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M.Sc. in Civil Engineering

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**EVALUATION OF FLOOD ANALYSIS UTILIZING THE HEC-
RAS MODEL**

**M.Sc. THESIS
IN
CIVIL ENGINEERING**

**BY
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**M.Sc. Thesis
In
Civil Engineering
Gaziantep University**

**Supervisor
Prof. Dr. Mustafa GÜNAL**

**by
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February 2024**



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ABSTRACT

EVALUATION OF FLOOD ANALYSIS UTILIZING THE HEC-RAS MODEL

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74 Pages

Syria faces a spectrum of natural hazards, encompassing drought and desertification and recurring instances of floods. One poignant incident illustrating this vulnerability occurred in February 2015, when a family of four tragically drowned following the flooding of the Al Kabeer Al Shemali River in Latakia. This flood event inundated citrus groves and greenhouses on both sides of the river course. The research is investigating flow behaviour during flooding in the Al Kabeer Al Shemali River in Latakia, Syria, and developing inundation maps based on various probability scenarios (for three specific recurrence intervals and three different water elevation scenarios) utilizing the HEC-RAS software. The inundation spaces were identified using Geographic Information System (GIS) tools, along with Digital Elevation Models (DEM) for contour lines. The findings indicated that the agricultural sector and urban facilities on the river are highly vulnerable to the impact of flooding, suggesting that the river is prone to flood hazards. Furthermore, the results indicated that inundated areas increase with the rise in the expected maximum values of flood intensity according to various assumed return periods.

Key Words: Syria, Flood risk, Al Kabeer Al Shemali River, HEC-RAS modeling, Geographic Information System (GIS).

ÖZET

TAŞKIN ANALİZİNİN HEC-RAS MODELİ KULLANILARAK DEĞERLENDİRİLMESİ

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74 Sayfa

Suriye, sadece kuraklık ve çölleşme değil, aynı zamanda tekrarlayan sel olaylarını da içeren bir dizi doğal tehlike ile karşı karşıyadır. Bu kırılganlığı gösteren etkileyici bir olay Şubat 2015'te meydana geldi, Latakia'daki Al Kabeer Al Shemali Nehri'nin taşması sonucu dört kişilik bir ailenin trajik bir şekilde boğulmasıyla sonuçlandı. Bu sel olayı, nehir yatağı boyunca her iki tarafındaki narenciye bahçelerini ve sera alanlarını su altında bıraktı. Araştırma, Latakia, Suriye'deki Al Kabeer Al Shemali Nehri'ndeki sel sırasındaki akış davranışını incelemekte ve HEC-RAS yazılımını kullanarak çeşitli olasılık senaryolarına dayalı sular altında kalma haritaları geliştirmektedir (üç belirli geri dönüş aralığı ve üç farklı su seviyesi senaryosu için). Sular altında kalan alanlar, Coğrafi Bilgi Sistemi (CBS) araçları ve kontur çizgileri için Dijital Yükseklik Modelleri (DEM) kullanılarak tanımlandı. Bulgular, nehir boyunca tarım sektörü ve kentsel tesislerin sel etkilerine son derece savunmasız olduğunu gösterdi ve nehrin sel tehlikelerine açık olduğunu öne sürdü. Ayrıca, sonuçlar, sel yoğunluğu beklenen maksimum değerleri arttıkça sular altında kalan alanların çeşitli varsayılan dönüş periyotlarına göre arttığını gösterdi.

Anahtar Kelimeler: Suriye, Sel riski, Al Kabeer Al Shemali Nehri, HEC-RAS Modellemesi, Coğrafi Bilgi Sistemi (GIS).



“Dedicated to my family”

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LIST OF SYMBOLS

A	Cross-Sectional Flow Area (m^2)
Q	Discharge (m^3/Sec)
t	Spatial Coordinate (m),
q	Flow Rate per Unit Width (m^3/s)



LIST OF ABBREVIATIONS

INFORM	Index for Risk Management
GUI	Graphical User Interface
	Hydrologic Engineering Center - Flood Damage
HEC-FDA	Analysis
	Hydrologic Engineering Center - Flood Impact
HEC-FIA	Analysis
USACE	United States Army Corps of Engineers
GIS	Geographical Information System
RS	Remote Sensing
WMS	Watershed Modeling System
SCS	Soil Conservation Service
IFSAR	Interferometric Synthetic Aperture Radar
KS	Kolmogorov-Smirnov test
LP3	Pearson Type III
MODDS	Presumably a Modeling or Monitoring System
	United Nations Educational, Scientific and Cultural
UNESCO	Organization
SRTM	Shuttle Radar Topography Mission
	Hydrologic Engineering Center's River Analysis
HEC-RAS	System
LiDAR	Light Detection and Ranging technology

CHAPTER 1

INTRODUCTION

1.1 Background and Context

Throughout the history of the human race, floods have always had an impact. People have been battling the water for a very long time, and the battle is still ongoing. Since water makes up over 70% of the Earth's surface and does not behave the way we would want it to, it will likely persist for a very long time. The world has changed and continues changing as a result of, among other things, the changing climate during the last several decades. For instance, from 1901 to 2010, the average global sea level increased by 19 centimeters (Stocker et al., 2013). These climatic changes will likely continue throughout the twenty-first century. The discharge of the Rhine is altered by climate change, according to several studies. By 2050, the winter flow in the river might rise by 0 to 30%, and there would be a higher likelihood of severe flood occurrences (Ward et al., 2014).

Additionally, The United Nations claims that the world's population is growing annually. This will increase the number of residents in flood-prone metropolitan areas, which will result in more significant economic losses. In 2003, 30% of people lived within 100 km of the shore; by 2030, that number would have increased to 50% (De Graaf, 2008). This may increase the number of flood-related deaths. The attitude of calamities has also changed recently. A calamity like an earthquake or a flood will be harder for people to accept. Take the earthquakes that occurred in Groningen, Netherlands. People are aware of the root of such problems, but they refuse to recognize that they must cope with property damage and other repercussions. This might be translated to the flood risk problem. Most of the nations have a definite policy against floods. In the Netherlands, for example, there is an emphasis on avoiding floods. However, in other nations, there is more of a 'wait-and-see' approach. They do not want to spend on prevention, but they are willing to pay for all the damages when

it occurs. It is fascinating to watch how various nations and even states within a country want to respond to hazards and how they are prepared for catastrophes in terms of, for example, evacuation preparations (Mohammad, H. 2016). The parameters that are discussed above have an enormous influence on our take on worldwide flood threats. Obtaining information regarding flood dangers is of very excellent service in the future. With the appropriate methodologies, we will be able to make the correct conclusions concerning flood protection concerns and management. Furthermore, those proper judgments include the policies that a given nation or place has against such tragedies.



Figure 1. 1 Effects of flooding in the study area (Mohammad, H. 2016).

1.2 Problem Statement

Syria faces a spectrum of natural hazards, encompassing not only drought and desertification but also recurring instances of floods. Notable flood events include the partial collapse of the Zeyzoun dam in northwest Syria in 2002 and a flood that struck Al Hasakeh City in the northeastern region in 2006. These flood occurrences have resulted in the obstruction of vital highways and roads across the country, inundation of irrigated areas in multiple governorates, and the deterioration of historical sites (UNDP, 2009). According to the INFORM country risk profile for Syria in 2016, the

annual expected exposure of individuals to floods in Syria stands at 48,875, and the physical exposure.

to flood risk is rated at 4.8. Additionally, a report by CRED EM-DAT in 2015 indicates that combined economic losses due to floods between 1990 and 2014 accounted for 5.8% of total losses, with flood-related mortality reaching 5.1%. In the realm of risk prevention and reduction, Syria's disaster risk management (DRM) plan faces substantial challenges, as outlined by the World Bank in 2014. These challenges encompass the absence of safety regulations in building and infrastructure design, limited public awareness, a dearth of pertinent laws and legislation, and the need for more effective coordination mechanisms to streamline disaster and emergency management plans, which, as it stands, remain largely reactive.

While Syria possesses national disaster response capabilities in various sectors such as fire services, civil defense, branches of the Red Crescent, and the women's union, it notably needs comprehensive risk assessment mechanisms. Flood vulnerability in Syria can be attributed to multiple factors. Firstly, uncontrolled urbanization within flood-prone areas has led to the concentration of vulnerable populations. Secondly, Syria's lack of disaster insurance programs, coupled with its economic fragility—primarily attributable to its vulnerable agricultural sector—exacerbates flood-related vulnerabilities (McEntire, 2008).

One poignant incident illustrating this vulnerability occurred in February 2015 when a family of four tragically drowned following the flooding of the Al Kabeer Al Shemali River in Latakia. Citrus groves and greenhouses on the river banks were flooded, and adjacent lands were submerged, causing property damage and car losses in some places. Additionally, it impacted the industrial zone in Latakia, Syria. A mixture or combination of natural and anthropogenic elements further compounds the implications of flood vulnerability in the study site. Natural causes comprise of long episodes of high-intensity rainfall and topographical factors (slope and basin elevation). These include improperly designed buildings, inappropriate regulation of riverbanks, deficient planning of flood plains, and insufficient emergency preparedness. Therefore, carrying out a vulnerability analysis along the Al Kabeer Al Shemali River in Latakia will help quantify the degree of vulnerability and establish the likely dangers associated with the area.

1.3 Research Objectives

This research project aims at undertaking a thorough evaluation of flood risk in part of Al Kabeer Al Shemali the river in Latakia, Syria. To achieve this overarching goal, the following specific research objectives have been delineated:

1. **Characterize Flood Hazard Patterns:** Historical analysis of the Al Kabeer Al Shemali River flooding events and patterns (including magnitude, frequency, and spatial extent).
2. **Assess Vulnerable Populations:** This will involve identifying and quantifying the communities and resources along flood-prone areas of the river for socio-economic assessment.
3. **Examine Environmental Factors:** Investigating natural factors on flood vulnerability comprising topography rainfall patterns that interact with flood incidences.
4. **Evaluate Anthropogenic Factors:** The paper explores human-induced factors leading to insecurity and vulnerabilities to flooding and considers issues such as urbanization, building methods, land use planning, and the presence and nature of flood control systems.
5. **Conduct Hydraulic Modeling:** Utilizing this model to develop hydraulic simulations to generate flood inundation maps, water-level profiles and velocity distributions for different flood scenarios.
6. **Calibrate and Validate the Model:** Calibrate the HEC-RAS model with observed flood data and validate its accuracy to historical flood events.
7. **Perform Vulnerability Assessment:** Combining findings from hydraulic modelling and socio-economic analysis in order to develop a holistic flood vulnerability assessment of the study location.
8. **Identify Risk Mitigation Measures:** Propose effective strategies to reduce flood risks and mitigate the consequences of this disaster based on the vulnerability assessment, focused on improving disaster preparedness and resilience of the Al Kabeer Al Shemali River region.

9. Contribute to Policy and Planning: Advancing resilient and sustainable development practices in flood-prone areas of Syria through the provision of valuable insights and recommendations which can guide policy formulation and urban planning.

10. Enhance Public Awareness: disseminating research findings and educating the local population on floods, their risks, and appropriate measures to take in case of an emergency.

This study aims to increase our awareness of flood vulnerability in the Al Kabeer Al Shemali River basin so as to generate more evidence-based flood risk reduction strategies and protect the livelihoods of the population and their assets.

1.4 Structure of the study

Including the Introduction chapter, this thesis is constituted of SIX chapters. The remaining FIVE chapters for this study are outlined here. First, a literature review defining a flood disaster assessment and the use of HEC-RAS software in order to create a better understanding of the flood characteristics and its impacts. It includes the definition of a floods, the causes of floods, the types of floods, flood mitigation measures; and tools for floodplain analysis and mapping, Second, definition of HEC-RAS software model. Third, description of the study area and data of the Al Kabeer Al Shemali River in Latakia. The fourth chapter presents the results of the study, whereas the fifth and sixth chapters are related to the discussion as well as conclusions and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Floods

One of the most frequent environmental risks is flooding (Smith, 1992). Floods may be caused by changes in the hydrology and geography of a floodplain (Yang & Tsai, 2000). These changes are specifically brought on by the spatial distribution of river valleys and low-lying beaches as well as their historical appeal to human habitation (Smith, 1992). Floodplain management, flood damage mitigation, engineering design, and site planning all depend on the assessment of flooding and the demarcation of flooded regions (Chang et al., 2000). Different flood-prone areas have a greater danger than others.

Flooding is caused by a variety of reasons, including heavy rainfall, quick snowmelt, strong winds over water, landslides, tsunamis, growing urbanisation, eight accidents, and the breakdown of hydraulic facilities such as dams and levees (Nfor et al., 2019; Zaifoglu et al., 2019).

The sources, causes, depth, flow rate, and effects of various flood types and classifications are contrasted. Coastal flooding, storm surges and tsunamis, river flooding, groundwater rise, flash floods, urban flooding, dam breach flooding, and overtopping levees or embankments are the primary categories of flooding (Kron, 2005). One of the most common and dangerous natural disasters is flooding. Floods severely impact both the environment and the inhabitants. Their repercussions include human and animal mortality, cattle loss, health issues, building devastation, agricultural and farmland degradation, social and economic harm, and environmental issues (Haltas et al., 2021). The majority of China's Hubei Province was destroyed in 1954 as a result of an enormous flood that was brought on by high rainfall in the

Yangtze River Basin. Over 30,000 fatalities were reported by official organisations. Additionally, the breakdown of illnesses and other cascading events brought on by this

severe flood exacerbated the number of victims. According to their study, the flood disaster had a significant impact on more than 18 million people and resulted in 200,000 fatalities (Hamidifar & Nones, 2021).

Floods struck Mozambique in 2000, killing 700 people, destroying over 150,000 dwellings, and affecting a large number of people; the country's GDP growth rate fell from 10 to 2 per cent (DFID, 2004). Flooding in Benin had a significant effect in 2010; floodwaters damaged around 55,000 residences, 500 schools, and 90 health facilities, resulting in at least 150,000 people being displaced and 81,000 heads of cattle being lost. Floods also ruined around 133,047 hectares of crops and submerged 12,000 tonnes of stockpiled food (Guha-Sapir et al., 2015).

2.2 Causes of Floods

Floods are often caused by natural sources such as significant hydrological and meteorological phenomena such as excessive flow and precipitation. Regardless, they may occur as a result of man-made activities, such as unforeseen expansion and construction in floodplains, resulting in property and land flooding. These manmade actions also include dam breaches, levee overtopping, and embankments that fail to protect planned projects. People often relocate from rural areas to cities or within cities due to a variety of circumstances, including fast population increase, and they commonly dwell in flood-prone areas in many parts of the world. Flood risk knowledge, preparatory measures, and flood protection infrastructure may leave people very exposed to flooding. Urban development and land-use changes reduce soil permeability, which increases surface rainfall-runoff, increasing the danger of floods and overloading drainage systems that were previously unable to handle more significant flows in many situations (Jha et al., 2012).

2.3 Types of Floods

Flooding is a body of water that rises to inundate land that is not normally flooded as a consequence of high precipitation and other circumstances. Floods are classified into three sorts and each has its own characteristics. Riverine flood, flash flood, and storm surge are the three primary types of floods, with unique types of floods including dam-break and levee overtopping floods, backwater (e.g., caused by a landslide that intercepts a watercourse), tsunami, waterlogging, groundwater increase, debris flow events, and others (Kron, 2005). A flood may be described and classified based on its

source, origin, and effect. Floods are typically classified as river (fluvial) floods, pluvial (overland), groundwater rise, coastal, or the collapse of manmade water projects such as dam breakdowns based on these factors. They are classified as urban floods, flash floods, semi-permanent floods, and progressively increasing floods based on their speed and velocity (Jha et al., 2012).

2.4 Flood Mitigation Measures

As one of the most common natural disasters, flooding may be included. Floods harm fragile communities all over the globe every year, costing billions of dollars in damage and resulting in fatalities. Flooding impacts cannot be eliminated, but they may be lessened in terms of damage and consequences by using workable flood mitigation strategies. Reducing the risk of flooding involves lessening its severity or the area's susceptibility. There are two types of flood mitigation strategies: structural and non-structural. Although structural mitigations may be more feasible for long-term planning and defence, they are often more costly (Alabbad et al., 2022). Plans for structural mitigation are well-known flood mitigation techniques that have been used by companies with general flood management strategies in the majority of floodplain locations. Construction of flood levees or embankments, dams, floodwalls, channel upgrades, diversion plans, reservoirs, river training works, and other structures are all examples of structural mitigation. To lessen the effects of flooding, non-structural mitigation criteria such as resistant materials have often been utilised. They minimise economic losses and are efficient, cost-effective, and faster to recover from. Non-structural mitigation strategies increase reliability and success rates in flood situations.

Regulations governing floodplains, population expansion, flood forecasting and alarm with an evacuation plan, floodproofing, public health precautions, flood fighting, flood insurance, the provision of relief, and recovery are examples of non-structural mitigating techniques.

Additionally, the features of the factors influencing rainfall-runoff of the catchment may be changed such that runoff is delayed in order to lessen the consequences of floods. These strategies include changing the way land is used, planting and removing trees, regulating the flow from metropolitan areas, and others. These actions might be combined under the umbrella term "watershed management." While this strategy may be suitable for controlling rainfall runoff from small catchments, its applicability to

significant catchments seems trivial (Sivakumar, 2015). This is because, in large catchments, the impacts of watershed management approaches are insignificant in the downstream regions. Residents may be more willing to withstand high flooding if structural and non-structural flood mitigation measures are combined (Heidari, 2009). The best mitigation must be chosen after a thorough analysis of possible risks and damages, as well as the costs and advantages of different mitigation classes. The conclusion of flood damage is a crucial component of hazard management. However, it is also a crucial factor in assessing mitigation strategies in terms of the kind and scope of actions. During the process, quantification of flood impact reduction for different options, be it structural mitigations or quantity of protective systems, is essential. Damage analysis leads to the selection of the best protection option and scope of the ideal protective structure.

2.5 Tools for Floodplain Analysis and Mapping

2.5.1 HEC RAS Model

The acronym HEC-RAS refers to Hydrologic Engineering Centre – River Analysis System. This model was part of the NexGen hydrological software developed by the Hydrologic Engineering Center (HEC). The scheme comprises river hydraulics (HEC-RAS), rainfall-runoff assessment (HEC-HMS), reservoir system simulation (HECResSim), flood assessment (HEC-FDA, HEC-FIA), and real-time river

Prediction HEC-RAS is an incorporated software for operating in a multi-tasking environment. The approach involves a graphical user interface (GUI), analysis tools, data management features, visualization options, mapping capabilities, and report generation systems.

Also, the HECRAS model supplies the four river analysis elements listed below: 1D steady flow and water 21 surface profile studies, 1D & 2D unsteady flow simulation, 1D water quality calculation, and partly or totally unsteady flow transportable border sediment transport assessments (1D and 2D). The critical point is that all four components share a similar geometric data model as well as conventional geometric and hydraulic calculation procedures. In addition to the four river calculation parts, the model includes a number of hydraulic design components that may be accessed after analysing water surface profiles. In addition, HEC-RAS has a mapping technique (HEC-RAS Mapper) and a thorough spatial data integration (USACE, 2022c).

2.5.2 Geographical Information System (GIS)

There are many applications for the rapidly developing technology: a Geographic Information System (GIS). Geographic information systems (GIS) are computers able to collect, store, alter, and present data that is somehow tied to a specific location. The benefit of GIS is seen in the precision with which data may be displayed and analysed. It can take unstructured, complicated data and map its geographical linkages, allowing researchers to get new insights. In flood hazard management, GIS may be used to create interactive map overlays that clearly and quickly highlight which parts of a town are in danger of flooding. After an incident, such maps might help coordinate prevention, response, and recovery efforts (Awal, R. 2003). In this way, GIS provides a powerful and versatile resource for promoting speedy and open deliberation. There are many kinds of GIS software, such as ArcView, Arc/Info, ILWIS, GRASS, MapInfo, etc.

Regarding swiftly loading spatial and tabular data for display as maps, tables, and charts, ESRI's ArcView, ArcGIS, and GIS are among the most intuitive and user-friendly options. These provide data querying and analysis, with the results being mapped for presentation purposes. Views, tables, charts, layouts, and scripts are all

organised into projects in ArcView/ArcGIS, a GIS software package. Avenue might be used to modify ArcView's user interface to meet the needs of particular use cases. Many third-party programs and plugins are available to extend ArcView GIS's functionality (Breslin, P. 1999).

2.5.3 Remote Sensing (RS)

When it comes to keeping an eye out for potential threats in the water supply, the Remote Sensing (RS) method is one of the most valuable tools at your disposal. Data gathered by sensors on far-flung platforms like satellites and aeroplanes may be mined for insights using RS techniques. The importance of satellite imaging in hazard and risk assessment has grown as technology has improved picture quality, stereo capabilities, and digital image processing techniques. This is supported by the rising tide of research on natural hazards using modern remote sensing techniques. Accurate and timely information on flooded areas, river behaviour and configuration before, during, and after floods is critical for flood management and related activities but is difficult to get using ordinary ground surveys. Improvements in satellite remote

sensing technologies have helped with problems like flood mapping, monitoring, and management in areas prone to flooding (Sulaiman et al. et al., 2012).

2.6 Previous Studies

Floods have become more dangerous because of the changes in global climatic conditions, changes in settlement structures caused by the growth of population, increasing demand for water, and an increase in industry facilities because of rising requirements. This point of view shows that there is a need to control floods, which may occur in residential areas and other areas that are growing due to the demand.

