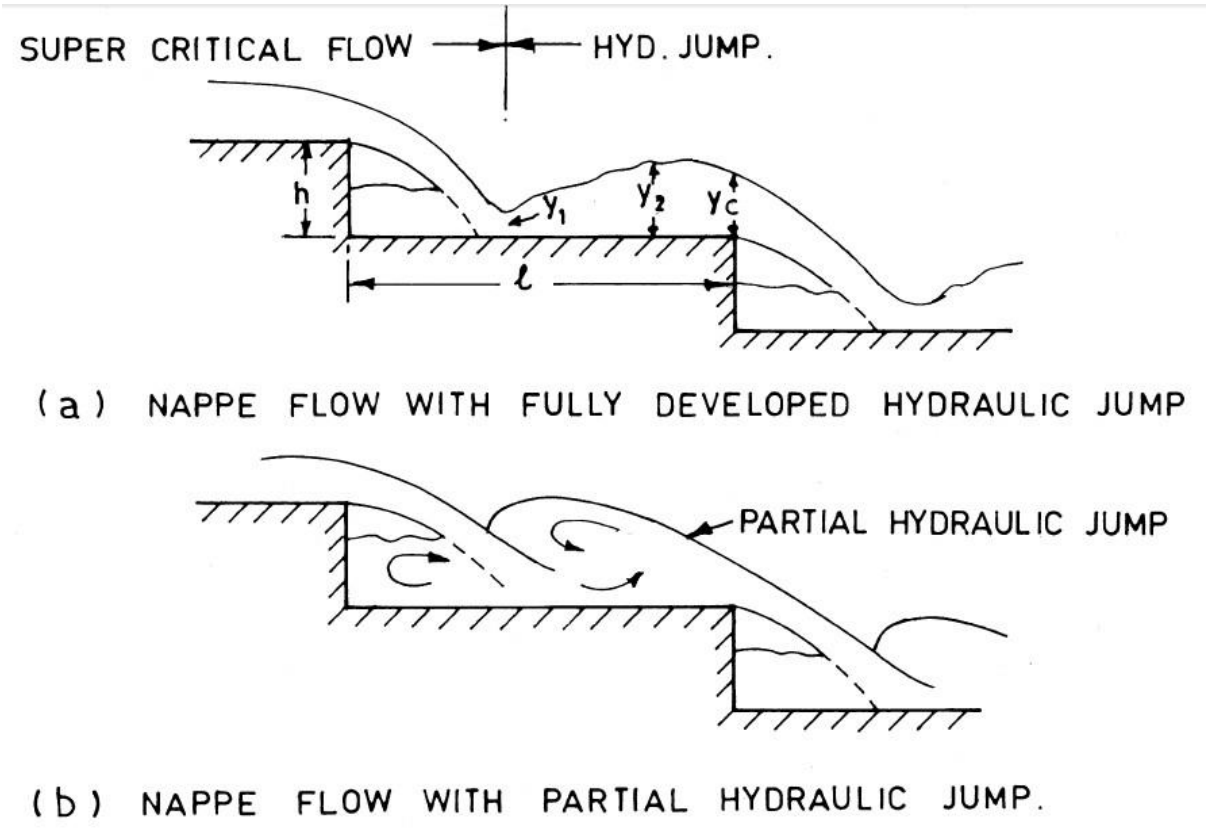
Based on the results presented by Rand (1955) concerning flow geometry at straight drop spillways, Chanson (1994-a) proposed the following condition for the occurrence of isolated nappe flow with a fully developed hydraulic jump, deduced for the interval $0.2 \leq h/l \leq 0.6$.

$$\frac{y_c}{h} \leq 0.0916\left(\frac{h}{l}\right) - 1.276$$

Hydraulic jump would not form with increase in discharge or chute slope.Yasuda et al.(2001) developed the following relationship for the lower

limit of the step height for the formation of nappe flow

$$\frac{h}{yc} = 0.57(\frac{h}{l})^3 + 1.3$$



Chanson (2001-a) defined upper limit of nappe flow regime as

$$\frac{h}{yc} = 0.89 - 0.4(\frac{h}{l})$$

The above relationship is valid for uniform or quasi-uniform flow (not rapidly varied flow) and within the range 0.05 ≤(h/l) ≤1.7.

