College of Engineering

Civil & Architectural Engineering Department

InfrastructureEngineering

Detection of floods in west bankIn Daraja and Al-Ghar Catchments

Prepared By:

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Submitted to the College of Engineering

in partial fulfillment of the requirements for the degree of

Bachelor In Infrastructure Engineering

Palestine Polytechnic University

٢٠٢٠- 2019

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Signature of the project supervisor **Signature of the Head of the Department**

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الإهداء

إلى من جرع الكأس فارغاً ليسقيني قطرة حب

إلى من كلت أنامله ليقدم لنا لحظة سعادة

إلى من حصد الأشواك عن دربي ليمهد لي طريق **العلم**

إلى القلب الكبير............ **والدي** العزيز

إلى من أرضعتني الحب والحنان

إلى رمز الحب وبلسم الشفاء .... والدتي الحبيبة

إلى القلوب الطاهرة الرقيقة والنفو**س** البريئة إلى رياحين حياتي

الى من يحملون في عيونهم ذكريات طفولتي **وشبابي .... إخوتي وأخواتي**

الى من سرنا سويا ونحن نشق الطريق معا نحو **النجاح والإبداع.....** زملائي وزميلاتي

الى من ضحوا بحريتهم من اجل حرية غيرهم**......... الاسرى والمعتقلين**

الى من هم اكرم منا مكانة........ شهداء فلسطين

إلى هذه الصرح العلمي الفتي والمبار........ جامعة بوليتكنك فلسطين

الى من احتضنتني كل هذا الكم من السنين .... فلسطين الحبيبة

إلى من سار معنا الخطوة تلو الخطوة،
إلى مشرفنا الدكتور اعتصام أبو عزية

الشكر والتقدير

(قل اعملوا فسيرى الله عملكم ورسوله والمؤمنون)

صدق الله العظيم

إلهي لا يطيب الليل إلا بشكرك ولا يطيب النهار إلا بطاعتك .. ولا تطيب اللحظات إلا

بذكرك. . ولا تطيب الآخرة إلا بعفوك .. **ولا**
تطيب الجنة إلا برؤيتك ...**ا□ جل جلاله**

لابد لنا ونحن نخطو خطواتنا الأخيرة في الحياة الجامعية من وقفة نعود إلى أعوام قضيناها في رحاب الجامعة مع أساتذتنا الكرام الذين قدموا لنا الكثير باذلين بذلك جهودا كبيرة في بناء جيل الغد لتبعث الأمة

من جديد

وقبل أن نمضي نقدم أسمى آيات الشكر والامتنان والتقدير والمحبة إلى الذين حملوا **أقدس رسالة** في الحياة

إلى الذين مهدوا لنا طريق العلم والمعرفة

إلى جميع أساتذتنا الأفاضل

" كن عالما فإن لم تستطع فكن متعلما ، فإن لم تستطع فأحب العلماء ،فإن لم تستطع فلا **تبغضهم"**

الى من قدم لنا يد العون وكان لنا سندا والذي علمنا التفاؤل والمضي إلى الأمام ، ونخص بالتقدير والشكر إلى من رعانا وحافظ

علينا ، إلى من وقف إلى جانبنا عندما
ضللنا الطريق الدكتور اعتصام ابو عزيه

الذي نقول له بشراك قول رسول ا□ صلى ا□
عليه وسلم
إن الحوت في البحر ، والطير في السماء ، "
"ليصلون على معلم الناس الخير

ABSTRACT

<u>Detection of floods in west bankIn Daraja and Al-GharCatchments</u>

Mohammad Abu Mustafa **Fares Rasras**

Mohammad Mustafa **WaseemFgyat**

Supervisor

Dr. ItissamAbuizia

The project aims to develop a model to simulate surface runoff in the future rain in order to overcome the problems of future surprise floods.

The study was conducted in Wadi Al-Darqa and Wadi Al-Ghar, which are located in the desert of Jerusalem.

The methodology of the research was to collect available information on soil, geology, topographic maps, precipitation, water flow and previous studies, and to analyze rain flow data to obtain the hydrological characteristics of the study area.

A HEC-HMS program that simulates surface runoff of water in valleys of the study area was used so that a model based on the physical characteristics of the area would be simulated. Also the HEC-RAS flood forecasting and mapping program for the region.