AL-Hussein, A. A., et. al. (2022). In this study, it explored how villages close to the floodplain of the Khazir River have faced repeated flood threats over time. Such floods have often resulted in heavy losses of crops, threatening residential zones. In turn, we used specialized hydrological software such as WMS and HEC-HMS to perform a comprehensive analysis in order to minimize the occurrences of flooding. For this research, hydrological software was used in order to estimate hydrographs for the flash flood flows within the river basins. It made it possible to quantify the volume of torrential water and its stream discharges over the planet. In addition, we assessed and developed the depth of rainfall, applying the SCS Unit Hydrograph for different return periods, including the following: 2, 5, 10, 20, 50, and 100 years.

The results indicated that the flood volumes varied between 29,680 to 2,229,200 m³ over different periods during the wet season. The highest flow rates were found to be between 10.4 to 66.4. Finally, combining the HEC-RAS model with the HEC-GeoRAS extension in ArcGIS allowed us to develop a comprehensive flood risk analysis for the Khazir River. The study was conducted on two separate occasions, in 2013 and 2018, using digital elevation models and data collected in the course of floods. The researchers established a flood depth classification map that divided areas at risk into low, medium, and high categories that accounted for 80.31%, 16.03%, and 3.8%.

Specifically, analysis of the results demonstrated that villages in close proximity to the river's mouth suffered more devastating effects of flooding compared to the ones far away downstream. Likewise, the data analysis indicated a high correlation between HEC-HMS and HEC-RAS in the assessment of flood risks. Therefore, the two models can also be used to forecast possible flooding eventsevents within this study area.

Üyüklüoğlu, M. (2015). This study uses the HEC-RAS program to describe the cross sections of the Ilica Stream floodplain. The modelling was intended to simulate the routing of floods at higher elevations from the water-surface profiles. They seek to identify a new mainstream route to contain the overflow water within the confines of the river bed and subsequent riverbed rehabilitation exercises. Water surface profiles for the rehabilitated streambed were obtained from the HEC-RAS study, and the analysis shows that control over the flood was achieved with implemented measures. It further demonstrates the importance of preventive measures against floods in flood-affected areas and the use of contemporary information processing tools for that purpose.

Romali, N. S., et. al. (2018). The use of a HEC-RAS model in the development of a floodplain map for Segamat, Malaysia. Primarily, the study was modelled by using Interferometric Synthetic Aperture Radar (IFSAR). Flood flow extremer with different return periods were estimated using five distribution models: Generalized Pareto, Generalized Extreme Value, Log-Pearson 3, Log-Normal (3P), and Weibull (3P). KS test showed that the generalized Pareto was the best distribution for the Segamat River. The anticipated associated flood levels were calculated with the help of peak floods from frequency analysis for some return periods by using the HEC-RAS model. The output of the HEC-RAS model was used in ArcGIS to develop floodplain maps for different return periods. The results indicated that most of the flooded regions in the expected 100-year return period were also affected by the 2011 historical floods. During the 100-year flood simulation, the Area submerged was nearly five times larger than the Area submerged in the 10-year flood scenario.

Development of Floodplain Mapping with the Help of HEC-RAS for a Section of Kabul River in Pakistan. The aim of the research of **Khattak M. S. et al. (2016)** is to assist policymakers and planners in developing effective flood mitigation measures in the Khyber Pakhtunkhwa Province, which suffered massive flooding in 2010, thereby demonstrating that the province is highly vulnerable to floods. Geometrical data for the river was extracted from the Shuttle Radar Topography Mission Digital Elevation Model due to its satisfactory accuracy and is freely available. The conventional flood frequency analysis using log-normal, Gumbel's, and log-Pearson type III (LP3) distributions were employed to compute extreme flows with varying return times. The

KS test revealed that LP3 was the ideal distribution for the Kabul River. Flood data from frequency analysis peak floods was used to compute equivalent flood levels that could be obtained in river reaches from Warsak dam to Attock in the HEC-RAS model. The HEC-RAS model results were overlaid onto ArcGIS for mapping floodplains at different return periods. Using floodplain maps helps in recognising areas vulnerable to flooding. Floodplain maps indicate that over 400% of the area is expected to be inundated compared to the average river flow. Most of the flood-prone land is under cultivation. In comparing the simulation of the 2010 flood with the MODDS picture of the same, it is evident that they have close agreement in relation to each other.

Singh, S. K., et. al. (2021). The present research used the hydrological model "(HEC-RAS)" and a GIS-based analytical framework to assess flood risk and potential effects with a particular repeat possibility generated from frequency analysis. Varanasi City Municipal Corporation's most hazardous flood-prone sub-area (Varanasi Sadar) has been designated as a case study. Based on the current conditions, flood inundation

Modelling is done, and it reveals that significant flooding begins at an extreme discharge probability of $1000 \text{ m}^3/\text{s}$ during a 5-year return period. With 10- and 20-year return floods, the predicted impact gradually increases. In terms of potential impact and land use sensitivity, built-up regions are most likely to be affected, followed by lucrative, communal, and semi-public uses.

Namara, W. G., et. al. (2022). This study's primary goal was to map flood inundation using the HEC-RAS model in the context of the Awash Bello flood plain in Ethiopia's Upper Awash River basin. Using HEC-Geo RAS, the river cross-sections along the floodplain were retrieved. Using the calibrated and validated HEC-HMS model, annual peak flood frequency analysis for various recurrence intervals (i.e., 2, 5, 10, 25, 50, and 100 years) was calculated using hydro-meteorological data gathered over 25 years (1990-2015) from the Ministry of Water Resources, Irrigation and Electricity and National Meteorological Agency, respectively. The model's output showed that the maximum flood flow for each interval of recurrence was 526, 610, 828.8, 1072.8, 1263.6, and 1461.3 m^3/s , respectively. The flood extreme value obtained from Log Pearson type-III, General Pareto, and Gumbel extreme value distribution functions was compared with the HEC-HMS model outputs for more excellent reliability, and it was discovered that the HEC-HMS model results for every recurrence interval were

higher than the extreme value distribution function outputs. The validated peak flood was then fed into the HEC-RAS model, and flood inundation mapping for various recurrence intervals was carried out after confirming the acceptability of the HEC-HMS model result. The HEC-RAS model result showed that the flood inundation mapping area was 71.475, 76.630, 89.150, 100.290, 105.160, and 109.462 km² for 2, 5, 10, 25, 50, and 100-year recurrence intervals, respectively. Finally, it was understood that the massive rainfall event was responsible for flooding the whole Awash Bello floodplain.

The study was done by **Çitgez., (2011)**, who investigated the possible damages due to floods in the Kaynaşlı District of Düzce Province, located in the Western Black Sea Region of Turkey, which is among the most vulnerable areas. The research extended up the watershed into the residential and agricultural lands, and it entailed restoration measures. To address the issues associated with the mentioned areas, the cross-sections and recurrence flows of the Kaynaşlı Stream and dry streams were established using the HEC-RAS program and calculations were made for the maximum flow rates that the existing cross-sections could withstand.

Efe, H. (2014) Performed an analysis of the Batman River flood using the HEC-RAS software package, where the river runs through the Batman Province. The analysis was carried out on high flow rates that, at times, cause deaths and destruction. As a result, it was determined that the chosen cross-section, defined within the frames of the Batman River Rehabilitation project carried out by DSI (the State Hydraulic Works), would be reasonable.

Yaylak, M. (2016) Tried to evaluate the effect of flood in Bitlis Creek, which has intermittent high flows, causing loss of lives and damage to the irregular urban development in Bitlis Province using the HEC-RAS program and GIS. For this study, the 1/5000 scale topographic maps were digitized using ArcGIS and the derived elevation models were used to identify floodplain water surface profiles in HEC-RAS. The resulting maps of flood inundation were developed using the HEC-GeoRAS software through the water surface profiles.

Because of population increase, the demand for water and settlements, poor zoning plans, and haphazard engineering practises, floods are getting dangerous for humans

every day. In order to reduce the damage caused by the floods, rehabilitation is the first step in the process. To conduct these analyses, it is necessary to specify the alterations that bridges on rivers, hydraulic structures like regulators, and the consequences of changes to water surface profiles brought on by changes in the land's natural condition must create in cross sections. Today's approaches for determining water surface profiles include a number of packages of software that have been created to make the analysis and calculating process easier. Of them is HEC-RAS. The investigation of the floodplain between the ancient Ten Eye (On Gözlü) Bridge and the Diyarbakır-Silvan Highway was done in the research by **OĞRAŞ, S., (2018)**. In addition to assessing the flow impact of the current natural section changes, bridges across the Dicle River and the cross-section changes induced by these hydraulic structures as well as VII as the facilities of the private businesses situated on the route of the floodplain regions, which may occur concurrently, may also occur. It has been attempted to determine the potential effects on the Dicle Valley project, which is

Anticipated to be completed in the coming years, as well as the facilities and hospitals associated with the university in the settlement of Dicle University, the ten-eye bridge (Dicle Bridge), Hevsel Gardens, and other sites listed on the UNESCO World Cultural Heritage List. Using the AutoCAD Civil 3D programme, the 1/1000 maps of the study area were converted to digital form, and cross-sectional purchases were made by getting the region's digital elevation models. The hydraulic properties of the flood bed, the water surface profiles of the Q25, Q50, Q100, and Q500 flood recurring, and one-dimensional floodplain analysis of the Tigris (Dicle) River were identified from the collected cross sections using the HEC-RAS programme. The findings of the study of the floodplain risk included water surface profiles for flow rates Q25, Q50, Q100, and Q500.

Regular storms cause annual floods in northeastern Romania's agricultural regions. The EU directive 2007/60/EC has started using rough hydrological risk maps to estimate and control flood risk. Furthermore, as a rule, the boundary of possibly floodable regions estimated based on SRTM – a DEM with 30 meters resolution made during the era does not correspond to actual topography as a rule. The study conducted three tests (T1, T2, and T3) simulating floodplains and a comparative assessment of possible damage at 30 sites in the research region (Başeu river basin), developed by

Stoleriu, C. C. et al. (2020). The results indicate that the damages likely incurred on account of a one-cent chance of hydrological events within the span of a hundred are understated by official statistics (T1). Other T2 [1%] (100-year) results also highlight the significance of hydro-technical projects in flood alleviation. The hydrological risk zones in T3 were created with an accuracy of 0.5 m, predicting the possible damage in case of events that may occur with 3%, 1%, and 0.1% recurrence intervals. The official hydrological hazard maps (T1) became more precise using high-density LiDAR data and HEC-RAS software (T3).

This paper assesses the predictive abilities of travel time flood wave and flood extent of one-dimensional, two-dimensional and HEC-RAS flood wave models. The study by **Ghimire E. et al. (2022)**, in the Grand River of Ohio, USA, used the same sets of geometric conditions like LiDAR data combined with field surveyed cross-section, the same set of flow conditions, within 1D, within the 1D, 2D, and coupled 1D/2D

Modelling features of HEC-RAS. According to the investigation, the linked 1D/1D/2D model and the 2D model consistently outperformed each other. Additionally, connected 1D/2D and 1D models are considerably more sensitive to the inputs than the 2D model, according to sensitivity analysis. Travel time was 20% longer than predicted by the 1D model than by the 2D model. Similar to this, it was discovered that the inundation area from the 1D model was somewhat larger (4.1%) than that from the 2D model. Urbanisation increases impervious area, hence increasing susceptibility to urban floods. Deer Creek in Brentwood, Missouri, has previously seen exceptionally high floods, flooding the surrounding neighbourhoods multiple times. The evaluation of the flood extent is a critical stage in flood mitigation. **Shrestha, A., et al. (2020)** Investigated the size of floodplains in urbanised areas using the Hydrologic Engineering Centre River Analysis System (HEC-RAS) and hydrodynamic modelling software—MIKE 21. A comparison of the models is carried out in order to assess the modelling benefits of each model. Furthermore, the research concentrated on each model's two-dimensional (2D) modelling skills since 2D models were more beneficial in metropolitan environments with a more significant number of discrete characteristics. When evaluating the 2D floodplain modelling capabilities of each model, the tradeoff between accuracy and resources was analysed. Channel morphology and flow parameters for various return periods were integrated during

modelling, and USGS gauge data will be used to calibrate the models. The models were calibrated at peak phases along Deer Creek, with a downstream boundary condition of typical depth, and unsteady flow simulations were carried out using the relevant flow hydrographs. The streamflow parameters simulated were obtained from observations taken at a USGS gauging station near Brentwood, Missouri.

The research of **Agrawal, R., & Regulwar, D. G. (2016)** focuses on calculating surface water heights on the downstream side of the upper catchment of the Dudhana River for various discharge amounts, as well as determining flooding areas for various discharge amounts from the dam. As a result, it triggered the catastrophic flood scenario and its downstream effect on the Dhudhana River basin. The River Analysis System (HEC-RAS 4.1.0) model of the chosen research region was created by the USACE Hydrologic Engineering Centre. There are 21 cross-sections in the study reach. The HEC-RAS hydraulics model was used to assess flood conveyance performance, and uniform flow calculation was performed. In the current research, existing storm drains are not only noted but the requirement for flood gates on storm drains is also evaluated based on the HEC-RAS water surface elevation calculation for different flood flows.

CHAPTER 3

HEC-RAS MODEL

3.1. HEC-RAS Hydrology

The HEC-RAS software program can be freely obtained from the website of the US Army Corps of Engineers at "<http://www.hec.usace.army.mil/software/hec-ras/>". The same could be used for downloading the user manual of the program. Once download this program into computer by executing the “Setup” file, it installs itself onto the computer, making its active desktop shortcut as seen in Figure 3.1 (HEC User Guide, 2010).



HEC- RAS 4.1.0

Figure 3. 1 Shortcut icon of the HEC-RAS program (HEC User Guide, 2010)

The HEC-RAS software package, in its one-dimensional form, is capable of conducting four distinct river analyses, which are as follows:

- 1) Calculation of regular flow water surface profiles.
- 2) Variable flow conditions modelling.
- 3) Modelling of Sediment Transport along the Moving Bed Boundary.
- 4) Water quality analysis studies.

The four methods include the definition of geometric data followed by both geometric and hydraulic calculations.

When fluid flow characteristics remain constant at any point and at any time, this implies a steady and uniform flow. Steady flow is characterized by slight variations in water depth and velocity from one section to another. The HEC-RAS program can handle flow problems which involve subcritical, supercritical or both flow conditions.

With regards to HEC-RAS, such analyses are instrumental in studying and modelling river behaviour, hydraulic phenomena, sediment transporting and water quality. This makes it a viable tool in addressing diverse hydrologic and hydraulic problems as it is able to handle different flow scenarios (Brunner, G. W. 1994).

The one-dimensional energy equation used by HEC-RAS is for calculation of water surface profiles. Accordingly, other factors affecting energy losses such as Manning's coefficient of roughness for frictional losses, the correction coefficient of kinetic energy for changes caused by junctions, outlets and regulators, and the momentum equation for sudden variations in the water surface are also included. They are used to analyze transitions from the river regime to the flood regime (hydraulic jumps), transformations of the flow characteristic brought about by bridges, and investigations of characteristics of confluence points when the river merges with another one.

In hydraulic calculations many barriers are considered such as bridges, culverts and channels. This program is greatly used for modeling river flows, floodplain management and flood insurance studies.

While direct step methods are employed to calculate water surface profiles, the fundamental calculation approach is built upon the solution of the following energy equation:

$$H = Z + Y + \alpha \frac{V^2}{2g} \quad (3.1)$$

3.2 Generating HEC-RAS Project

When the HEC-RAS program is installed and run on a computer, the main menu as shown in Figure 3.2 is displayed on the screen. To start a project, it is necessary to first create a new project on the computer by clicking on the "New Project" option in the File menu (Flood Hazard Assessment Methodologies. 2013).

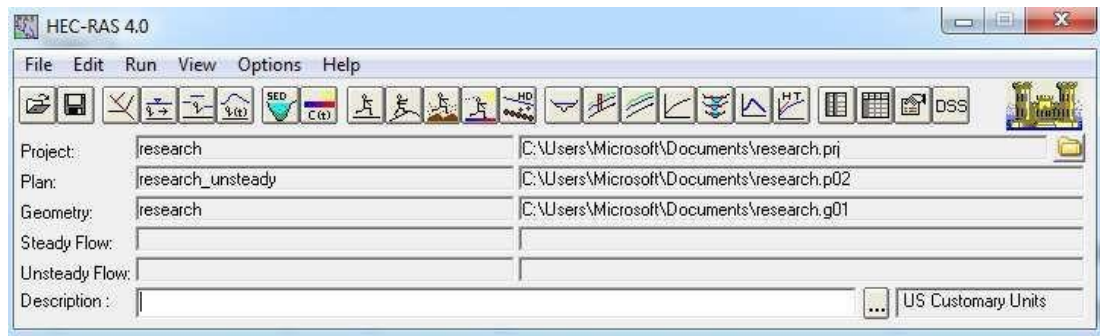


Figure 3. 2 Main menu of HEC-RAS program

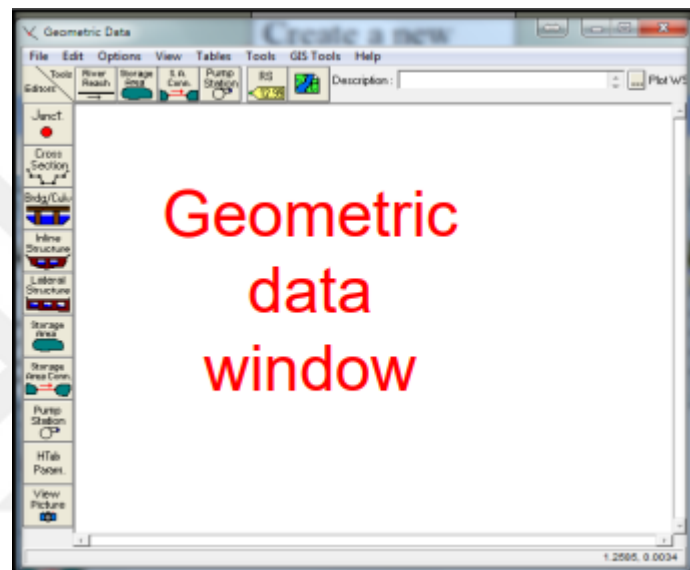


Figure 3. 3 Geometric data window

In HEC-RAS, there are two fundamental data inputs: Geometric data and Flow data. Geometric data includes cross-sections, bridge, culvert, and pump station data, while flow data consists of discharges and boundary conditions. When the Geometric data button is clicked, the data input area shown in Figure 3.4 is displayed on the screen. To define the river, the "river reach" button is clicked, allowing for the definition of a schematic river plan in the direction of flow. Subsequently, the "cross section" button is used to define cross-sections, and if applicable, the "brdg/culv" button can be used to define bridges and culverts (Flood Hazard Assessment Methodologies. 2013).

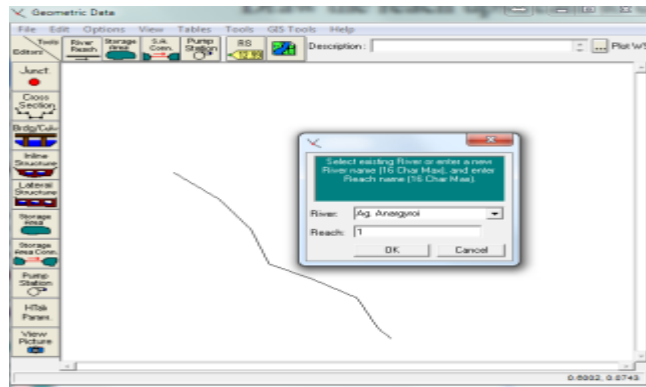


Figure 3.4 Create a reach for river

When the 'Cross Section' button is clicked, the interface shown in Figure 3.5 is opened. To define a cross-section, first, the 'add a new cross section' option should be selected from the 'options' menu. Then, a number that will identify that cross-section should be provided in the small dialog box that appears.