Chinnarasri (2002) states upper limit of nappe flow as

$$\frac{Yc}{h} = 0.98\ (0.55)h/l$$

It would be seen that an increase in discharge would require flattening of the chute slope for the flow to be maintained as nappe flow, with a given step height. In addition, reducing the step height (without changing the chute slope) would require decrease in discharge.

The above relationships plotted superimposed in Figure 2 show a fair degree of consistency in the results obtained by different investigators**.**

III.3 The calculation

The topography marked 14 site where the natural slope has to be fixed

The geology allows us to design a structure with a maximum width of 17 meters within the city due to the local residential houses, and up to 20 meters outside the city. Additionally, the aim is to address three critical points where the slope urgently needs to be downgraded.

The value if the critical height :

We have B = 10

$$\boldsymbol{Yc} = \sqrt[3]{\frac{\mathbf{3.2^2}}{\mathbf{9.81}}} = 0.85$$

The proposed step height h = 1

$$\frac{Yc}{h} = \frac{\mathbf{0.85}}{\mathbf{1}} = \mathbf{0.85}$$

Chinnarasri (2002) states upper limit of nappe flow as

$$\frac{\mathbf{yc}}{\boldsymbol{h}} \leq \mathbf{0.0916}\left(\frac{\mathbf{1}}{\mathbf{5.7}}\right) - \mathbf{1.276}$$

$$\mathbf{= 0.86}$$

The results were verified and we have upper limit of nappe flow

After plotting the results, we have a TR transit flow

Energy Dissipation and Residual Head for Nappe Flow

For a stepped channel with nappe flow, having enough steps so that uniform flow can be reached in the last step,

$$\frac{\Delta E}{E_1} = 1 - \frac{\left((1-\alpha)\left[1+1.5\left(\frac{y}{h}\right)\right]+\Sigma(1-\alpha)\right)}{\left(N+1.5\left(\frac{y}{h}\right)\right)}$$

N= number of steps

i=1

Ho= upstream head referred to step elevation

a = average energy loss per step

The proportion of energy loss per step a, is not a constant but varies with (h/A) and (y/h) for a horizontal stepped spillway. In the case of spillway with steps inclined at an angle of o, a varies also with o. Tatewar and Ingle (1999) evolved a relationship for a by regression analysis, as

$$a = -0.1169 - 0.822\, log\left(\frac{y}{h}\right) + 0.0675\, logo\, \Phi.5481\, log\left(\frac{h}{l}\right)$$

Φ is expressed in degrees.

The coefficients in the expression for a in Equation 11 have been evaluated for the range of from 5° to 20°, (h/ λ) from 0.421 to 0.842, and (y/h) from