The system was calibrated and validated through an operational perspective to test the feasibility of developing the model

الملخص

Detection of floods in west bankIn Daraja and Al-GharCatchments

Mohammad Abu Mustafa **Fares Rasras**

Mohammad Mustafa **WaseemFgyat**

Supervisor

Dr. ItissamAbuizia

يهدف المشروع الى تطوير نموذج لمحاكاة الجريان السطحي لهطول الامطار في المستقبل من اجل التغلب على مشاكل الفيضانات المفاجأة المستقبلية .

أجريت الدراسة على منطقة واد الدرجة وواد الغار الذان بقعان في صحراء القدس .

كانت المنهجية لاجراء البحث جمع المعلومات المتاحة عن التربة والجيولوجيا والخرائط الطبوغرافية وهطول الامطار وتدفق المياه والدراسات السابقة ،وتحليل بيانات تدفق الامطار للحصول على الخصائص الهيدرولجية لمنطقة الدراسة .

تم استخدام برنامج HEC-HMS الذي يقوم بمحاكاة الجريان السطحي للمياه في الاودية لمنطقة الدراسة بحيث سيتم محاكاة نموذج بناء على الخصائص الفيزيائية للمنطقة .

كذلك برنامج HEC-RAS للتنبؤ بالفيضانات ورسم الخرائط للمنطقة .

تم عملية المعايرة للنظام والتحقق منها من خلال منظور تشغيلي لاختبار مدى قابيلة تطوير النموذج

Acknowledge

We would like to express our thanks and gratitude to Allah, the Most Beneficent, the most Merciful who granted us the ability and willing to start and complete this project. We pray to his greatness to inspire us the right path to his content and to enable us to continue the work started in this project to the benefits of our country.

We wish to express our deep and sincere thanks and gratitude to Palestine Polytechnic University, the Department of Civil & Architectural Engineering, College of Engineering & Technology.

We can find no words to express our sincere, appreciation and gratitude to our parents, sisters and brothers, for their endless support and encouragement, we are deeply indebted to you and we hope that we may someday reciprocate it in some way.

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1.7 Research Objectives

1.1 Background

Water resources in the West Bank, Palestine are scarce. This is due to the fact that, geographically, the West Bank is located in arid to semi-arid region. Therefore, societies in the West Bank are very vulnerable to variability of water resources availability. This vulnerability is caused by the strong constraints on the use of natural resources due to limited and low reliable water resources availability in addition to an often high population density and growth rate. The population is strongly dependent on these resources with few short-term options to reduce such dependency.

The existing political situation adds another constraint to the availability of water resources in the West Bank. Water is one of the most essential elements vital for human well-being. It is a main factor in most domestic, industrial and agricultural activities. In the West Bank, rainfall averages 450 mm per year, with area of 5,879 km2, this gives an average total of about 2,600 million m3 of rain per year. Around 680 million m3 of this is estimated to infiltrate into the soil to replenish aquifers, the remainder becoming surface runoff or lost through evapotranspiration (WRAP, 1994). Unfortunately, Palestine suffers from shortage in water resources quantity and quality.

It is important to understand these water resources, their distribution and use as base for assessing the deficit in the different sectors and to propose solutions and methods that may help in mitigate these obstacles .on other hand, the political issues between Palestinian and Israelis according water crisis are still increasing the water problem in Palestinian territories. mainly from rainfall stored in aquifers (although 75% of the to¬tal rainfall evaporates), but some return flow from irrigation, sewage effluent, and water leakage from pipes. Some 80% of ground water is exploited by Israel, accounting for 25% of Israel’s water needs.

In watershed modeling, if we consider water quantity and water availability, traditionally, simulating the relation between precipitation and discharge at the catchment’s outlet should be carried out. Rainfall-runoff modeling is a major part of this job. Therefore, rainfall-runoff modeling is considered a standard tool routinely used today for the investigation and application in watershed hydrology.