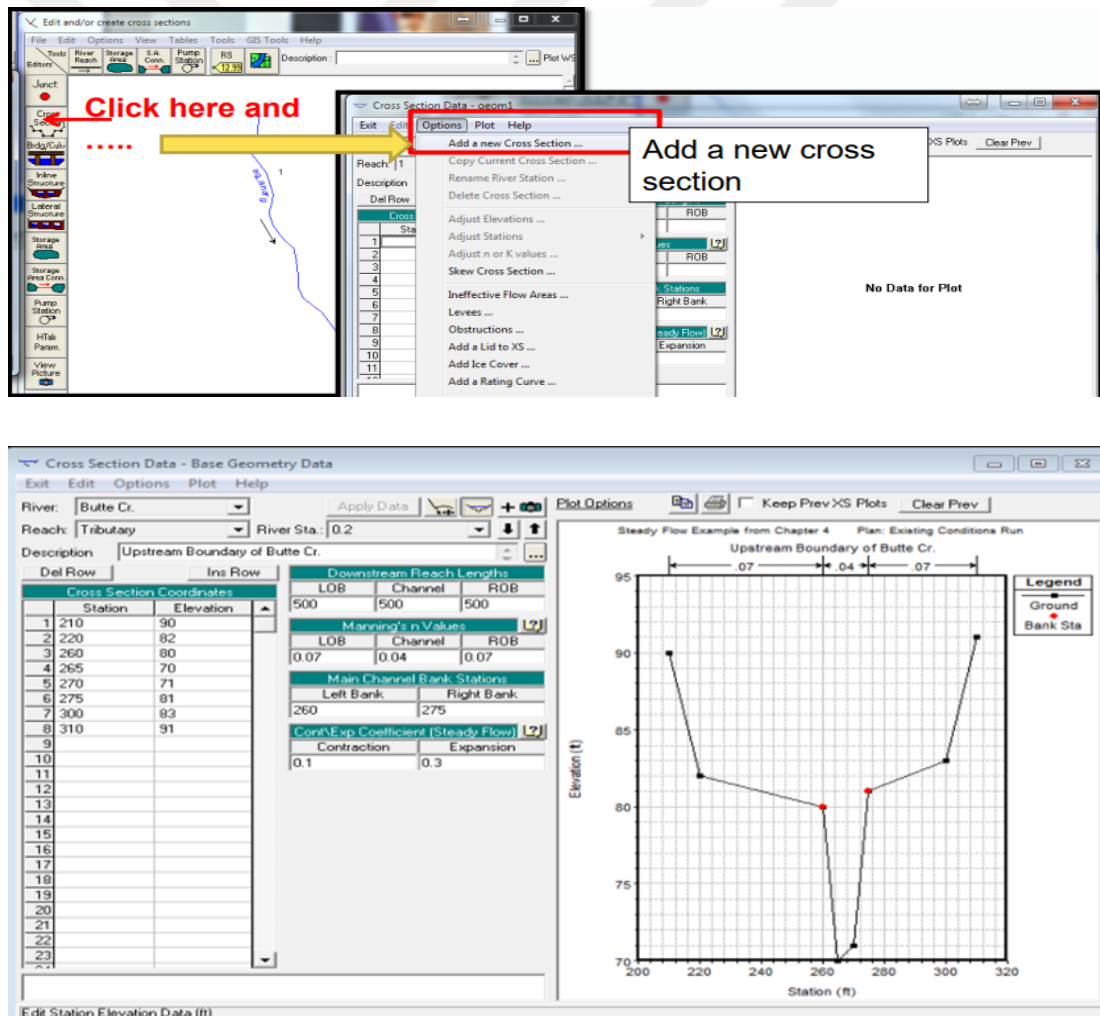


Figure 3.5 Cross-Section data input

- **Inputting data**

Regarding the flow and environmental conditions, including data on unsteady flow as depicted in Figure 3.6, as well as the initial and boundary conditions for the unsteady flow as illustrated in Figure 3.7 (Brunner, G. W. 1994).

Figure 3. 6 The required data for unsteady flow

Figure 3. 7 The initial and boundary conditions for unstable flow.

- **Performing Hydraulic Calculations**

After entering all geometric and flow data, we proceed to conduct hydraulic calculations as illustrated in Figure 3.8. Following the input of comprehensive geometric and associated flow information, hydraulic calculations are carried out in accordance.

Figure 3. 8 Hydraulic calculations for unsteady flow

- **Viewing Results**

Presentation of results that illustrating Cross-Sectional Profiles, as Depicted in Figure 3.9, to Convey Water Level, Bank Elevation, Manning's Coefficient, and Cross-Section Coordinates, Along with Optional Display of Various Variables; and Depicting Longitudinal Profiles, as Shown in Figure 3.10 (Brunner, G. W. 1994).

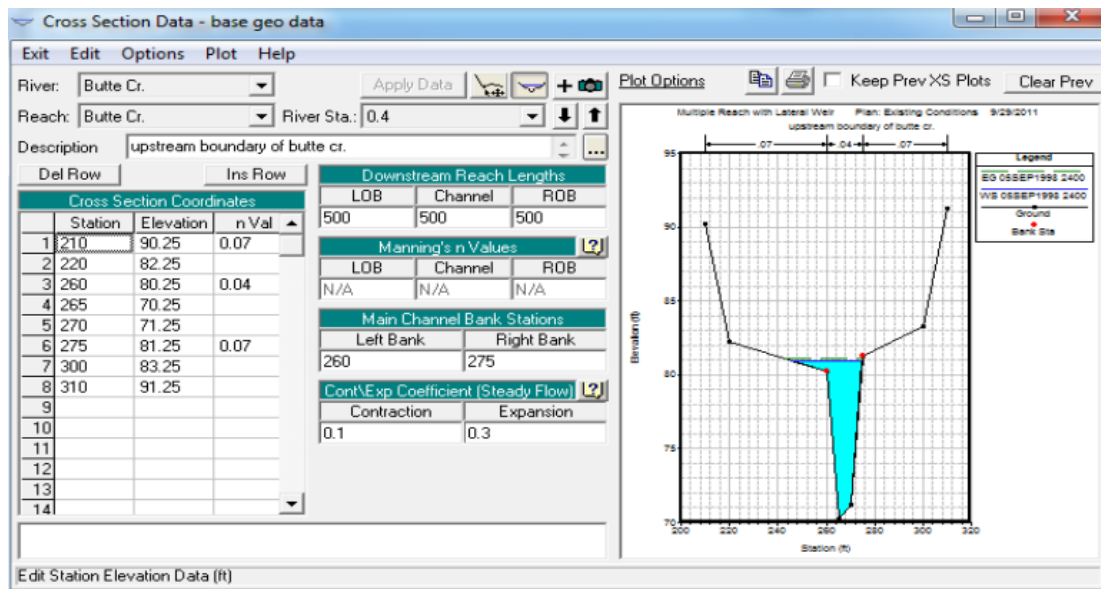


Figure 3. 9 Cross sections.

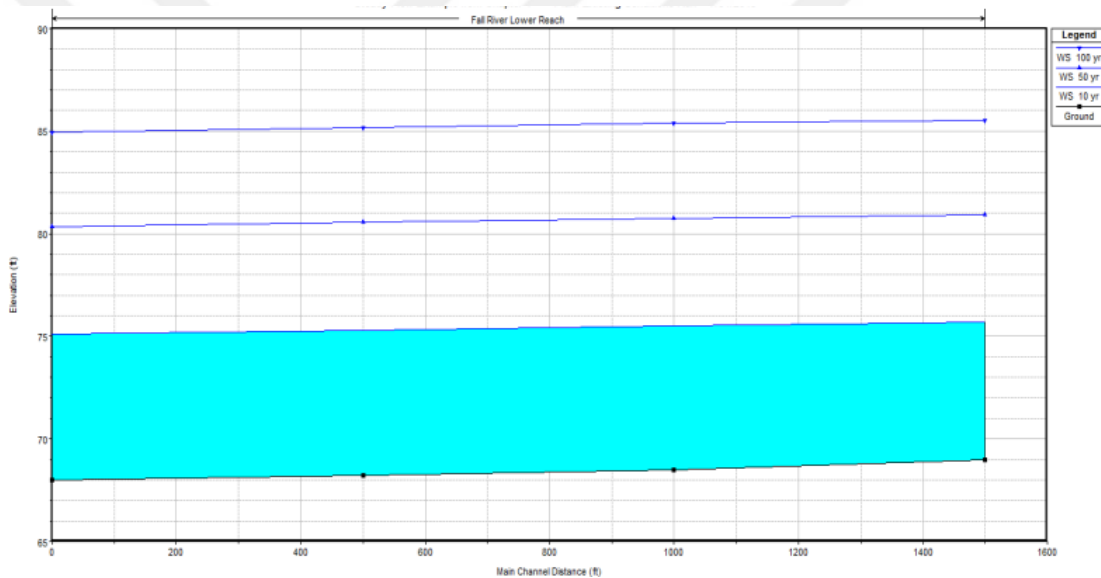


Figure 3. 10 Longitudinal sections

As shown in Figure 3.11. Displaying Inundation Areas on a Three-Dimensional Plot in the (X-Y-Z) Perspective, along with the Time of Arrival of the Flood Wave.

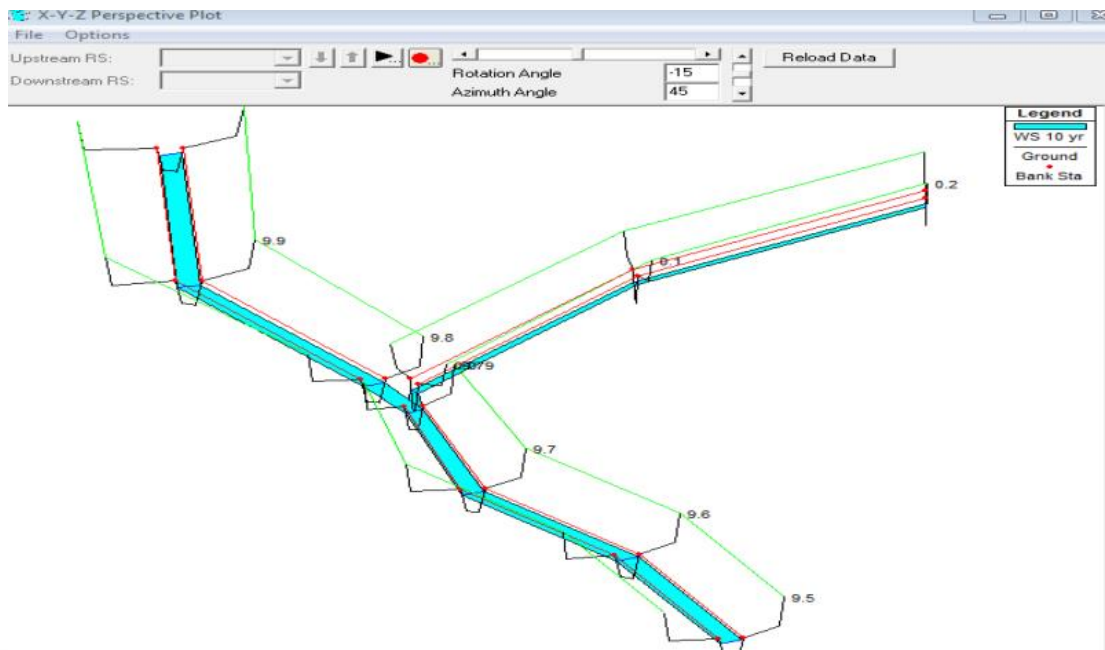


Figure 3. 11 A trilateral exposition illustrating submersion zones

CHAPTER 4

METHODOLOGY

4.1 General Characteristics of the Al Kabeer Al Shemali River

The Al Kabeer Al Shemali River is considered one of the most significant water resources in the coastal basin, and its course descends rapidly until the construction site of the October 16 Dam. Beyond this point, the river transforms into plains characterized by dense vegetation and fertile agricultural land.

In Syrian territory, the river spans a length of 96 kilometers, with a peak flow of 40 cubic meters per second. During hot seasons, it may decrease to 1 cubic meter per second or even less, as observed in 1985. The river's flow pattern is closely linked to rainfall amounts, with an average flow during rainy seasons (early November to late February) reaching 17.1 cubic meters per second, while the average flow in hot seasons (June to early September) is 2.3 cubic meters per second (Mahmoud, A., & Khudair, M. Y. 2023).

The bed of the Al Kabeer Al Shemali River is situated within the coastal plain, where agricultural lands, human settlements on mountains and plateaus, as well as agricultural, animal, and industrial facilities, are scattered along the riverbed (Ghatfan Ammar, et al. 2012).

The study area is located in the northwestern part of the Syrian Arab Republic, east of Latakia city, within the northern part of the coastal basin. The course of the Al Kabeer Al Shemali River serves as a natural boundary between two mountainous masses: the Syrian Coastal Mountain Range to the south and the Bayir and Biscay Mountains to the north and west.

The source of the Al Kabeer Al Shemali River is in the northwestern end of the Latakia Mountains, specifically from the area near the Turkish border known as the Ansari

Mountains, at an elevation exceeding 1,100 meters. It covers a distance of 89 km, eventually flowing into the Mediterranean Sea south of Latakia city, approximately 2 kilometers from the village of Al-Basa (Mohammad, H. 2016).

The drainage basin of the Al Kabeer Al Shemali River, from its source to its mouth, covers about 1,104 square kilometers. Approximately 174 square kilometers of this basin are located in Turkish territories, while 930 square kilometers are within Syrian territories, distributed as follows: around 36 square kilometers in Idlib, about 5 square kilometers in Hama, and approximately 889 square kilometers in Latakia (Ghatfan Ammar, et al. 2012).

Regarding the Syrian part of the drainage basin, it takes a triangular shape, with its base extending from northeast of Salma to Kassab on the southeast slopes of Mount Aqraa. These base forms the watershed line that separates the basins of the Al Kabeer Al Shemali River and the Aasi River. The mentioned watershed line coincides with the summits of Mount Salma, and the Jisr al-Shughur, passing through the heights of Baddama village, Fadra, and the plateau of Bayir. The apex of the triangle is the river's mouth, which is located 3 kilometers south of Latakia city on the Mediterranean Sea. The southern side of this basin forms the watershed line separating it from the basin of the Sanobar River, aligning with the axis of the villages (Salma, Al-Harah, Mazar al-Qatariyah). As for the northwestern side of the triangle, it forms the watershed line for the axis of the villages (Kassab, Ain al-Bayda), separating it from the basin of the Qandil Valley, the Western River, and some streams that directly discharge into the sea (Mohammad, H. 2016).

The drainage basin of the Al Kabeer Al Shemali River is situated in a region with a Mediterranean climate. The study area experiences a semi-tropical climate characterized by low rainfall, high temperatures in the summer, and humidity in the winter. Figure 4.1 illustrates the study area, and Figure 4.2 show the topography of the Al Kabeer Al Shemali River basin, while Figure 4.3 delineates the boundaries of the drainage basin for the Al Kabeer Al Shemali River. Figure 4.4 provides a detailed depiction of the studied section of the Al Kabeer Al Shemali River.

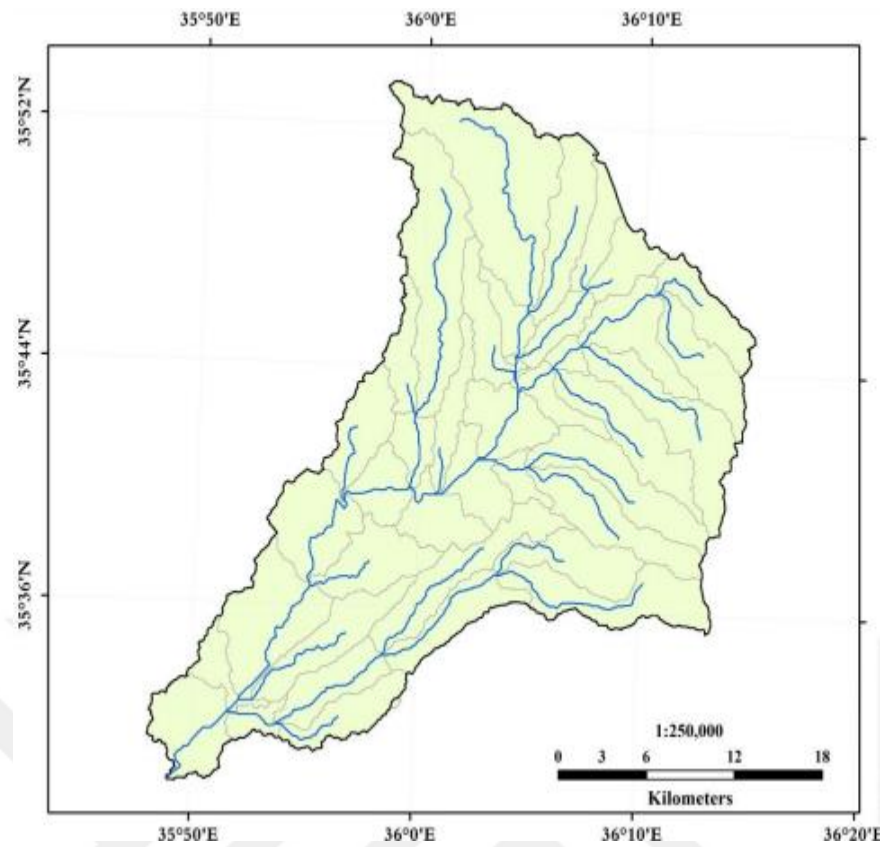


Figure 4. 1 Study area (Al Kabeer Al Shemali River)

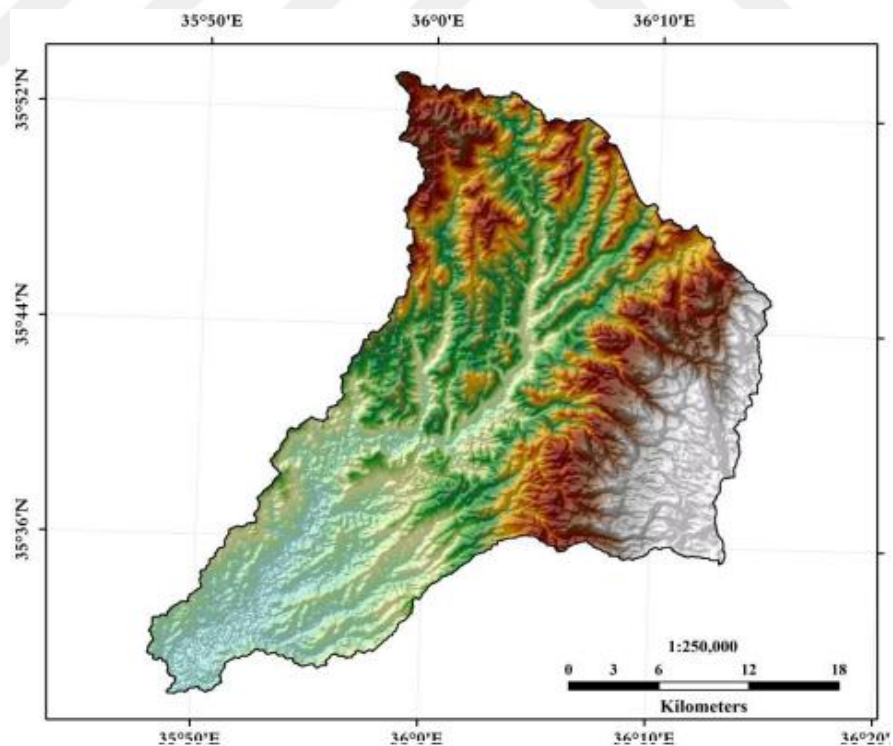


Figure 4. 2 Topography of the Al Kabeer Al Shemali River basin derived from digital elevation model.



Figure 4. 3 The boundaries of the catchment area for the Al Kabeer Al Shemali River.



Figure 4. 4 The studied section of Al Kabeer Al Shemali River

Table 4.1 shows where Al Kabeer Al Shemali River passes through a number of districts in Syria. The table outlines the area covered by the river in various

administrative sub-divisions with the corresponding square. Latakia has a surface area of 889.05 km² while Idlib is about 35.82 km², and Hama is about 4.8 km².

Cumulatively, these districts comprise of 929.67 km² (Mohammad, H. 2016). The following table represents the spatial distribution of the Al Kabeer Al Shemali River as it crosses different governors in Syria providing information about its presence and spread within varied administrations.

Table 4. 1 Area distribution of Al Kabeer Al Shemali River (Mohammad, H. 2016).

	District	Area (km ²)
Syria	Latakia	889.05 km ²
	Idlib	35.82 km ²
	Hama	4.8 km ²
Sum of Area		929.67

4.2 Flood in Al Kabeer Al Shemali River

The Al Kabeer Al Shemali River Basin has abundant bushy vegetation with many seasonal plants, grasses, and shrubs.

At the joining points of tributaries, there is much fluctuation in the area of the basin. This channel has a length of approximately 65km wide, averaging 17 km, with a maximum width of 25km. The slope of the channel from Dam 16 to the estuary is not significant, ranging around 0.0012. The gradient of the channel from Dam 16 to the estuary is nearly the upper basin is mountainous, while the lower basin is almost flat. Therefore, the slope decreases gradually. The watercourses in Al Kabeer Al Shemali Basin vary in density from 2–3.5 km/km, moving from the upper to the lower parts of the basin. This is attributed to the change in topography from mountainous in the upper region to almost flat in the lower region near the estuary (Mahmoud, A., & Khudair, M. Y. 2023).

The average rainfall in the basin over the last ten years is 900 mm, with previous studies indicating rainfall averages ranging from 800 to 1200 mm. The region experiences relatively heavy rainfall, especially in its upper section. There is a flow

measurement station on the Northern Great River (Ghamam Station), located near Lake Dam 16 to the northeast. The monthly average values of river flow range from 0.3 m³/s to 9.6 m³/s, reaching up to 23 m³/s in winter, while decreasing to 0.03 m³/s in summer, during the monitoring period from 2011 to 2007 (Mohammad, H. 2016).

4.3 Research Method

In constructing a hydrological model for the flood flow of the Northern Kabeer River in Latakia, the HEC-RAS and GIS software were employed. This model considered the presence of the October 16 Dam. Subsequently, the model was integrated with satellite imagery provided by Google Earth.

4.3.1 GIS Model using Hec-GeoRas Tools

The model was built in GIS using the Hec-GeoRas toolbar. The development phase involved the creation of river layers, such as drawing the river channel, defining the banks, developing cross-sectional profiles, and laying out the flow path along the banks. Using the Gumbel distribution, the maximum flows for the repeat cycles were calculated from the maximum annual runoff records of the October 16 Dam station between 1976 and 2010—Water Resources Directorate in Latakia (2015). In addition, a DEM digital model having a spatial resolution of 12.5 meters for the studied area was incorporated into the model, as shown in Figure 4.5.