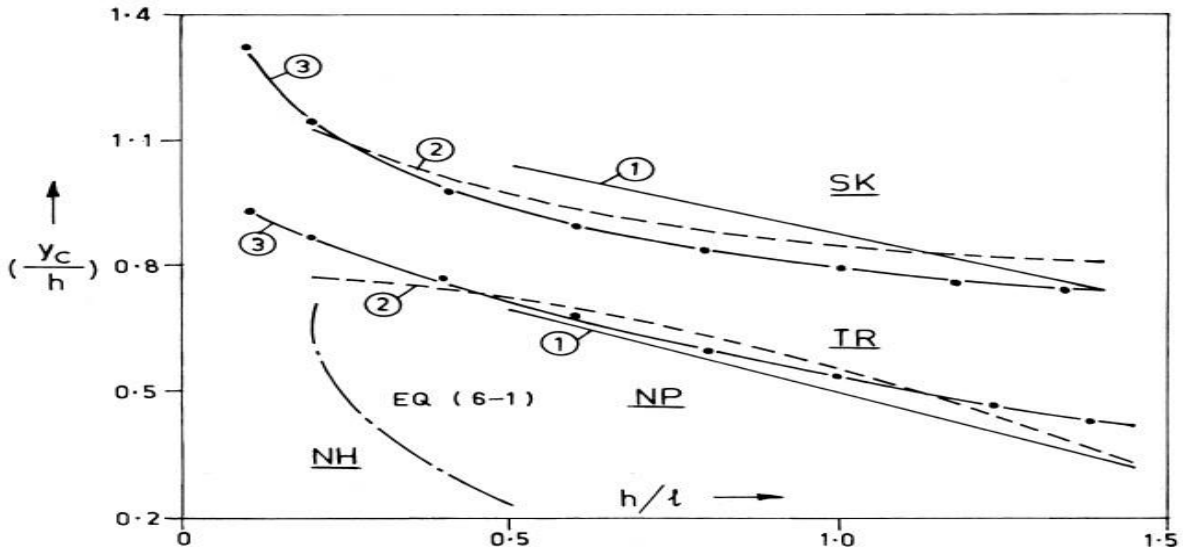


Figure 2 Flow regimes on stepped spillways: ① Chanson (2001), ② Yasuda et al. (2001), ③ Chinnarasi (2002), NH is nappe flow with hydraulic jump, NP is nappe flow, TR is transition flow, and SK is skimming flow.

0.05 to 0.833.

For horizontal steps, further regression analysis using the same set of data gave the relationship

$$a = -0.746\ log\left(\frac{y}{h}\right) 0.5481\ log\left(\frac{h}{l}\right) - 0.0455$$

Table 37 The a value with different angels

a	**Value**
15	0.424
20	0.432

Table 38 the result of the dissipated anegry of 20 degree angle

Steps	**Dissipated energy**
4	61%
5	63%

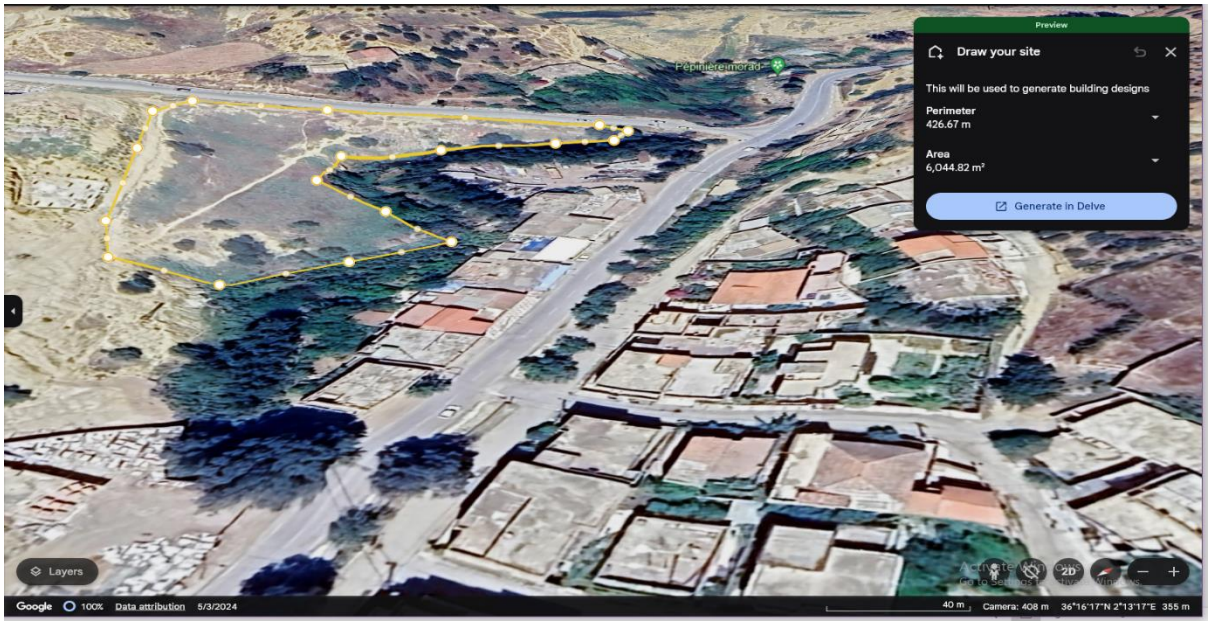


Figure 76 aimed area for a family park as a suggestion

III.3.1 aimed area for a family park as a suggestion

and for the hight cost of the project we proposed a area for a investment with around a 120 K Da a year of revenue

III.3.2 Cost estimation.