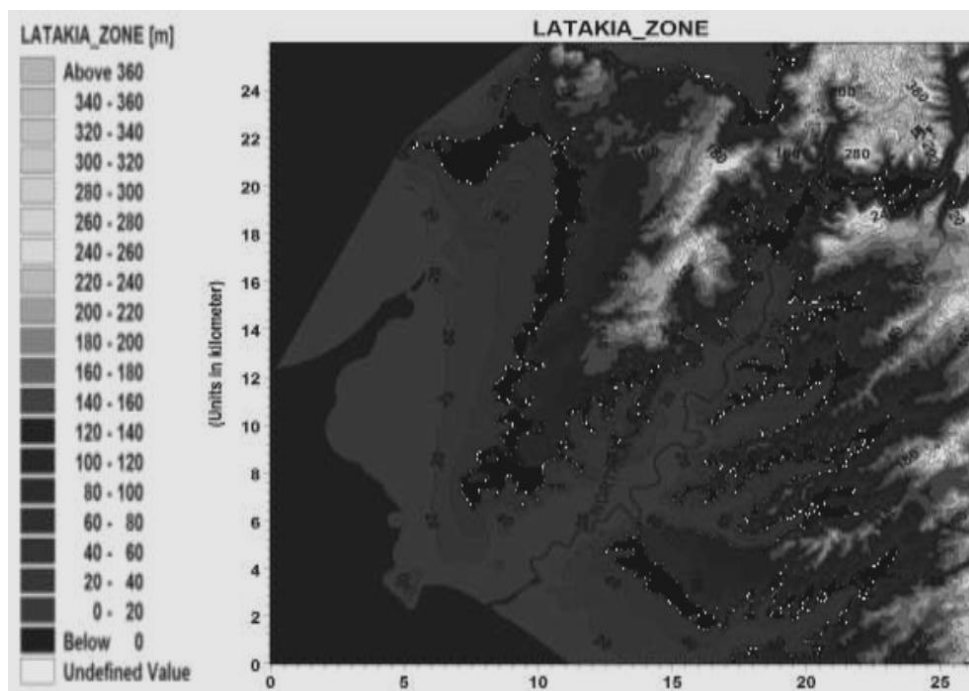


Figure 4. 5 A topographic diagram representing the study area in the form of a Digital Elevation Model (DEM).

The work within the HEC-RAS program involves utilizing the software for river modeling. This program is designed to store, analyze, and manage data, providing graphical or tabular reports. It calculates steady-state flow, simulates unsteady flow, and requires input of cross-sectional profiles, their distances, and the hydraulic structures along the entire river. The cross-sectional profiles must be perpendicular to the watercourse, with closer distribution along the channel to enhance accuracy. Such strategic placement entails such locations as meander zones, changes in slope, variability of roughness coefficients, zones of expansion and contraction, river bifurcation points, and sites of impediments to flow or hydraulic structures. Additionally, energy losses resulting from roughness, expansion, and contraction are included together with initial and boundary conditions for these calculations.

- **Model Creation**

Through the main interface of the HEC-RAS program, as depicted in Figure 4.6

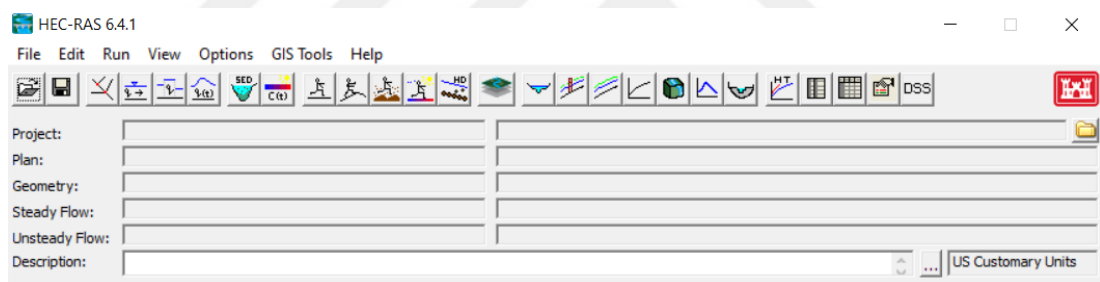


Figure 4. 6 HEC- RAS software interface

- **Inputting Geospatial Data Dimensions**

This encompasses modeling the longitudinal path of the watercourse, cross-sectional profiles detailing the edges of the channel, and the Manning's roughness coefficient for both the banks and the bed of the watercourse. Figure 4.7 illustrates the modeling of the studied watercourse path from the starting point to the outlet, indicating the flow direction towards the river's estuary using the "River reach" command. The cross-sectional profiles along the watercourse path using 24 cross-sections. This is accomplished utilizing the Cross Section command, taking into account the boundary points of the river channel on the right and left, as well as the values of Manning's roughness coefficients for both the banks and the channel. Creating the necessary layers for study (Layers Ras Create), Figure 4.7, then illustrating each layer separately.

The blue line represents the watercourse, while the yellow lines denote the locations of the primary cross-sectional profiles. The direction of the orange arrow indicates the flow direction (towards the estuary).

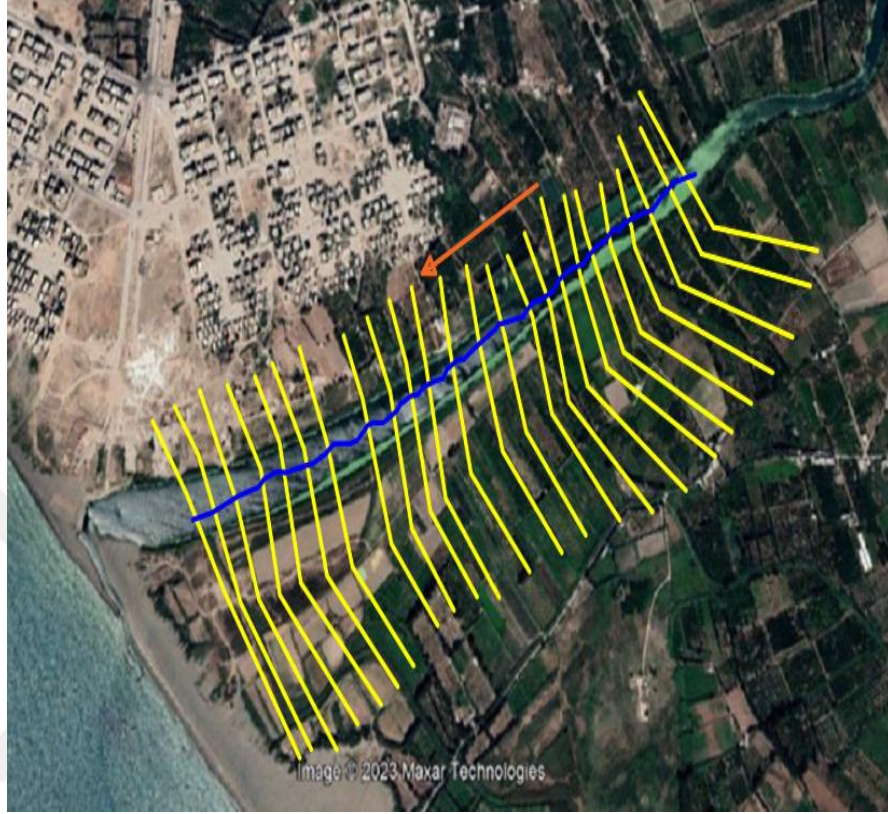


Figure 4. 7 Extracted image from google earth for the studied section of Al Kabeer Al Shemali River

Modeling hydraulic parameters of watercourses, including longitudinal channel profile representation, where the studied portion of the river spans 11.5 km. Cross-sectional profiles were generated with specifications for channel edges and Manning's roughness coefficient (applied to both banks and the channel bed). Figure 4.8 illustrates the modeling of the studied watercourse path from the starting point to the estuary, indicating the flow direction toward the river's outlet into the sea using the River Reach command.

River cross-sections were modeled along the watercourse using 24 segments with the Cross Section command. A primary cross-section was generated every 500 meters along the watercourse. This involved incorporating boundary points of the river channel from both the right and left sides and specifying Manning's roughness coefficients for the banks and channel, with an average value of $38 \text{ m}^{\frac{1}{3}}/\text{sec}$.

Subsequently, the Interpolation XS command was employed to generate secondary additional cross-sectional profiles between every two primary cross-sectional profiles at an interval of 50 meters totaling 207 sections, as illustrated in Figure 4.9. It is noteworthy that these additional cross-sectional profiles encompass a larger portion of the left bank of the studied river section (when facing the flow direction). This is because they include plains and low valleys more extensively on the left side compared to the right side.

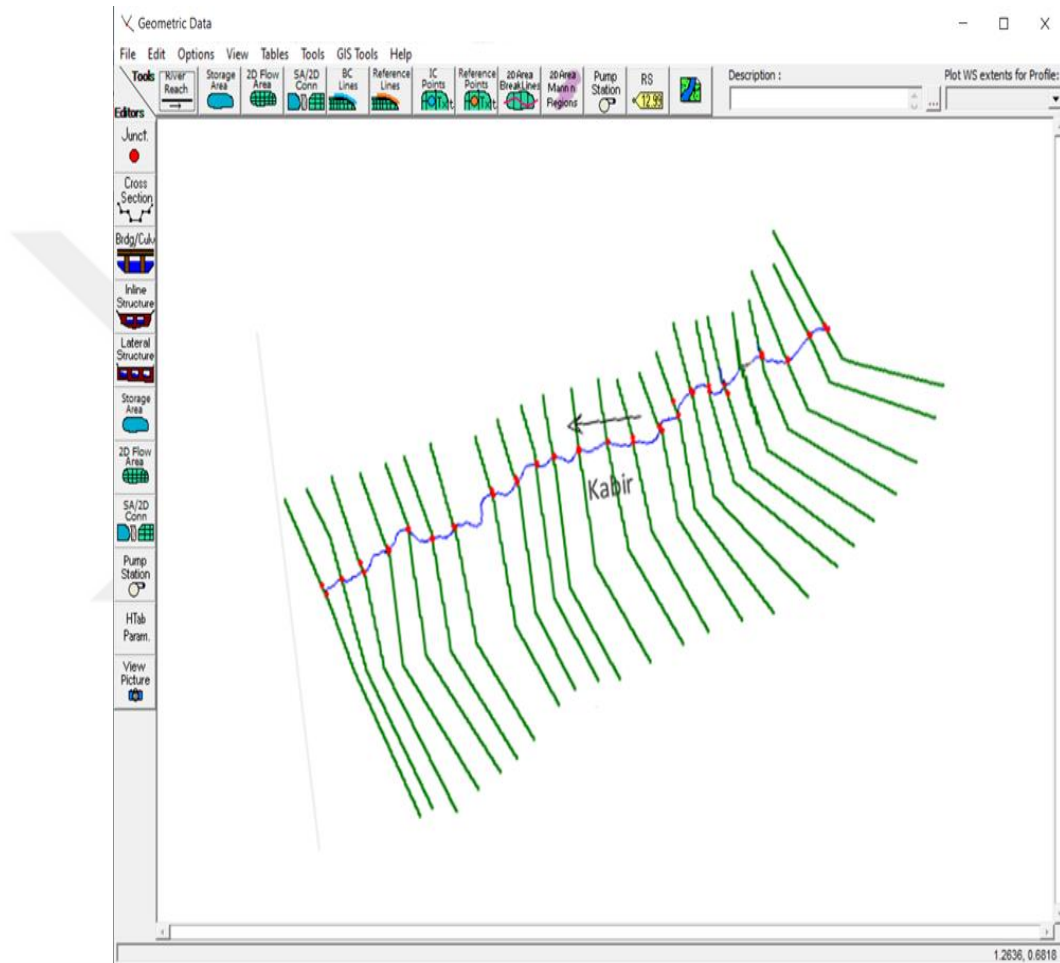


Figure 4. 8 Locations of cross sections 24 along the course of the watercourse

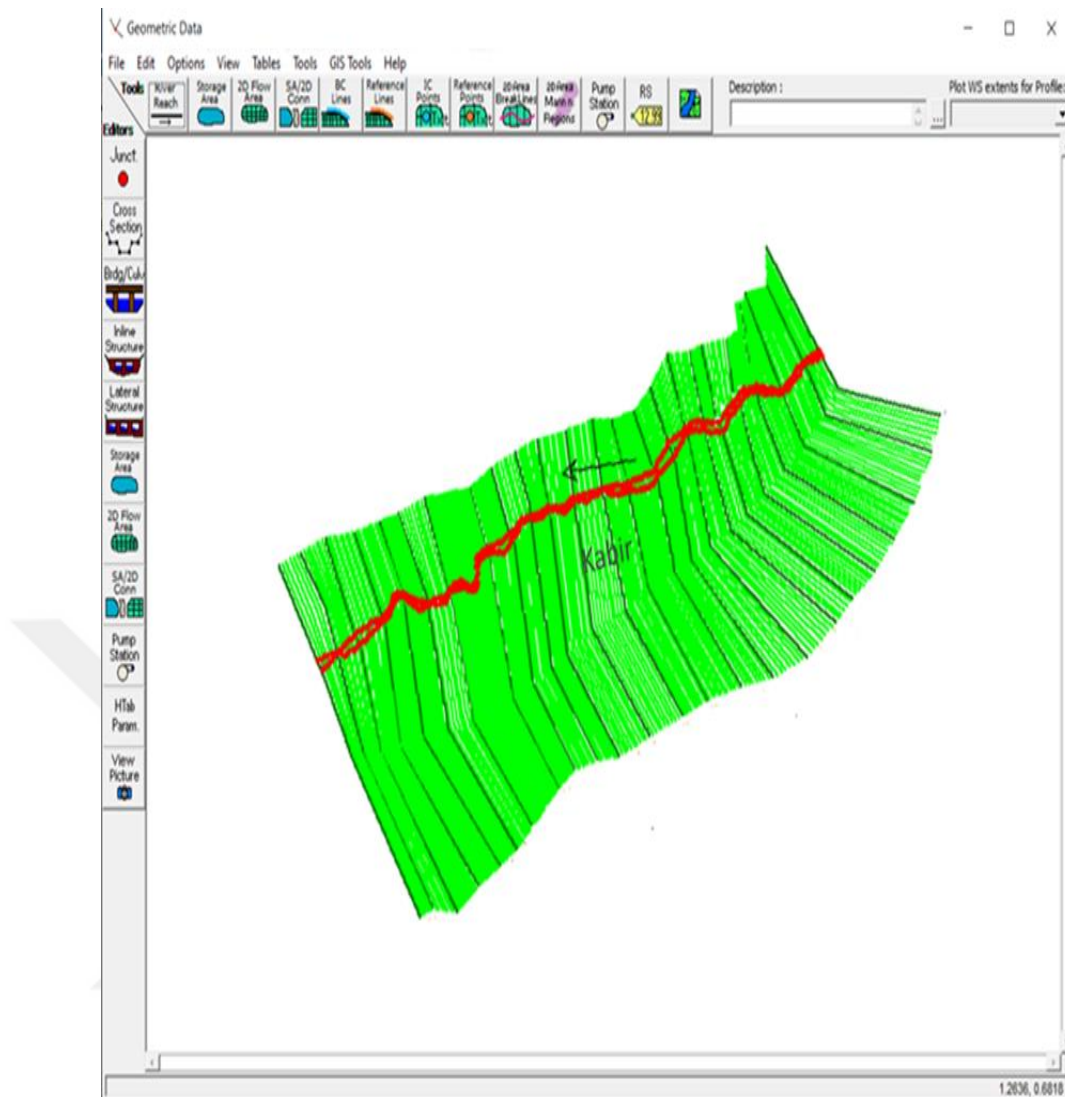


Figure 4. 9 Generation of additional Cross-Sectional profiles

4.3.2 Cross-Sectional Models

The methodology under consideration entails the application of three principal cross-sectional models, denoted by Figures 4.10, 11, and 12, to facilitate the modeling process. These cross-sectional representations are strategically positioned along the course of interest, serving distinct purposes within the analytical framework:

1. Initial Cross-Section

This cross-sectional model is strategically situated at the initiation point of the meticulously planned trajectory. Its role is pivotal in capturing the geometric characteristics and hydraulic parameters at the inception of the studied path. As shown in Figure 4.10.

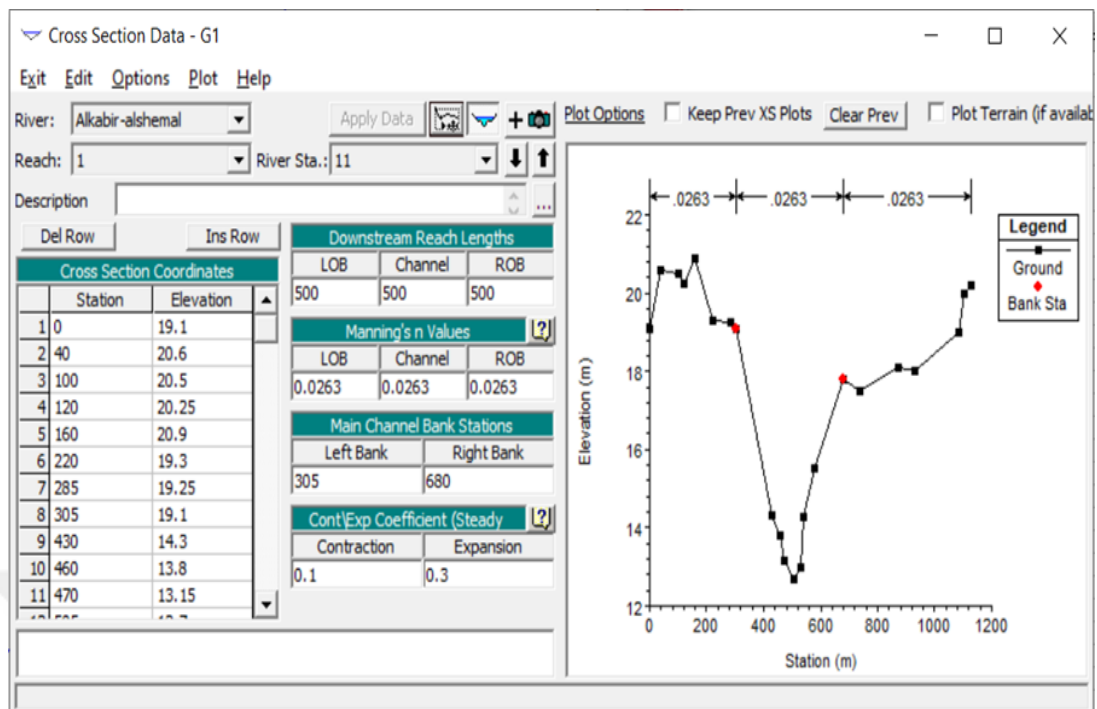


Figure 4. 10 The first cross-sectional profile of the watercourse trajectory

2. Intermediate Cross-Section

Positioned at the midpoint of the envisaged trajectory, the intermediate cross-sectional model provides insights into the evolving hydraulic conditions as the flow progresses along the planned path. This particular cross-section is instrumental in understanding the transitional dynamics within the system. As shown in Figure 4.11.

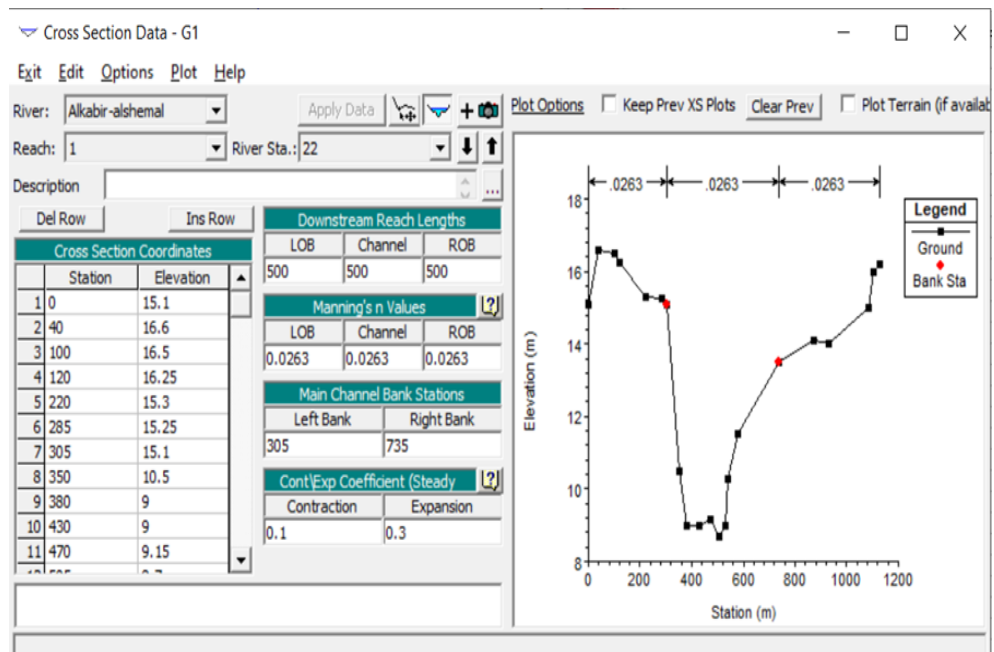


Figure 4. 11 The Second cross-sectional profile of the watercourse trajectory

3.Terminal Cross-Section

The terminal cross-sectional model is strategically located at the discharge point or outfall. Its primary function is to characterize the hydraulic conditions and geometric attributes at the conclusion of the designated trajectory, offering valuable data for comprehensive analysis. As shown in Figure 4.12.

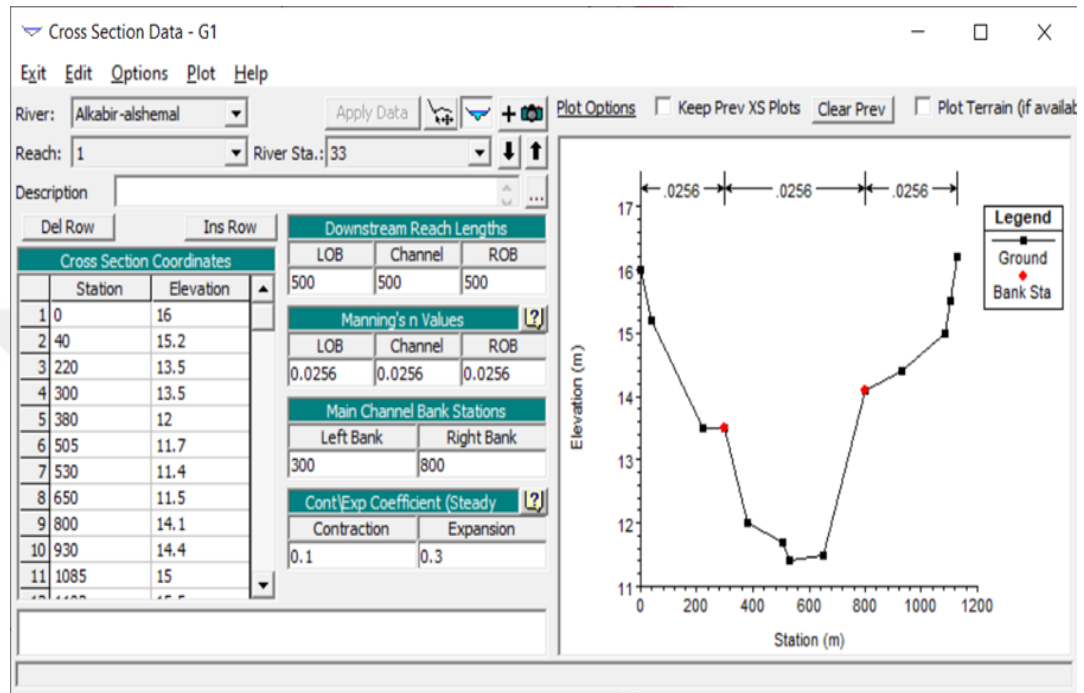


Figure 4. 12 The Third cross-sectional profile of the watercourse trajectory

Moreover, to enhance the granularity of the analysis, the generation of additional cross-sectional segments beyond the initial set of 24 sections is facilitated through the application of the "interpolation XS" command within the software. This interpolation mechanism enables the insertion of supplementary cross-sectional profiles between the existing 24 sections, contributing to a more detailed and nuanced representation of the hydraulic features along the entire trajectory.

4.3.3 Determining channel roughness and Manning's coefficient

The hydraulic analysis undertaken to determine channel roughness and Manning's coefficient involved a systematic and thorough examination of samples collected from diverse locations along the watercourse. The primary objective of this analysis was to provide a precise representation of the actual river roughness conditions. The selected sampling locations were strategically identified to capture variations in channel

characteristics, ensuring a comprehensive assessment of roughness factors channel (Arcement, G. J., & Schneider, V. R. 1989).

Sampling At three sites within the reach of the stream, a sampling was performed so as to identify different conditions in the channel. This was the first sampling site, which was placed at the end of the tranquilization basin with the aim of capturing the quality of the water as it passed from a relatively calm state to others. The second site near Safsaf pumping station attempted to determine the influence of human activities and built infrastructure at the channel roughness. To understand roughness conditions in close proximity to a notable structure within the stream, the third site was selected and placed adjacent to the upper end of the Khan Atallah Bridge.

At each sampling site, samples were taken from both the left and right banks. Samples were carefully drawn from depths reflective of the watercourse overall. Moreover, the samples were collected in sufficient weight to meet the required analytical conditions. The six samples were later analyzed at the laboratory facilities operated by the general directorate of irrigation for the coastal basin. The laboratory was well-equipped with instruments and experts that enabled accurate sizing and hydraulic data measurement. The Manning's roughness coefficient was determined using the Mueller relationship, where d_{90} stands for the particle size distribution. From this analysis, Manning coefficients were computed and listed in Table 4.2. The coefficients were used as indices or metrics of channel roughness for those points. The subtly different Manning's coefficients at the three sites point out the significance of site-specific conditions and structures when it comes to evaluating hydraulic properties for watercourses. This detailed analysis contributes valuable insights for understanding and managing the hydraulic behavior of the Al Kabeer Al Shemali river system.

$$M = \frac{1}{n} = \frac{26}{(d_{90})^{\frac{1}{6}}} \text{ m}^{\frac{1}{3}}/\text{sec} \quad (4.1)$$

In the given context, D_{90} represents the diameter through which 90% of the sample particles pass. The relationship between the Manning coefficient and the three specified locations is provided in Table 4.2.

Table 4. 2 Determine the Manning's coefficient values along the entire watercourse based on the locations.

First Site	d90 = 100 mm	$M = 38 \text{ m}^{\frac{1}{3}}/\text{sec}$	$n = 0.0263 \text{ sec}/\text{m}^{\frac{1}{3}}$
Second Site	d90 = 100 mm	$M = 38 \text{ m}^{\frac{1}{3}}/\text{sec}$	$n = 0.0263 \text{ sec}/\text{m}^{\frac{1}{3}}$
Third Site	d90 = 85 mm	$M = 39 \text{ m}^{\frac{1}{3}}/\text{sec}$	$n = 0.0256 \text{ sec}/\text{m}^{\frac{1}{3}}$

These values are considered acceptable as they pertain to the field of natural river roughness. Subsequently, they have been incorporated into the computational cross-sections of the HEC-RAS program, as depicted in the previous figures (where the value of $1/M n$ is entered into the program).

4.4 Equations for analyzing flow within a watercourse in the HEC- RAS Model

The program uses the Saint Venant equations in the context of examining the circulation of water within a river or any watercourse (Toupin, R.A. 1965).

Saint Venant equations are a group of partial differential equations formulating the one-dimensional unstable flow of open channel water. The basic equations for hydraulic engineering and fluid dynamics are instrumental in the modeling of water behavior in rivers and channels during flood events. The program thus provides information about how floodwaters spread over time, helping in flood risk analyses and hydraulic analysis (Ghiba, ID. 2014).

- **Continuity Equation (Conservation of Mass)**

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q = 0 \quad (4.2)$$

Where:

A: is the cross-sectional flow area (m^2),

Q: is the discharge (m^3/sec),

t: time (sec),

x: the spatial coordinate (m),

q: Flow rate per unit width (m/s)

- **Momentum Equation (Conservation of Momentum)**

$$\frac{\partial v}{\partial t} + \alpha V \frac{\delta v}{\delta x} + g \frac{\delta y}{\delta x} = g(S_o - S_f) \quad (4.3)$$

Where;

$\frac{\partial v}{\partial t}$: The acceleration of fluid velocity with respect to time

$\alpha V \frac{\delta v}{\delta x}$: The convective acceleration, where α is the wave celerity, and V is the average velocity. The product αV represents the momentum of the flow.

$g \frac{\delta y}{\delta x}$: This term represents the gravitational acceleration component in the direction of flow. g is the acceleration due to gravity, and $\frac{\delta y}{\delta x}$ represents the slope of the channel bottom.

$g(S_o - S_f)$: This term represents the net gravitational driving force.

CHAPTER 5

RESULTS AND DISCUSSION

The chapter was very careful with the data processing and analysis applied in the flood analysis by the HEC-RAS model on the Al kabeer Al Shemali River. In this part, it discussed the findings of this thorough study, analyzing the results and providing a nuanced explanation of their significance. As mentioned already, these findings have great significance in explaining the hydraulic response of the Al Kabeer Al Shemali River during flood conditions.

5.1 Understanding Flood Frequencies of Al Kabeer Al Shemali River

The hydrological characteristics were investigated, taking into consideration the maximum annual flow values recorded for the period 1976–2010 in the Al Kabeer Al Shemali River. The analysis showed that the highest flow was recorded at 2360 m³/s in 1976 and the lowest flow of 320 m³/s was observed in 2007, as shown in Appendix 1. Figure 5.1 provides an account of the observed stream flow and peak flood data during a period of 35 years. The trend line equation exhibits a coefficient of determination (R^2) of 0.8906, suggesting a tight scatter pattern. Therefore, the implementation of Gumbel's distribution method can be used to predict the river's possible flow.

Table (Appendix 1), shows an analysis of flood data using Gumbel's distribution method. Also, a plot of reduced variate versus flood peak for the Al Kabeer Al Shemali River had been produced. Reduce variate analysis, which is the way data are treated to make them align with log-normal or normal distribution, is applied in flood data distribution analysis. This transform makes it possible to use well-defined statistical approaches that provide more precise and truthful analysis.

Tabled below is the flood peak data for the Al Kabeer Al Shemali River, arranged in descending order. Data include order, return period (T) and reduced variate (Y_t).

The data will help determine flood quantiles, or return periods, and improve overall flood forecasts. The mean instantaneous flow of the river is $40.2286 \text{ m}^3/\text{s}$, with a return period of say two years, showing very accurate flood forecasts. The precision of forecasting has implications for flood safety because it includes hydraulic infrastructure, bridges, and emergency evacuation procedures. This illustrates the adaptability of the methodology in other regions for similar studies.

$N = 35 \text{ (Years)}$

$X = (\text{Mean}) = 40.2286 \text{ m}^3/\text{s}$ (Mean of Flood peak)

$Sx = (\text{Std. Dev}) = 13.2822 \text{ m}^3/\text{s}$ (Standard deviation of Flood peak).

$Y_n = 0.5402 \text{ m}^3/\text{s}$ (The value of reduced mean Y_n in Gumbel's extreme value distribution, as shown in Appendix 2).

$S_n = 1.1285 \text{ m}^3/\text{s}$ (The value of reduced mean standard deviation in S_n Gumbel's extreme value distribution as shown in Appendix 3).

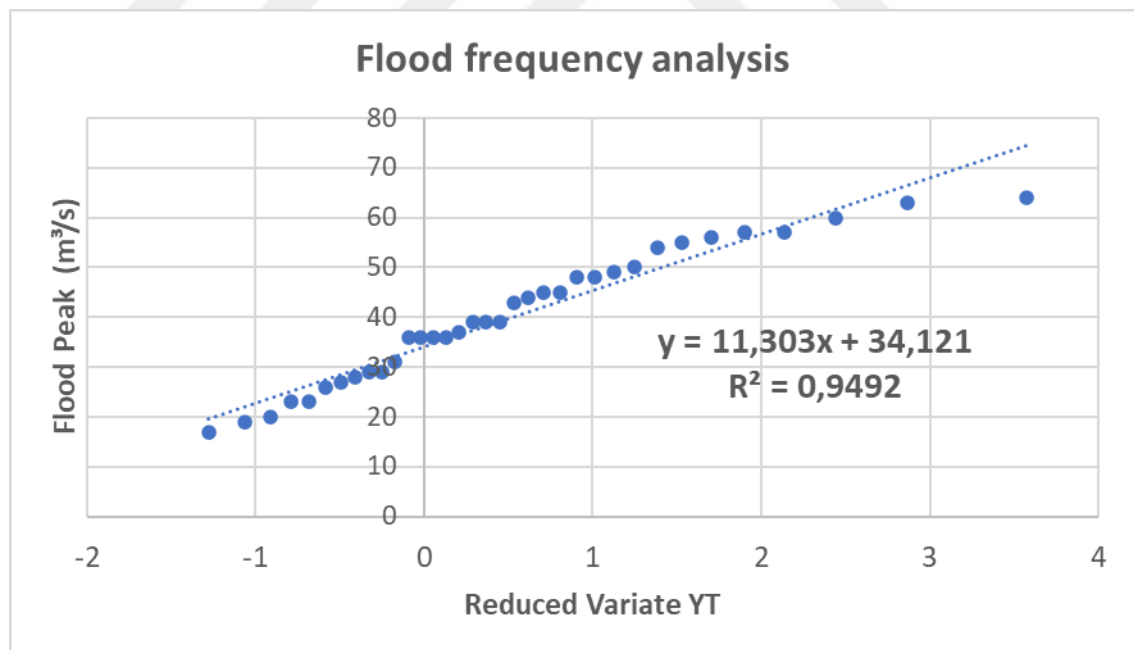


Figure 5. 1 Reduced Variate v/s Peak Flood for Al Kabeer Al Shemali River

The calculation results in order to ascertain flood frequency based on diverse recurrence periods are presented in Table 5.1. For floods in the river reach, the flood level expected for return periods of 50, 100, and 500 years is presented.

➤ **Reduced Variate**

$$Y_T = - \left[\ln * \ln \left(\frac{T}{T-1} \right) \right] \quad (5.1)$$

$$\text{For 50 years } Y_T = - \left[\ln * \ln \left(\frac{50}{50-1} \right) \right] = 3.9019 \text{ m}^3/\text{s}$$

$$\text{For 100 years } Y_T = - \left[\ln * \ln \left(\frac{100}{100-1} \right) \right] = 4.6001 \text{ m}^3/\text{s}$$

$$\text{For 500 years } Y_T = - \left[\ln * \ln \left(\frac{500}{500-1} \right) \right] = 6.2136 \text{ m}^3/\text{s}$$

➤ **To calculate Frequency factor**

A value called the “Frequency Factor” or coefficient of variation is used in flood frequency analysis to estimate the probability of a recurrence of flooding in a given location during an arbitrary period of time. It is based on the average and standard deviation of the flood information and is the calculation used to factor in the probability of a flood happening during the specified period.

$$K_T = \frac{y_t - y_n}{S_n} \quad (5.2)$$

Value of Reduced Mean Y_n from Table (Appendix 2) for 35 years is equal to 0.5402 m^3/s

Value of Reduced Mean standard division S_n from Table (Appendix 3) to 35 years is equal for 1.1285 m^3/s

$$\text{For 50 years } K_T = \frac{3.90193 - 0.5402}{1.1285} = 2.9789 \text{ m}^3/\text{s}$$

$$\text{For 100 years } K_T = \frac{4.6001 - 0.5402}{1.1285} = 3.5976 \text{ m}^3/\text{s}$$

$$\text{For 500 years } K_T = \frac{6.2136 - 0.5402}{1.1285} = 5.0273 \text{ m}^3/\text{s}$$

➤ **To calculate Expected flood**

The expected flood is an estimated flood expected to occur in any place within any specified duration of time. It is done by taking the mean and standard deviation of the flood data and the probability of having a flood in the specified time period.

$$X_T = X + K_T * S_x \quad (5.3)$$

$$X = \text{Mean} = 40.2286 \text{ m}^3/\text{s}$$

$$K_T = \text{Frequency factor}$$

$$Sx = (Std. Dev) = 624.7623 \text{ m}^3/\text{s}$$

$$\begin{aligned} \text{Expected flood for 50 years } XT &= 40.2286 + 2.9789 * 13.2822 \\ &= 79.7949 \text{ m}^3/\text{s} \end{aligned}$$

$$\begin{aligned} \text{Expected flood for 100 years } XT &= 40.2286 + 3.5976 * 13.2822 \\ &= 88.0126 \text{ m}^3/\text{s} \end{aligned}$$

$$\begin{aligned} \text{Expected flood for 500 years } XT &= 40.2286 + 5.0273 * 13.2822 \\ &= 107.0022 \text{ m}^3/\text{s} \end{aligned}$$

Table 5. 1 Calculation of expected flood along Al Kabeer Al Shemali river

Return Period (T) in years	Reduced variant	Frequency factor	Expected flood
50	3.9019	2.97894	79.80
100	4.6001	3.59765	88.01
500	6.2136	5.02739	107.00

5.2 Initial Conditions at the Commencement of the Computation

This section highlights the key step of including the initial conditions at the start of the computation process. These conditions form the fundamental parameters, such as flows and elevations, at the first time point ($T = 0$). Initially, a ($Q = 0$) is assumed to denote an external flow that is not present, followed by a meticulous examination of boundary conditions.

5.3 Integration of Boundary Conditions

The second phase is key in developing the parameters in the network (x, t) for the introduction of the variable charges with time. The computational results are greatly affected by stabilizing the water elevation or discharge and its relations with one

another inside the channel. Three types of boundary conditions are typically utilized in estimating flows in natural channels:

- First-order boundary conditions represent constant water elevation over time ($z = cte$).
- Second-order boundary conditions represent constant flow discharge over time ($Q = cte$).

- Third-order boundary conditions represent variable flow discharge with water elevation ($Q = f(z)$).

The considered scenario encompassed two types of boundary conditions at the inception and termination of the studied model. At the outset of the analyzed segment, a second-order boundary condition, namely the Flow Hydrograph, was employed to depict the flow rate over time for each of the three examined scenarios. This condition articulates the variation of flow with time and is utilized when modeling water flow in watercourses at the initiation of the studied channel.

Conversely, for the conclusion of the studied segment (at the outlet), a first-order boundary condition, the Normal Depth, was adopted. This condition involves determining the natural water depth by inputting the channel slope (0.00292) into the program, as illustrated in Figure 5.2, and applying the Manning equation to ascertain the natural depth. The case was investigated for the probability of recurring rainfall events (50 years, 100 years, and 500 years) relying on the calculated hydrograph for each scenario. The assumption of the occurrence of three rainstorms, with their peak intensities aligning with the calculated maximum intensities based on the Gumbel distribution, as shown in Tables (5.2-3-4) delineate the single flood wave (individual hydrograph) for the adopted return periods.

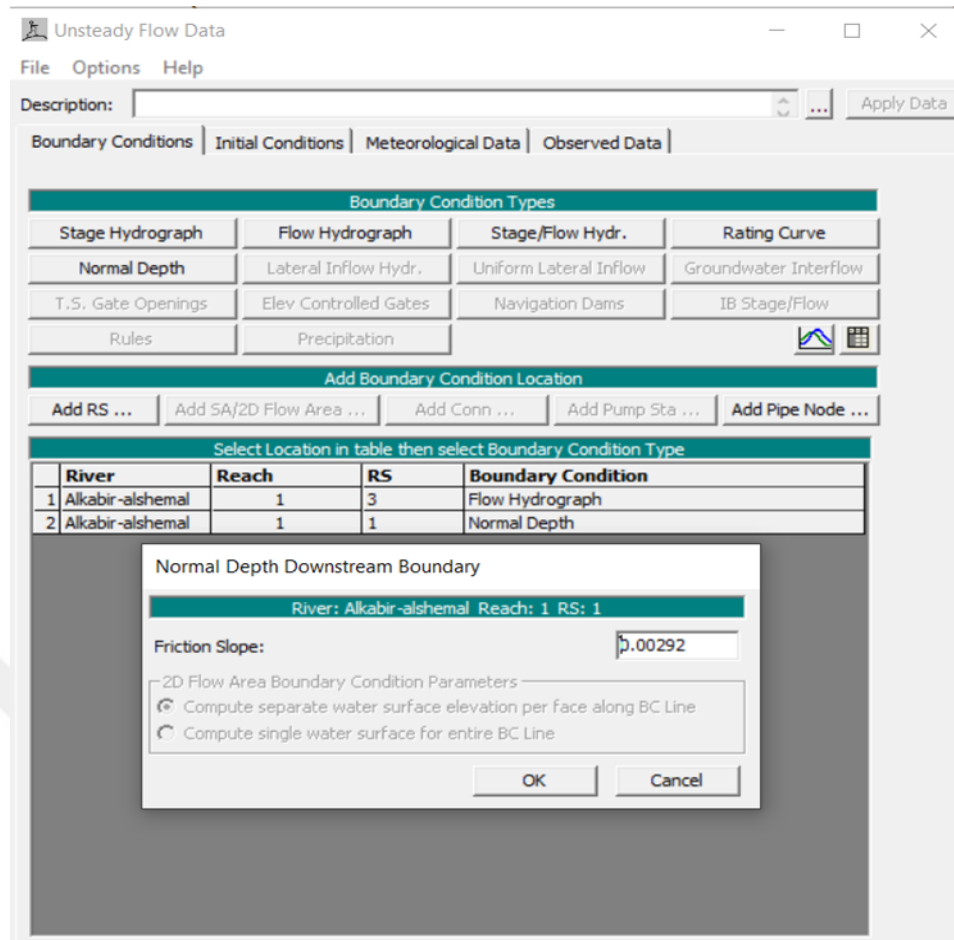


Figure 5. 2 First-Degree boundary condition

The table 5.2 shows the flood wave flows with a return probability of 50 years and a high-water level of 5 meters. The table shows the flood wave flow in cubic meters per second (m^3/s) at different times ($T[h]$). The flood wave flow increases rapidly at first, reaching a peak of $59.72 \text{ m}^3/\text{s}$ at $T[h] = 2$. The flow then gradually decreases over time, reaching a value of $0.59 \text{ m}^3/\text{s}$ at $T[h] = 17$. The shape of the flood wave is typical of a flash flood, which is a sudden and rapid flooding of a river or stream. Flash floods can occur within minutes or hours of a heavy rainfall event, and they can be very dangerous. The high-water level of 5 meters indicates that the flood wave is capable of causing significant damage to property and infrastructure. The flood wave flow of $59.72 \text{ m}^3/\text{s}$ is also very high, and it could easily erode river bank of Al Kabeer Al Shemali. And illusion it as shown in figure 5.3.

Table 5. 2 Flood wave flows with a return probability of 50 years

Flood wave flows with a return probability of 50 years																		
τ [h]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Q [m³/s]	0.59	29.49	59.72	79.80	77.13	54.86	42.47	30.23	21.09	14.01	10.03	7.23	4.87	3.24	2.65	1.47	1.18	0.59

The Figure 5.3 shows a single wave flood hydrograph for a 50-year flood event with a peak discharge of 79 m³/s and a duration of 3 hours. The hydrograph is characterized by a rapid rise to peak discharge, followed by a gradual recession.

Single wave flood hydrographs are typically generated by short-duration, high-intensity rainfall events. These events can produce large volumes of runoff that quickly overwhelm the drainage capacity of rivers and streams, leading to flooding.