The cost estimation for one-step is around 82k DZD. In some sections we need 5 steps and in others 4 steps in multipole location along

III.3.3 Explanations

In conclusion, the area surrounding the bridge that connects Jardin City with Road N4B offers a prime opportunity for long-term investment, supported by its advantageous geological conditions and strategic location. The riverbanks, with widths of up to 27 meters, provide an ideal foundation for hydraulic structures, including the proposed three-step pooled cascades. The addition of 14 stepped spillways and a pooled cascades spillway not only enhances the slope and aesthetics of the city but also sets the stage for future investment opportunities. By integrating functionality with striking design, this development could transform the area into a landmark of modern urban planning, blending natural beauty with engineered solutions.

Conclusion

This chapter, we proposed and evaluated three development options for the Botan Valley. All could handle a 100-year flood, but the concrete channel was preferred for its quicker flood evacuation. We also designed and sized two culverts at the valley-road intersection, confirming their ability to prevent flooding. In addition, proposed a hydraulic construction to handle the slope and the Froude number

General conclusion

This study addresses one of the most frequent and devastating hydro meteorological hazards globally, particularly in Khemiss Milliana: rapid and intense surface flooding caused by high-intensity convective thunderstorms with limited spatio-temporal extension and a high slope .Flood management is increasingly gaining attention, with various approaches being explored. However, the random and unpredictable nature of these meteorological phenomena makes effective management a complex and challenging task. In response to this complexity, numerical simulation has emerged as a key tool, offering valuable insights into the flood phenomenon. The primary objective is to contribute significantly to flood risk management by informing the development of more effective policies. This includes the creation of robust warning systems and the implementation of efficient protection and response plans to mitigate the impact of such disasters.

This in-depth study has provided significant insights into the flood risks facing the city of khemiss milliana . The detailed results of hydrological analyses and hydraulic modelling have highlighted vulnerable areas, contributing factors, and the complex dynamics of flooding in our specific urban context. They reveal a complex combination of factors, ranging from geographical features to climate change, that contribute to the region's vulnerability to flooding.

This study is divided into six chapters. The first chapter provides an overview of the geographical, geological, hydrogeological and meteorological features of the study area. The region, including Khemiss Milliana, has a Mediterranean Atlas climate, with distinct climatic variations between mountainous and lowland areas. The mountains are characterized by heavy precipitation, cold temperatures and snowfall, while the plains have a drier, warmer climate with wide temperature variations. Secondary climatic phenomena such as white frost, hail and thunderstorms are also present. In addition, this section reviews the history of flooding in Algeria, with a particular focus on the town of Khemiss Milliana.

The hydro morphological study of the study area shows that the khemiss milliana watershed has an elongated shape and is characterized by very high relief and a very low time of concentration, which favors flooding.

The GRADEX method was used to estimate the 100-year flood discharge, evaluated at 32 m3/s. Hydrometric data from the ababbsa station were used, then adjusted to the Gamble. This enabled us to determine the flow for the 100-year return period, as well as other parameters. In the second part, the use of engineering techniques, particularly hydraulic modelling, is essential to effectively counter the risk of overflow. This approach is an absolute necessity, providing an accurate description of the natural behavior of valleys. Using these results, we were able to assess the extent of the flood risk, providing the appropriate dimensions for the design of the structure to be built.

Using the RAS-Mapper tool in the HEC-RAS software, we were able to obtain water levels at several points in the valleys beds. This enabled us to determine the water level heights corresponding to the predicted flood flows, and to localize the areas

invaded by flooding. We used the field data as the topographic basis for constructing the geometry of our valley, including longitudinal profile, cross-sections and banks, while specifying the inlet flows and all the necessary boundary conditions.