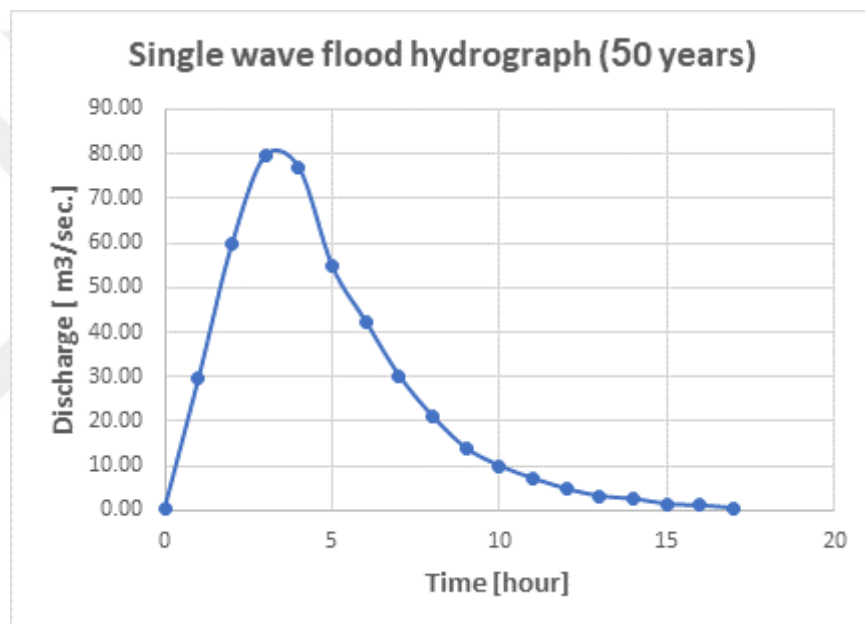


Figure 5. 3 Single wave flood hydrograph (Period= 50 years)

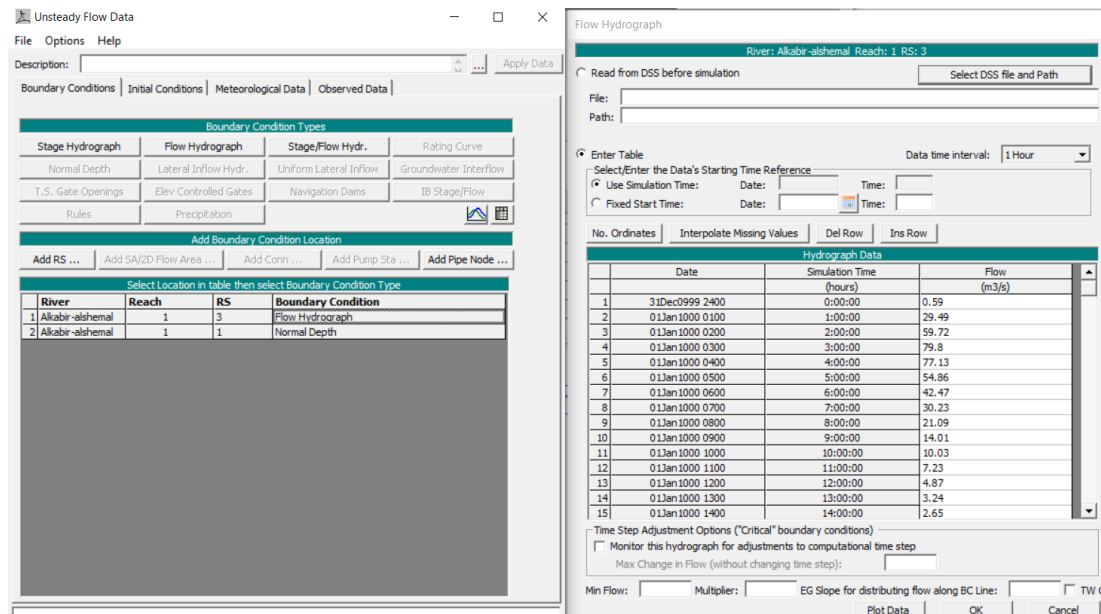


Figure 5. 4 Hydrograph data (Period= 50 years)

The table 5.3 you sent shows a flood wave flow with a return probability of 100 years and a high-water level of 10 meters. This means that there is a 1% chance of this flood wave occurring in any given year. The flood wave is represented by a hydrograph, which is a graph of the flood discharge (Q) over time (T). The hydrograph shows that the flood wave peaks at a discharge of 88.01 cubic meters per second (m³/s) at time step 5. The flood wave then recedes gradually, reaching a discharge of 0.65 m³/s at time step 17.

Table 5. 3 Flood wave flows with a return probability of 100 years

Flood wave flows with a return probability of 100 years																		
T [h]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Q [m3/s]	0.65	32.53	65.88	88.01	85.07	60.51	46.84	33.34	23.26	15.45	11.06	7.97	5.37	3.58	2.93	1.63	1.30	0.65

The Figure 5.4 shows a single wave flood hydrograph for a 100-year flood event with a peak discharge of 88 m³/s and a duration of 3 hours. The hydrograph is characterized by a rapid rise to peak discharge, followed by a gradual recession.

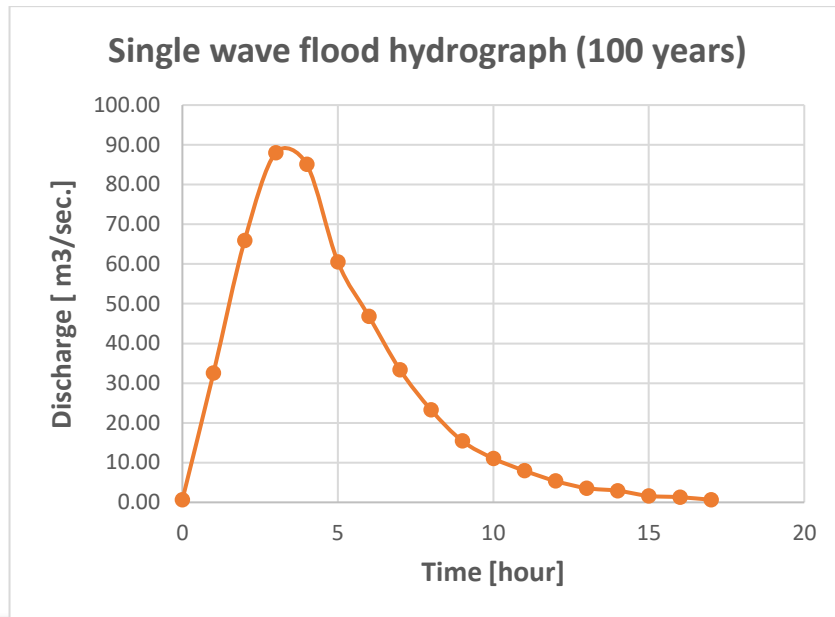


Figure 5. 5 Single wave flood hydrograph (Period= 100 years)

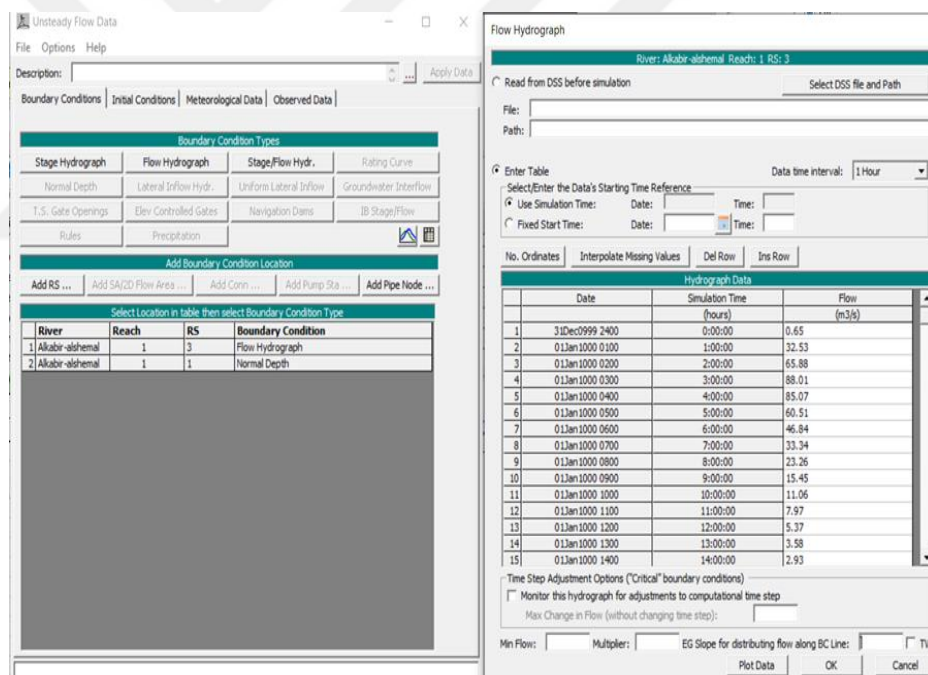


Figure 5. 6 Hydrograph data (Period= 100 years)

The table 5.4 shows a hydrograph of a flood wave flow with a return probability of 500 years, with a high-water level of 15 meters. The hydrograph shows the discharge (Q) of the flood wave over time (t). The discharge is in units of cubic meters per second (m^3/s).

The hydrograph shows that the flood wave rises rapidly, reaching a peak discharge of 107 m³/s at 3 hours. The flood wave then recedes slowly, taking 13 hours to return to pre-flood levels.

Table 5. 4 Flood wave flows with a return probability of 500 years

Flood wave flows with a return probability of 500 years,																		
T [h]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Q [m3/s]	0.79	39.55	80.09	107.00	103.42	73.56	56.95	40.54	28.28	18.79	13.45	9.69	6.53	4.35	3.56	1.98	1.58	0.79

The figure 5.7 you sent shows a single wave flood hydrograph for a 500-year event with a peak discharge of 107,000 m³/s. The hydrograph is characterized by a sharp rising limb, followed by a more gradual recession limb. The peak discharge occurs at approximately 3 hours after the start of the hydrograph.

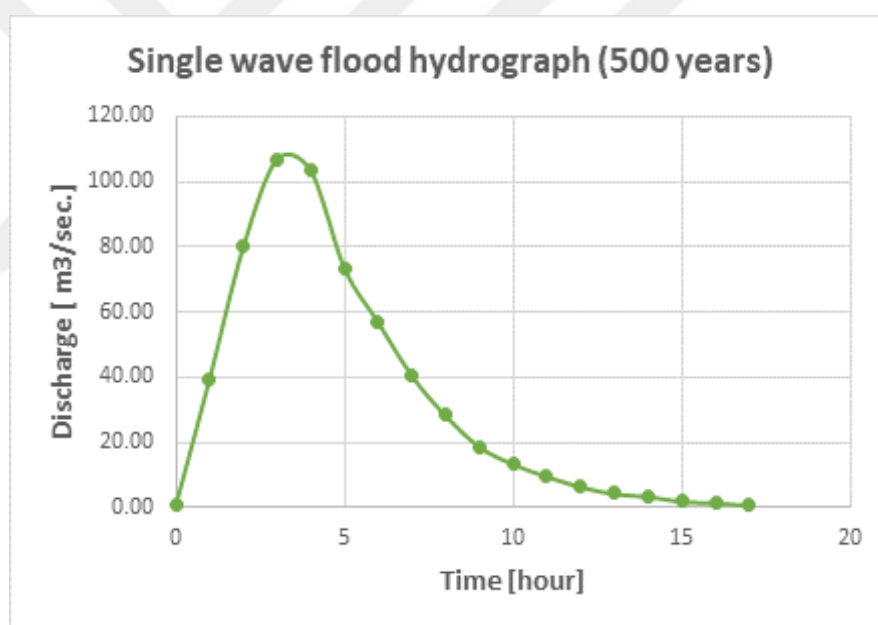


Figure 5. 7 Single wave flood hydrograph (Period= 500 years)

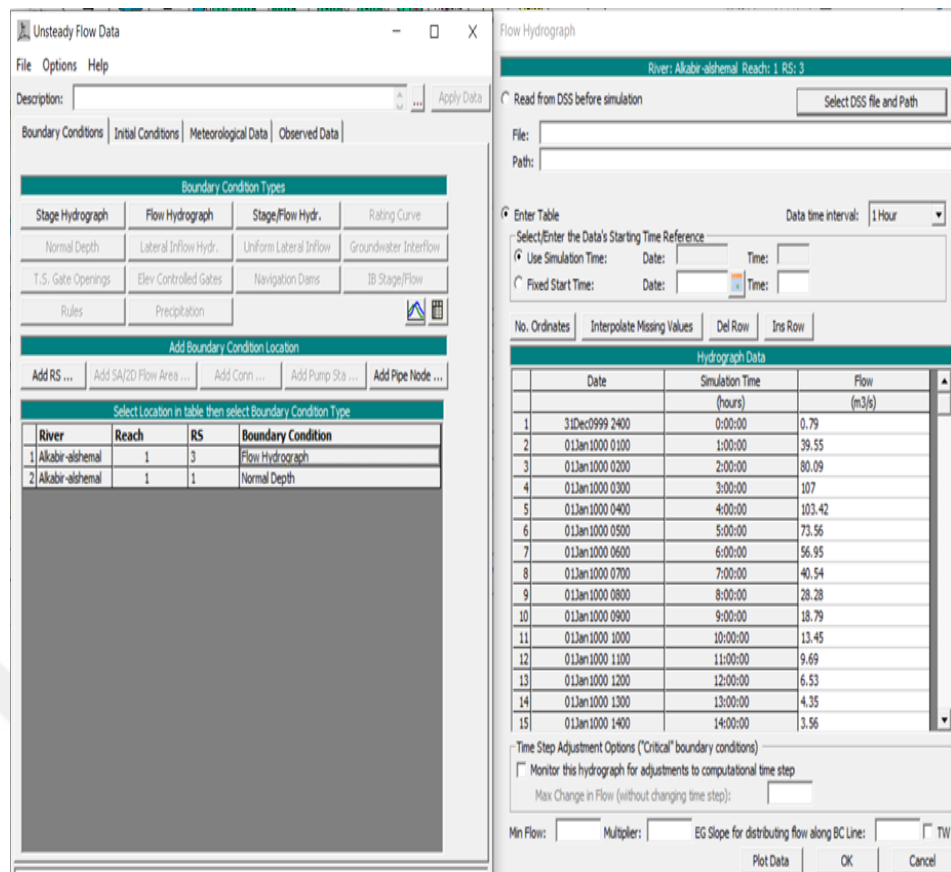


Figure 5. 8 Hydrograph data (Period= 500 years, h= 15 m)

After entering the aforementioned values and saving them within the program, the program interface for a specific case becomes as follows, as shown in Figure 5.9:

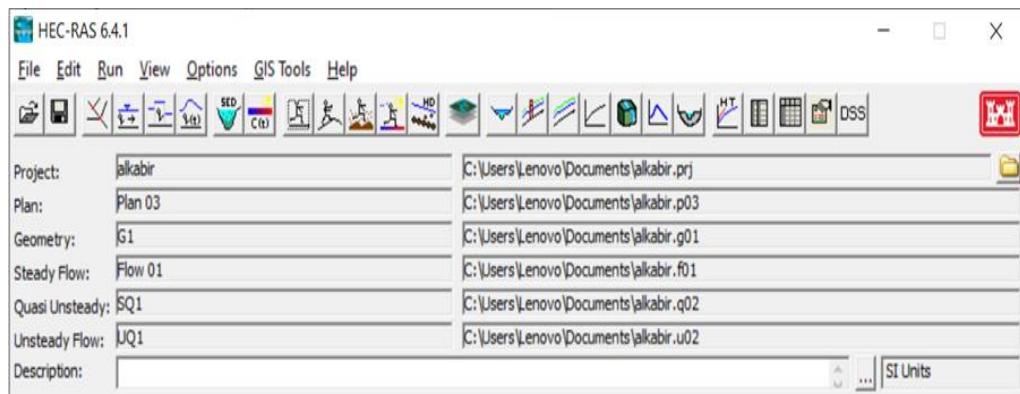


Figure 5. 9 HEC- RAS software interface after entering data of river

It conducts the analysis process three times according to each return period, and the program interface is displayed upon completion of the analysis for a specific case. As shown in figure 5.10.

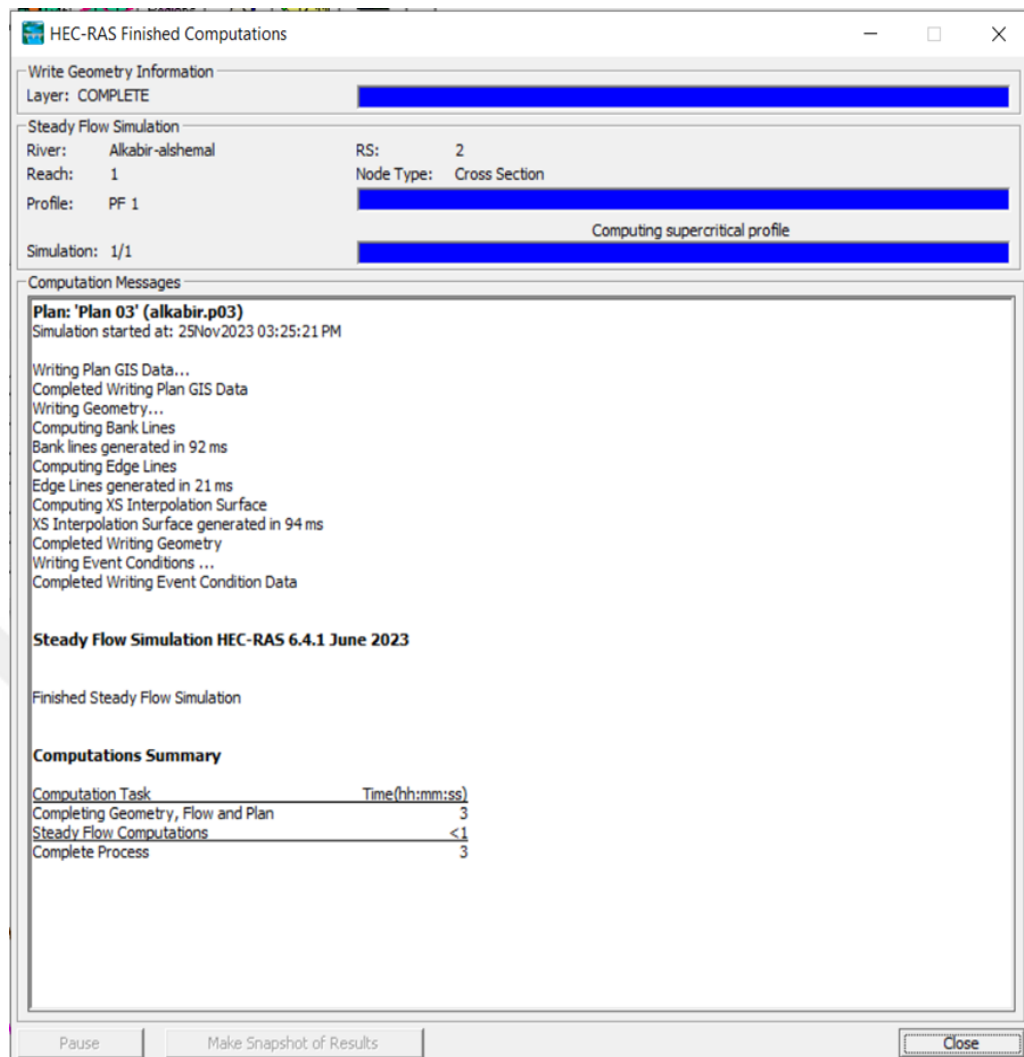


Figure 5. 10 Program interface indicating the completion of the analysis

5.4 Water Level in the Cross-Section

The water level elevation in a specific cross-sectional profile for each return period (50, 100 and 500) years is depicted in Figures 5.11-12 and 13. It is observed that the water level rises above the banks of the watercourse, and this elevation increases proportionally with the flood intensity, corresponding to an increase in the return period. Water elevation in the cross-section for scenario of 50 years, as shown in Figure 5.11.