After locating the areas at risk, in the third part we opted for relevant developments to take into account the diversity of issues present along the watercourses. The aim was to encourage land-use planning better adapted to the risk of flooding, while at the same time studying the stability of the variants chosen.

Design and layout of the reinforced concrete channel. Several variants were proposed, and a speed check ruled out the concrete canal variant and the gabion retaining wall variant. Finally, the variant chosen for our layout is the reinforced concrete with a hydraulic proposal for torrential correction of the slope to ensure stability against erosion at the base.

When structures are not properly maintained, they do not work as well and offer less protection. It is important for communities to understand the need to be prepared and realize that building houses or villas above or near a protected valley is not safe. Doing so can increase the risk of flooding and other danger

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Degrees of freedom (*df*)	Significance level (α)							
	.99	.975	.95	.9	.1	.05	.025	.01
1	-------	0.001	0.004	0.016	2.706	3.841	5.024	6.635
2	0.020	0.051	0.103	0.211	4.605	5.991	7.378	9.210
3	0.115	0.216	0.352	0.584	6.251	7.815	9.348	11.345
4	0.297	0.484	0.711	1.064	7.779	9.488	11.143	13.277
5	0.554	0.831	1.145	1.610	9.236	11.070	12.833	15.086
6	0.872	1.237	1.635	2.204	10.645	12.592	14.449	16.812
7	1.239	1.690	2.167	2.833	12.017	14.067	16.013	18.475
8	1.646	2.180	2.733	3.490	13.362	15.507	17.535	20.090
9	2.088	2.700	3.325	4.168	14.684	16.919	19.023	21.666
10	2.558	3.247	3.940	4.865	15.987	18.307	20.483	23.209
11	3.053	3.816	4.575	5.578	17.275	19.675	21.920	24.725
12	3.571	4.404	5.226	6.304	18.549	21.026	23.337	26.217
13	4.107	5.009	5.892	7.042	19.812	22.362	24.736	27.688
14	4.660	5.629	6.571	7.790	21.064	23.685	26.119	29.141
15	5.229	6.262	7.261	8.547	22.307	24.996	27.488	30.578
16	5.812	6.908	7.962	9.312	23.542	26.296	28.845	32.000
17	6.408	7.564	8.672	10.085	24.769	27.587	30.191	33.409
18	7.015	8.231	9.390	10.865	25.989	28.869	31.526	34.805
19	7.633	8.907	10.117	11.651	27.204	30.144	32.852	36.191
20	8.260	9.591	10.851	12.443	28.412	31.410	34.170	37.566
21	8.897	10.283	11.591	13.240	29.615	32.671	35.479	38.932
22	9.542	10.982	12.338	14.041	30.813	33.924	36.781	40.289
23	10.196	11.689	13.091	14.848	32.007	35.172	38.076	41.638
24	10.856	12.401	13.848	15.659	33.196	36.415	39.364	42.980
25	11.524	13.120	14.611	16.473	34.382	37.652	40.646	44.314
26	12.198	13.844	15.379	17.292	35.563	38.885	41.923	45.642
27	12.879	14.573	16.151	18.114	36.741	40.113	43.195	46.963
28	13.565	15.308	16.928	18.939	37.916	41.337	44.461	48.278
29	14.256	16.047	17.708	19.768	39.087	42.557	45.722	49.588
30	14.953	16.791	18.493	20.599	40.256	43.773	46.979	50.892
40	22.164	24.433	26.509	29.051	51.805	55.758	59.342	63.691
50	29.707	32.357	34.764	37.689	63.167	67.505	71.420	76.154
60	37.485	40.482	43.188	46.459	74.397	79.082	83.298	88.379
70	45.442	48.758	51.739	55.329	85.527	90.531	95.023	100.425
80	53.540	57.153	60.391	64.278	96.578	101.879	106.629	112.329
100	61.754	65.647	69.126	73.291	107.565	113.145	118.136	124.116
1000	70.065	74.222	77.929	82.358	118.498	124.342	129.561	135.807

Figure 77 annex I table of khai