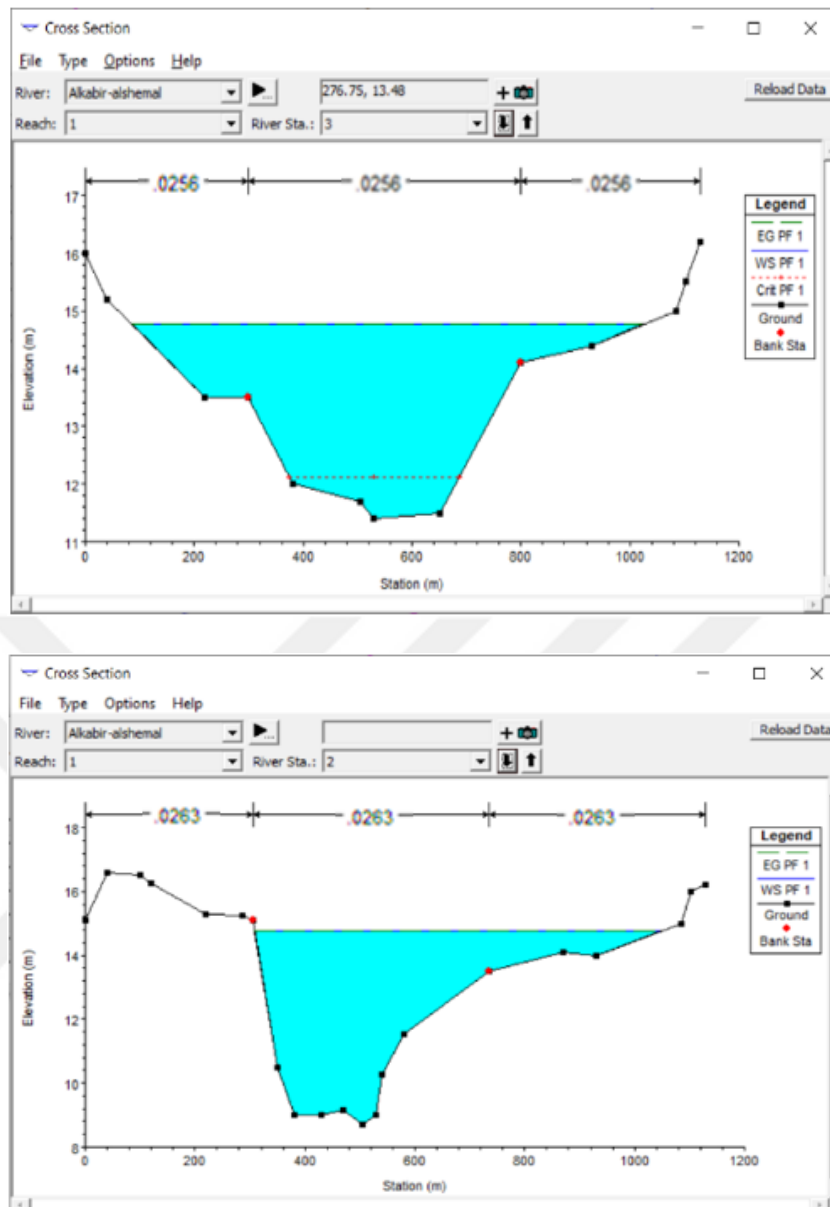


Figure 5. 11 Water level in cross section (return period 50 years)

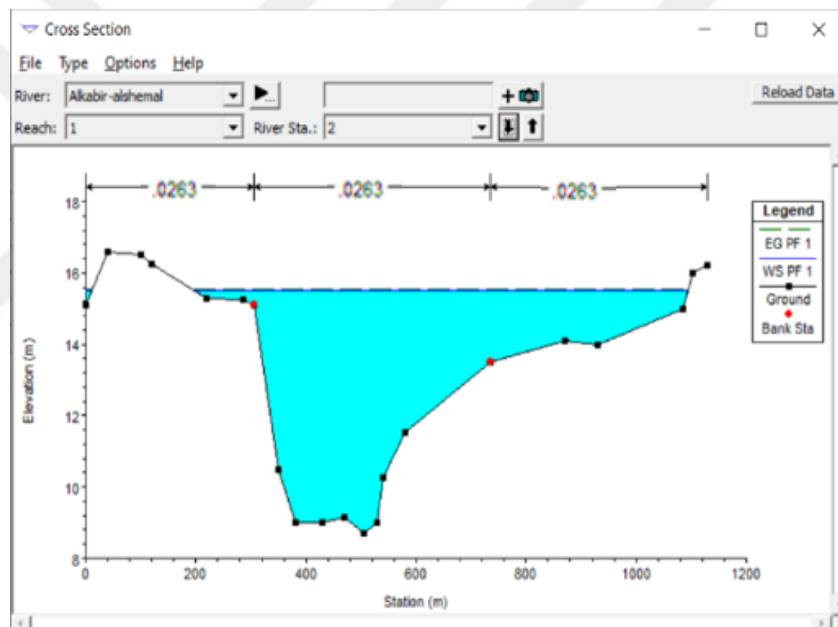
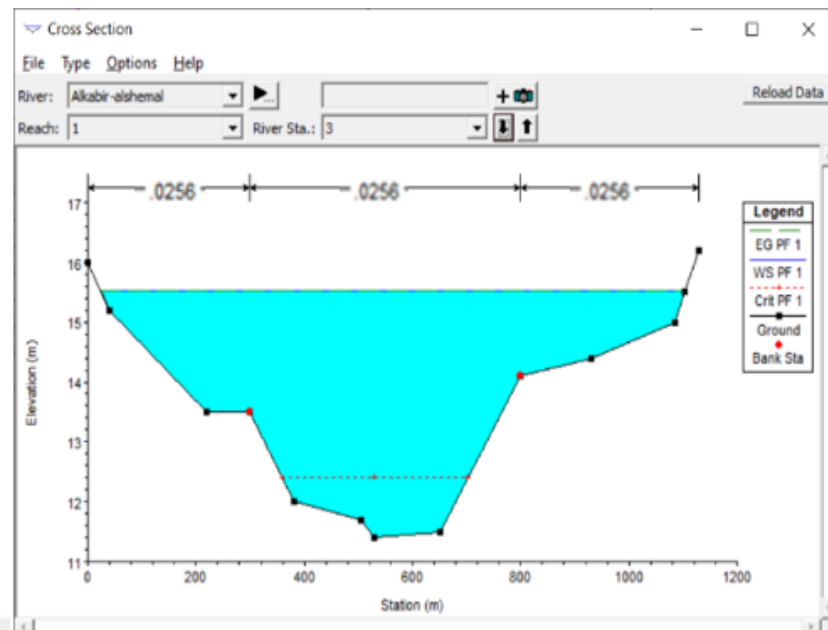


Figure 5. 12 Water level in cross section (return period 100 years)

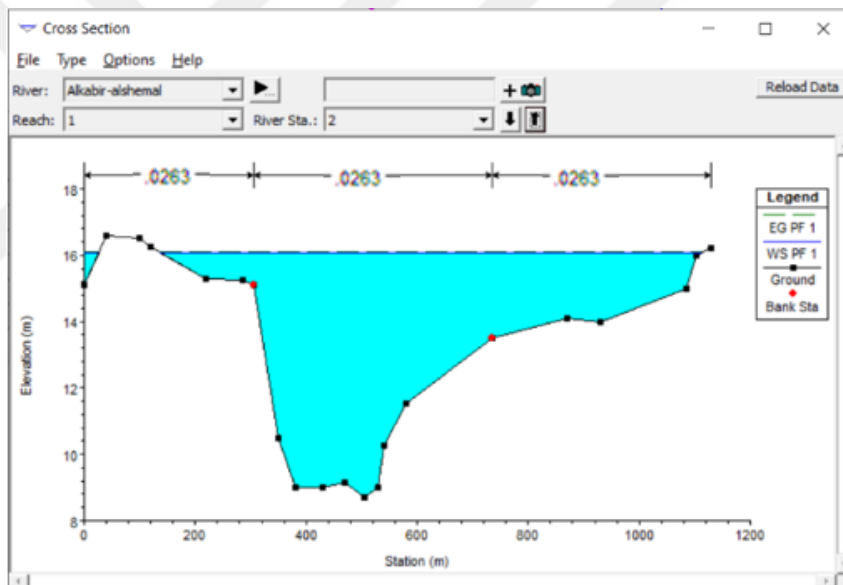
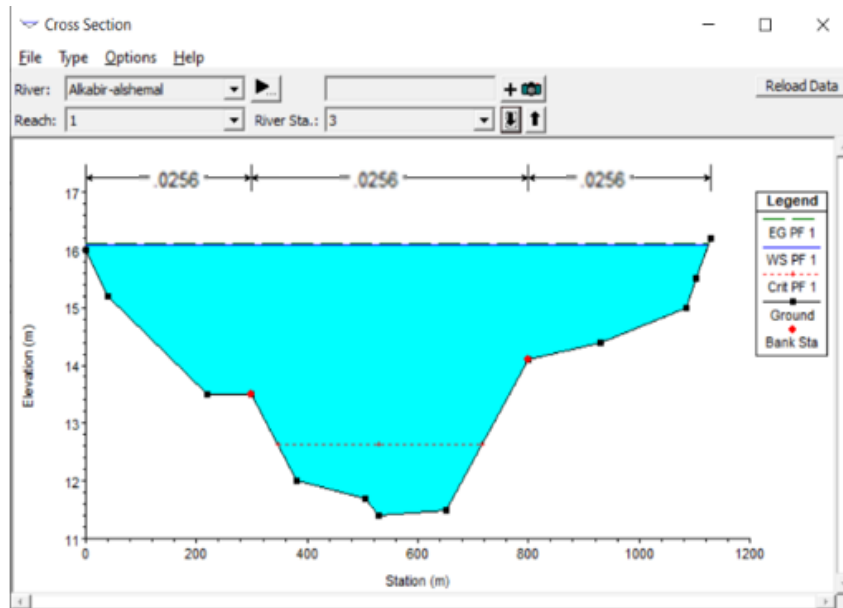


Figure 5. 13 Water level in cross section (return period 500 years)

5.5 Longitudinal Section Analysis of the Entire Designed Watercourse

The figure 5.14 shows a longitudinal section of the designed watercourse for the first scenario (50-year return period). The water level is shown in blue, the bed elevation is shown in black, and the bank levels of the right and left banks are shown in black dashed lines.

The water level is highest at the upstream end of the watercourse and gradually decreases towards the downstream end. The water level also decreases downstream

but slowly relative to the bed elevation. This forms a gradient in the watercourse and thus enables the flow of water movement.

The banks on both sides have marginally higher elevations than the upstream water level in the watercourse. This will aid in the prevention of water being spilt over during floods. Nevertheless, the bank levels fall below the water level along the last part of the watercourse downstream. At the downstream end, the water velocity is low; hence, the chances of flooding are minimal.

At the top are banks, and at the bottom is a bed that makes up the overall shape of the watercourse in trapezoidal form. This particular shape is intended to offer the optimum throughput potential for the water channel.

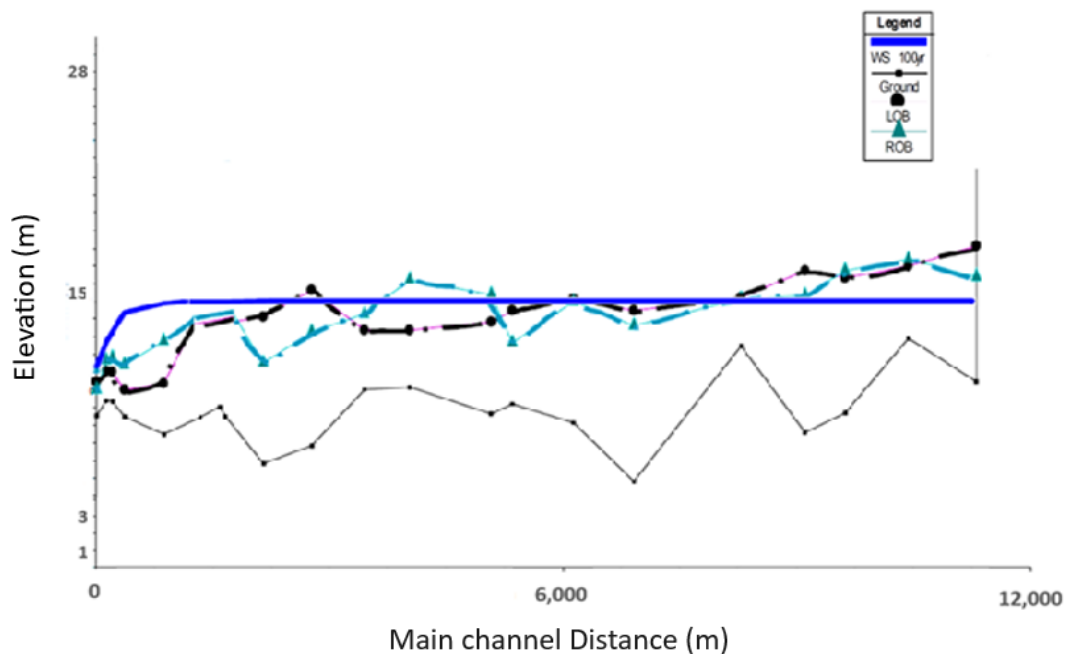


Figure 5. 14 Longitudinal Section of return period 50 years

Longitudinal section of the Al Kabeer Al Shemali River in the watercourse with the second scenario (100-year return period) as shown in Figure 5.15.

At the upstream end, the water level is high and decreases as you approach the downstream end of the watercourse. In addition to this, the watercourse has a slope that allows it to carry away flood waters from the populated habitations and the speed of flowing water is reduced because of the slope.

The channel bottom elevation also decreases from the upstream to downstream end of the watercourse. This is because the watercourse is designed to be self-scouring, meaning that the flowing water will erode the channel bed over time until it reaches a stable slope.

The right and left bank elevations remain relatively constant along the length of the watercourse. This is because the banks of the watercourse are protected by engineered structures, such as levees and retaining walls.

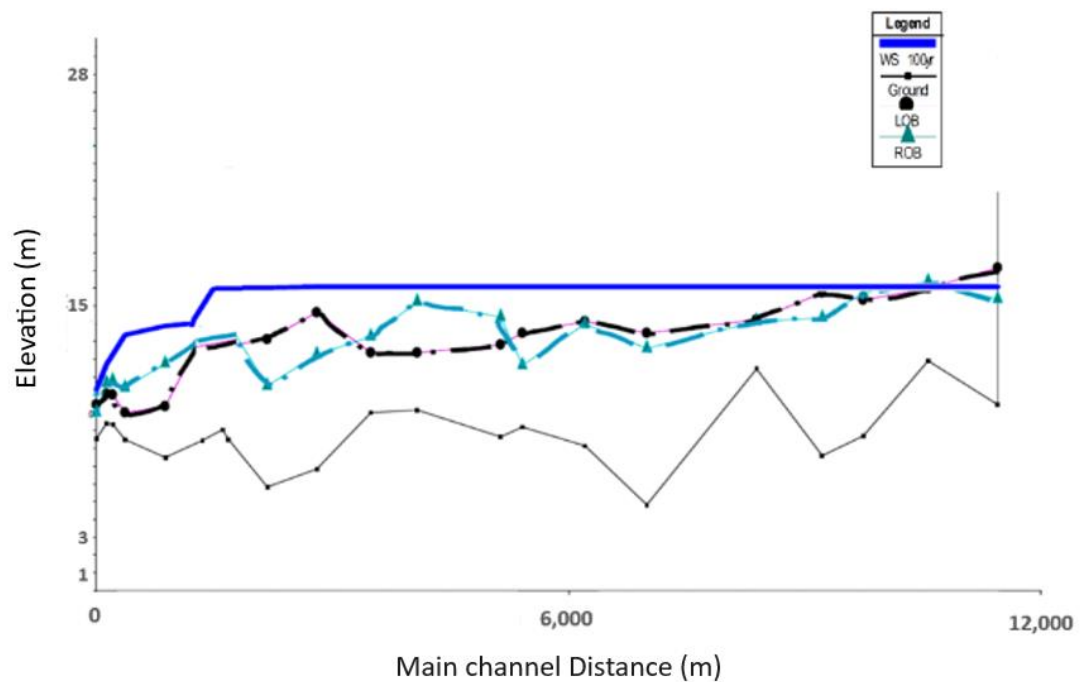


Figure 5. 15 Longitudinal Section of return period 100 years

Figure 5.16 shows the longitudinal section of the Al Kabeer Al Shemali River along the engineered hydraulic channel for the third scenario (500-year return period).

The water level for the 500-year return period is significantly higher than the water level for the 100-year return period (shown in Figure 5.15). This is to be expected, as the 500-year return period flood is a more extreme event

The hydraulic channel is designed to accommodate the 500-year return period flood without overtopping. This is evident from the fact that the water level remains below the bank elevations along the entire length of the hydraulic channel.

However, the water level is very close to the bank elevations at the upstream end of the hydraulic channel. This suggests that the hydraulic channel may be vulnerable to overtopping in the event of a 500-year return period flood with higher-than-expected peak flows.

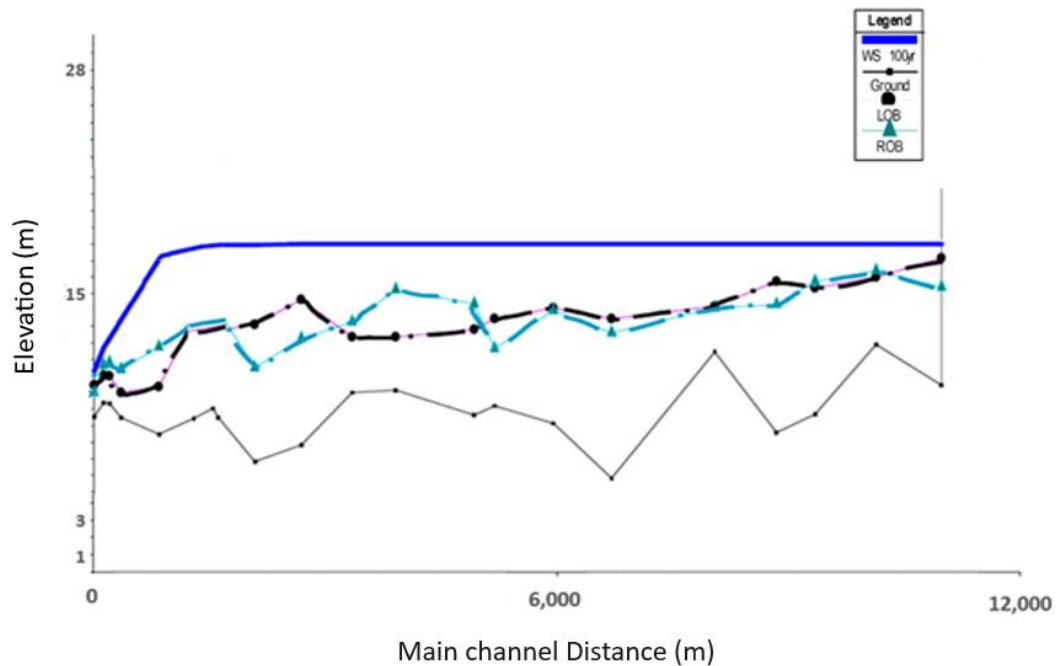


Figure 5. 16 Longitudinal Section of return period 500 years

5.6 Inundation Maps of Al Kabeer Al Shemali River

Flood inundation models resulting from the rainstorm for each return period (50, 100, 500) years, determining the areas submerged along the watercourse perimeters, as shown in Figures 5.17-18, and 19. An observable increase in water-submerged areas is noted along the riverbanks, particularly on the left side where plains and low valleys are situated. Additionally, there is an evident escalation in the submerged areas corresponding to the increasing flood intensity, proportionally escalating with the return period.

In the first scenario of the inundation analysis, the focus is directed towards the hydrological repercussions of a 50-year return period rainstorm event along the Al Kabeer Al Shemali River. Employing the HEC-RAS model, the investigation unfolds with meticulous consideration of a maximum discharge of 79.80 m³/s, an integral parameter in delineating the dynamic nature of the river's response to this infrequent meteorological episode.

The resultant flood inundation model intricately maps the submerged terrain, revealing a spatial extent of 12.61 km² under the aforementioned climatic conditions. This broad aquatic area reflects the expression of the surge of the river, encompassing the complexities of hydraulic actions in the basin. Thus, the inundation map becomes a visual proof that the hydraulic aspects that occur during the 50 -year interval event. As shown in Figure 5.17.

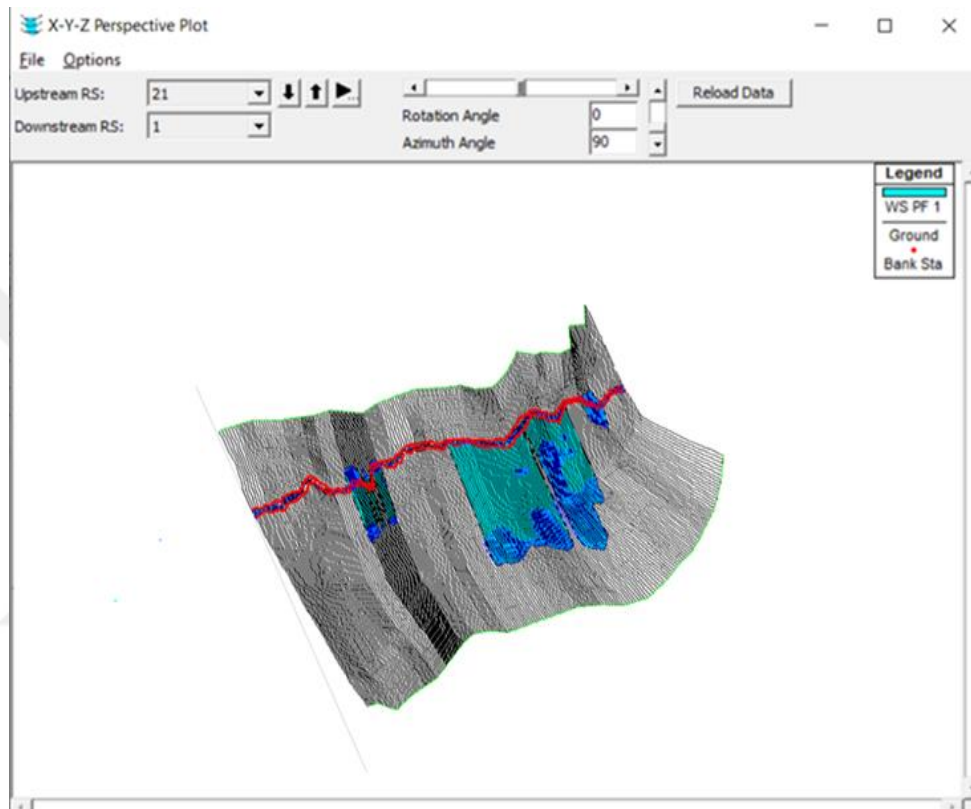


Figure 5. 17 Inundation areas resulting from the return period 50 years using the HEC-RAS

The findings about the second case involving the 100-year return period inundation map of the Al Kabeer Al Shemali River are crucial. A closer look shows that the swamped area, measuring 31.62 km², represents a consequential manifestation of the hydrological dynamics ensuing from a rainstorm event of specified recurrence.

The refined effect of increased maximum rainfall intensity on these variables is notable, too, relative to that obtained in the antecedent scenario, with a marked difference in the increasing amount of 10.29%. This increase in precipitation intensity is the main component, dramatically altering the landscape. As depicted through the

inundation model, this consequent effect sees the submerged area rising by an outstanding 150.75% from the base condition.

The increase in flood coverage demonstrates the sensitivity of the Al Kabeer Al Shemali River to changes in rainfall amounts. It thus lends credence to the model's capability to simulate interactions between climate factors and resultant flood patterns. As shown in Figure 5.18.

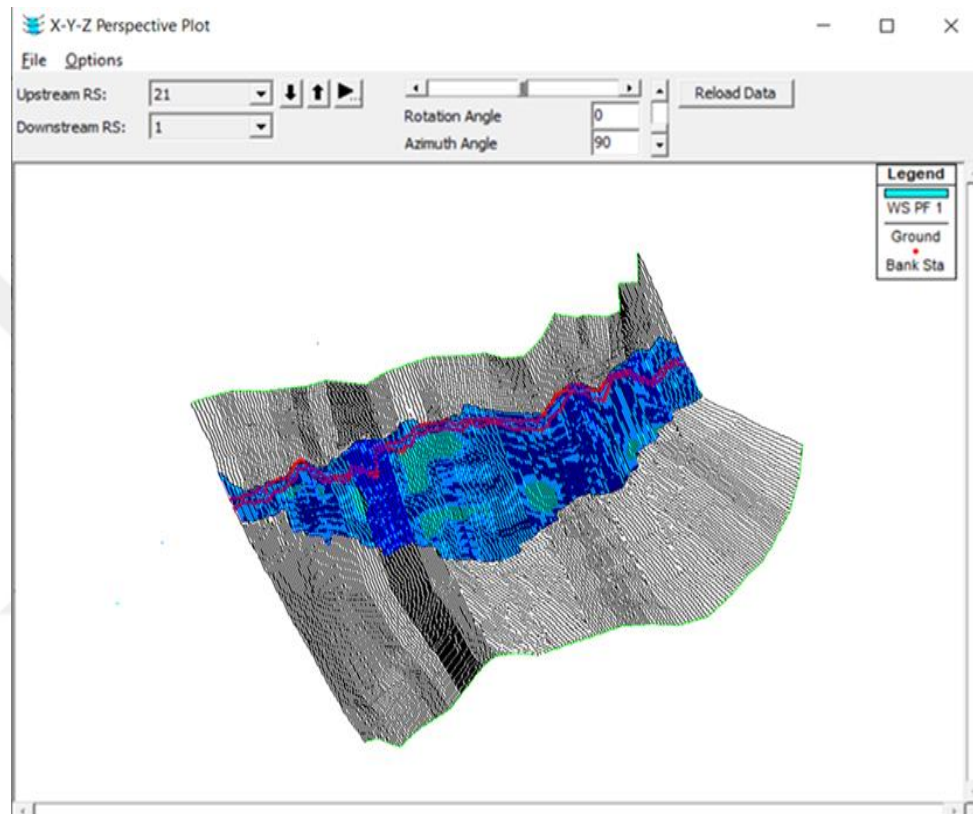


Figure 5. 18 Inundation areas resulting from the return period 100 years using the HEC-RAS

The complex relationship distinguishes the third case between meteorological and hydrological elements. Within this scenario, the flood inundation model covering about 40.84 km² is mapped with a return period of 500 years.

Surprisingly, detailed consideration of meteorological phenomena indicates an increase in extreme rainfall intensity of about 34.09%. The coupling of this meteorological abnormality with the complex hydraulics of the riverine system results in a colossal magnification in the flooded area to a startling increment of 223.87%.

Such an observation illustrates the high sensitivity of the Al Kabeer Al Shemali River basin to extreme climate events and infrequent but intense precipitations. An increase

in submersions provides evidence of the combined effect of higher rain intensity under a long-term return period. Such intricate analyses not only contribute to the refinement of flood modeling techniques but also offer valuable insights into the vulnerabilities and resilience of riverine systems in the face of extreme climatic events. As shown in Figure 5.19.

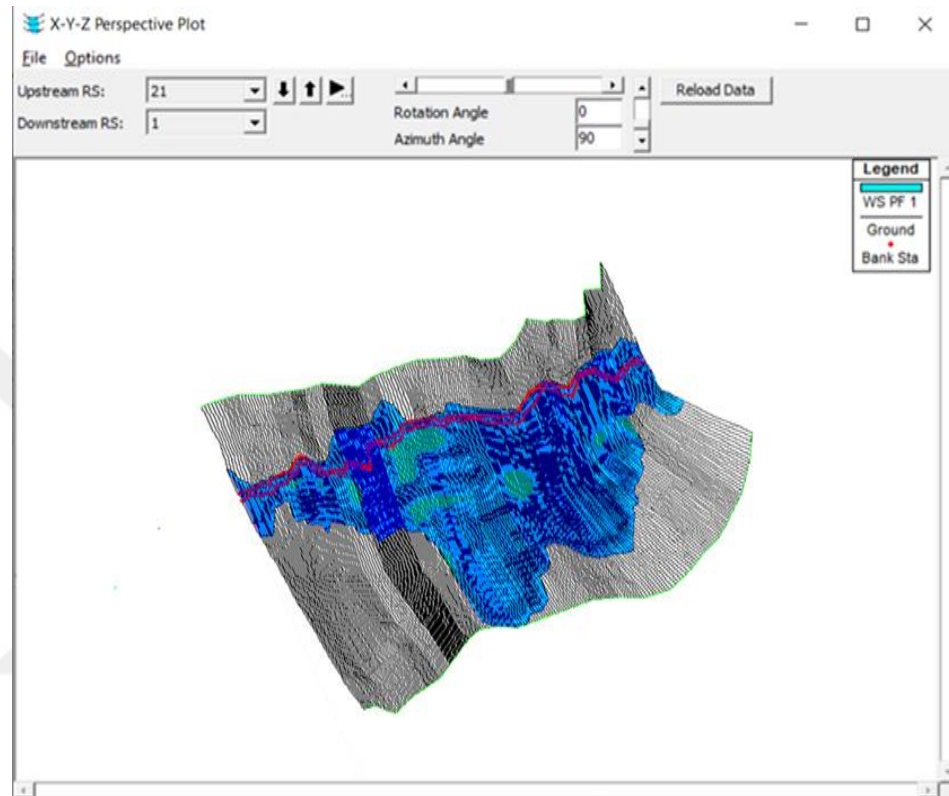


Figure 5. 19 Inundation areas resulting from the return period 500 years using the HEC-RAS

Table 5.5 provides a comprehensive depiction of the interrelationship among return periods, flood peak magnitudes, and the associated inundation areas. The data elucidate a discernible correlation wherein an augmentation in the return period directly corresponds to an escalation in flood magnitude, subsequently manifesting as an observable amplification in the extent of inundated areas.

For the specified return periods of 50, 100, and 500 years, the reduced variant values exhibit a progression from 3.9019 to 6.2136, signifying an incremental trend in flood intensity over time. Concurrently, the water immersion areas also experience a proportional augmentation, escalating from 12.61 km² to 40.84 km² as the return period extends from 50 to 500 years.

Moreover, the ratio of inundation area to the basin area is expressed as a percentage, elucidating the spatial impact of floods in relation to the overall basin. The percentage values of 1.14%, 2.86%, and 3.70% for return periods of 50, 100, and 500 years, respectively, further accentuate the direct correlation between the recurrence of extreme events and the consequential increase in inundation extent. Table 5.5 highlights the empirical link between return periods, flood peaks, and inundation areas, thereby illustrating how flooding events become more severe over time.

Table 5. 5 The Relationship between return period, flood peak, and inundation areas

Return Period (T) in years	Flood peak (m ³ /s)	Water immersion area (km ²)	ratio of inundation area to the basin area is expressed (%)
50	79.80	12.61	1.14%
100	88.01	31.62	2.86%
500	107.00	40.84	3.70%

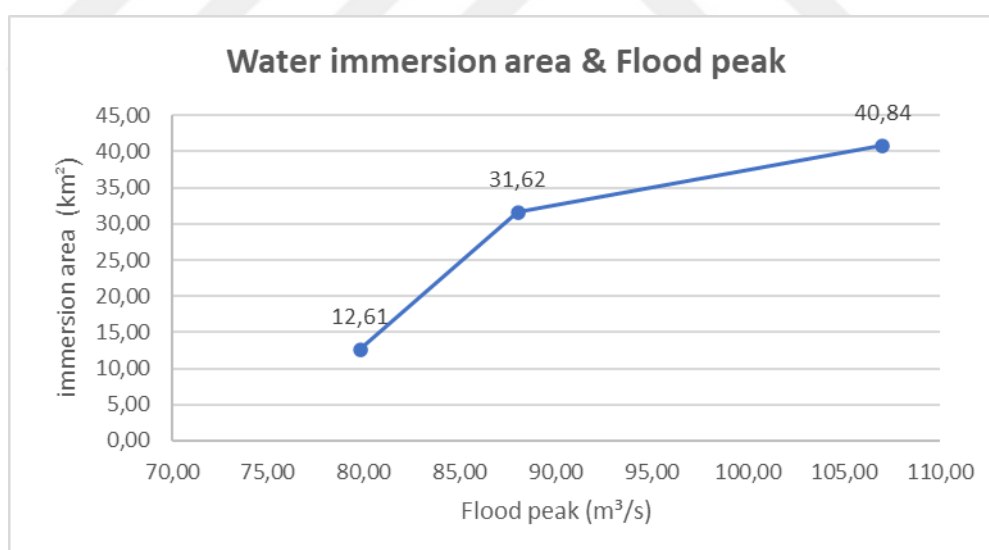


Figure 5. 20 Water immersion area & Flood peak

The relationship in Figure 5.21 below shows how flood extremes affect the water immersion area. The return period indicates the mean interval between the events of floods with a certain magnitude or intensity—the return period of 50, 100 and 500 years is shown in the table.

As the return period increases, it can be observed that the water immersion area scales upwards. This means the chances of experiencing much broader and more severe flooding increase in the long run. Water immersion represents spatial scales affected by flooding and what it may translate for varying time intervals.

The water immersion area in the provided data increases from 12.61 km² to 40.84 km², moving from a return period of 50 years to 500 years. The relationship indicates that less frequent but more extreme floods affect more expansive areas, implying that flood-prone areas could be subjected to escalated risks and consequences in rare and severe occurrences.

Knowing the relationship between the water immersion area and the return period is critical in designing effective flood risk control measures and infrastructure planning. It provides a means for stakeholders to evaluate the scope area of flooding for varying recurrence intervals that can assist in devising measures to limit flooding impacts on settlements and facilities.

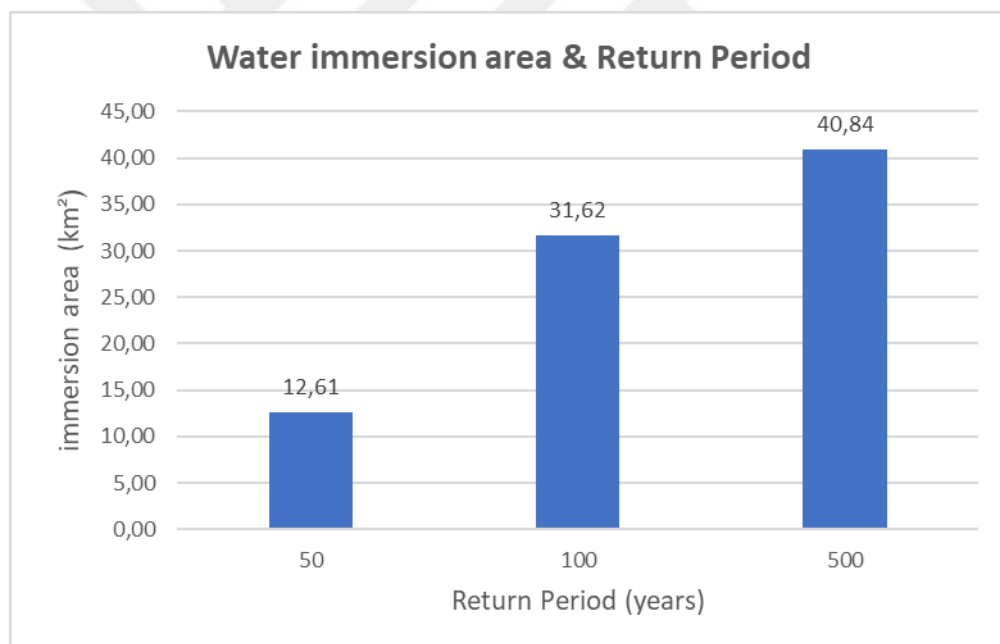


Figure 5. 21 Water immersion area & Return Period

CHAPTER 6

CONCLUSION

6.1 Conclusion

It is essential to develop a hydraulic model using the HEC-RAS program, integrated with GIS such as Google Earth and DEMs, to analyze stormwater floods and map inundated areas. The existence of geospatial, topographic, and hydrological data for the river is critical when locating and delineating floods. It helps identify the flooded zones; an essential part of the flood management technology that makes flood risk maps possible. Therefore, Al Kabeer Al Shemali River must create a model capable of reducing flood damage.

As a result, the dominance of water is significantly pronounced in shallow and narrow regions, evident throughout the entire course of the river. In contrast, it diminishes in wide and deep areas, forming marshes, especially in the central part of the meticulously studied channel.

According to the studied section of the Al Kabeer Al Shemali River, it exhibits variations, alternating between narrow and deep stretches and wide, shallow expanses. This variability contributes to the prevalence and extension of water during winter floods (rainstorm events) onto surrounding lands and structures. This phenomenon results in erosion and destruction of a portion of these areas while submerging another part for an extended period. Consequently, a thorough study is imperative along its entire length, incorporating realistic flow behavior assessments and planning for protective structures in the event of flooding.

The 50-year return period is associated with the potential occurrence of a flood leading to water inundation covering an area of 12.61 km². Observing the flood inundation diagram, representing 1.14% of the total basin area, indicates that it remains possible to contain water levels in the floodplains. However, this impact is confined to the adjacent agricultural areas.

On the other hand, the 100-year return period is linked to a flood potentially covering an area of 31.62 km². The flood inundation diagram, representing 2.86% of the total basin area, suggests a more northern return of water, affecting additional agricultural areas and parts of the industrial zone in Latakia within the river's sub-basin.

The 500-year return period is associated with a flood potentially covering an area of 40.84 km². The flood inundation diagram, representing 3.70% of the total basin area, depicts the inundation of the study area with elevated water levels, spreading easily on the riverbank due to low slopes. This flood posed a threat to some villages in the adjacent plains and a significant portion of the industrial zone. It is noteworthy that such events are rare but may occur under extreme rainfall and intense storm conditions.

Analyzing the Gambel distribution of flood frequencies reveals an increase in flood peaks with a longer return period, accompanied by a proportional increase in the inundation area. For instance, a 10.29% increase in peak intensity in the second scenario results in a 150.75% increase in the flooded area compared to the first scenario. Similarly, a 34.09% increase in peak intensity in the third scenario leads to a 223.87% increase in the flooded area compared to the first scenario.

It is evident that flat areas within the sub-basin are more susceptible to flooding events as they allow water to flow rapidly. Conversely, steep slopes are more prone to rapid surface runoff.

Last but not least, flood inundation schematics resulting from the centennial flood events of the Al Kabeer Al Shemali River illustrate the extent of water inundation in the adjacent lands. The relationship between this inundation and the channel width and depth is elucidated. Flood waves result in losses to properties and infrastructure. The rapid arrival of water to residential areas near the river can occur within a short timeframe, making evacuation time limited unless early warnings are issued.

6.2 Recommendations

- It is imperative to organize and correct the course of the Al Kabeer Al Shemali River, aiming to prevent various forms of flooding to the lands and water structures in the region. This includes reducing erosion and preventing damage to facilities.

- The plains of the Al Kabeer Al Shemali River are highly susceptible to flood risks. Therefore, it is essential to enhance the flood resistance capacity of these river plains by installing protective structures and flood diversion mechanisms where necessary. This will mitigate the vulnerability to flood risks along the river, requiring a comprehensive plan for organizing the course in harmony with the topography of flood-prone areas.
- Rehabilitation of urban plans for residential clusters should be undertaken to align with the possibility of flood disasters. It is crucial to prohibit housing in areas close to riverbanks to ensure the safety of inhabitants.
- It is necessary to train residents living in areas prone to flooding on an annual emergency plan basis, enhancing their preparedness and response capabilities.
- The presence of chemical, pharmaceutical, or nuclear materials in the industrial zone, as well as in exposed factories and facilities, must be strictly prohibited. This is to avoid chemical contamination, and it is recommended that industries in flood-prone areas adopt a lightweight manufacturing approach to prevent significant economic losses in the event of catastrophic rainfall.
- Sufficient importance should be given to planning and research to identify optimal shelter locations. This is essential for determining areas safest from water hazards, preserving human lives, and implementing necessary measures for the rapid dissemination of alerts and warnings.

6.3 Future Studies

1. Investigating flood waves resulting from the collapse of the mishad dam on the river course (e.g., 16 october dam) utilizing current research tools and programs.
2. Analyzing flood waves arising from rainfall storms with return periods extending up to 10,000 years.
3. Assessing flood risks on other segments along the river's watercourse.

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APPENDIX

Appendix 1. Computation Table for flood frequency analysis

Years	Flood peak (m ³ /s)	Flood Peak in Descending order (m ³ /s)	Order	Return Period T	Reduced Variate YT
1976	55	64	1	36.00	3.5695
1977	50	63	2	18.00	2.8619
1978	57	60	3	12.00	2.4417
1979	43	57	4	9.00	2.1389
1980	48	57	5	7.20	1.9002
1981	54	56	6	6.00	1.7020
1982	60	55	7	5.14	1.5314
1983	56	54	8	4.50	1.3811
1984	64	50	9	4.00	1.2459
1985	63	49	10	3.60	1.1226
1986	45	48	11	3.27	1.0088
1987	57	48	12	3.00	0.9027
1988	48	45	13	2.77	0.8029
1989	36	45	14	2.57	0.7083
1990	36	44	15	2.40	0.6180
1991	49	43	16	2.25	0.5314
1992	39	39	17	2.12	0.4477
1993	39	39	18	2.00	0.3665
1994	28	39	19	1.89	0.2873
1995	45	37	20	1.80	0.2096
1996	36	36	21	1.71	0.1330
1997	39	36	22	1.64	0.0571
1998	44	36	23	1.57	-0.0184

1999	36	36	24	1.50	-0.0940
2000	29	31	25	1.44	-0.1703
2001	26	29	26	1.38	-0.2476
2002	23	29	27	1.33	-0.3266
2003	37	28	28	1.29	-0.4082
2004	31	27	29	1.24	-0.4932
2005	29	26	30	1.20	-0.5832
2006	27	23	31	1.16	-0.6801
2007	23	23	32	1.13	-0.7872
2008	19	20	33	1.09	-0.9102
2009	20	19	34	1.06	-1.0614
2010	17	17	35	1.03	-1.2763

Appendix 2. Reduced mean Y_n in Gumbel's extreme value distribution.

Reduced mean Y_n in Gumbel's Extreme Value Distribution

N = sample size

N	0	1	2	3	4	5	6	7	8	9
10	0.4952	0.4996	0.5035	0.5070	0.5100	0.5128	0.5157	0.5181	0.5202	0.5220
20	0.5236	0.5252	0.5268	0.5283	0.5296	0.5309	0.5320	0.5332	0.5343	0.5353
30	0.5362	0.5371	0.5380	0.5388	0.5396	0.5402	0.5410	0.5418	0.5424	0.5430
40	0.5436	0.5442	0.5448	0.5453	0.5458	0.5463	0.5468	0.5473	0.5477	0.5481
50	0.5485	0.5489	0.5493	0.5497	0.5501	0.5504	0.5508	0.5511	0.5515	0.5518
60	0.5521	0.5524	0.5527	0.5530	0.5533	0.5535	0.5538	0.5540	0.5543	0.5545
70	0.5548	0.5550	0.5552	0.5555	0.5557	0.5559	0.5561	0.5563	0.5565	0.5567
80	0.5569	0.5570	0.5572	0.5574	0.5576	0.5578	0.5580	0.5581	0.5583	0.5585
90	0.5586	0.5587	0.5589	0.5591	0.5592	0.5593	0.5595	0.5596	0.5598	0.5599
100	0.5600									

Appendix 3. Reduced mean standard deviation in S_n Gumbel's extreme value distribution.

Reduced mean Standard Deviation S_n in Gumbel's Extreme Value Distribution
 N = sample size

N	0	1	2	3	4	5	6	7	8	9
10	0.9496	0.9676	0.9833	0.9971	1.0095	1.0206	1.0316	1.0411	1.0493	1.0565
20	1.0628	1.0696	1.0754	1.0811	1.0864	1.0915	1.0961	1.1004	1.1047	1.1086
30	1.1124	1.1159	1.1193	1.1226	1.1255	1.1285	1.1313	1.1339	1.1363	1.1388
40	1.1413	1.1436	1.1458	1.1480	1.1499	1.1519	1.1538	1.1557	1.1574	1.1590
50	1.1607	1.1623	1.1638	1.1658	1.1667	1.1681	1.1696	1.1708	1.1721	1.1734
60	1.1747	1.1759	1.1770	1.1782	1.1793	1.1803	1.1814	1.1824	1.1834	1.1844
70	1.1854	1.1863	1.1873	1.1881	1.1890	1.1898	1.1906	1.1915	1.1923	1.1930
80	1.1938	1.1945	1.1953	1.1959	1.1967	1.1973	1.1980	1.1987	1.1994	1.2001
90	1.2007	1.2013	1.2020	1.2026	1.2032	1.2038	1.2044	1.2049	1.2055	1.2060
100	1.2065									

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