This research study aims to gain an understanding of the hydrological processes (rainfall-runoff) in arid and semi-arid watershed. This is achieved through the modeling of rainfall-runoff process in the study area (two watersheds in Jerusalem Desert) which is characterized as arid to semi-arid region located in the southern West Bank, Palestine. Nowadays rainfall-runoff modeling is considered a standard tool normally used for the investigation and application in watershed hydrology. In this study, surface runoff, process-oriented modeling techniques (HEC) integrating existing scientific results have been applied.

1.2 Objective

The objective of this research is to determine the quantity of surface runoff in the Judean desert that flow to Dead Sea in arid and semi-arid environment of the West Bank, Palestine. Darja and Gharwadis catchments which are both of the catchments contributing to the Dead Sea basin are the focus study areas in this research study. The HEC model is to be used in this research to evaluate the availability of surface water

Resources in the both wadis. Such evaluation can be utilized in the development of best management practices that can be adopted to manage the scarce water resources in the Judean terrains and lead towards understanding and managing the regional water resources in the Dead Sea basin. In light of the above, the general objectives of this research can be summarized as follows:

1. To collect high quality rainfall and runoff data in high temporal and spatial resolution for hydrological modeling;
2. To collect relevant model parameters for HEC model. These include infiltration characteristics of different terrain types and GIS-parameters for the runoff generation routine and channel routing routine of the model;
3. To apply the HEC(HMS and RAS) model for selected single rainstorm events followed by continuous simulation for the entire rainy seasons;
4. To assess the total available surface water in both watersheds and generate flood hazard maps for the both study areas.
5. To develop proper surface water management options for the most efficient water under present and global climate change induced conditions based on the assessment of total available water resources in both catchments.

1.3 Problem Statement

The result of limitations of hydrological measurements equipment's, and the fact of inability of having sufficient knowledge about watershed hydrology processing according to time and space are considering the motive force to utilizing models. In addition the model application should improve the decision making about hydrological problems. By the way surface runoff and flash floods are not caused particularly by meteorological phenomena: heavy rainfall is necessary, but flood generation also depends on the physical watershed characteristics and the hydrological response of it during the event. Flood generation in the study areas is becoming a serious threatening process due to recent human and infrastructure losses, while, the area suffering from lack of flood forecasting system.

The transformation of precipitation to surface runoff (sometimes flood) and flow into channels is a highly complex physical process. A common practice is to use a hydrological model to represent watershed processes. They offer a wide range of complexity and data requirements, and various degrees of technical support and training, however little attention has been given to the task of short-term flood forecasting .

The modeling generation depends on the prediction objective, geographical and environmental factors, climatologically, physical watershed properties as well as institutional capabilities. Every hydrological model requires the following: determination of the amount of rainfall participates in hydrograph formation, and the distribution of that runoff in time, to form the shape of the storm hydrograph . Therefore, efforts should be done to select the model that fit proper to the parameters and conditions oft he watershed to calculate discharge, hydrograph and rainfall hyetograph that can help to predict flood occurrence under similar conditions. By utilizing a GIS based approach in rainfall runoff modeling to use of different land use patterns especially in regions with different styles of land use features and different soil types. Therefore, the selection of surface runoff generation and estimation instrument needs to be based on a systematic approach .

Many models available and utilized in such areas, HEC-HMS is model widely applied for estimating streamflow. Hence HEC HMS is fit more to similar catchment hydrological response, according to many researchers .Modeling efforts will concentrated at the watershed scale and aimed to understand the processes responsible for rainfall runoff and flood formation at different spatial and temporal flow towards Dead Sea, the soil erosion from the headwater of each catchment and the interception processing during the storm among the watershed surface. HEC-RAS is hydraulic model that will be utilized to derive flood forecast system and flood hazard map for the study areas.

There will many obstacles that faced the processing of modeling surface runoff such as : In general, the spatial variations of rainfall occurrence in the arid area. Beside that shortage in rain gauges among the study area. Rainfall in arid regions tends to be less and more variable in time than in humid regions, and long sequences with very little rain are common in many regions.

In most such catchments, evaporation from bare soil considered a greater importance relative to transpiration from very few plants occurrence, because the wider area is already bare soil and the frequency of small rainfall events which allow bare soil to build up soil crust formation that strongly assist in water runoff generation and help in return water to the atmosphere rather than percolation .

1.4 Time Table

The time schedule in table (1.1) shows the stages of developing theoretical work and the process project that includes (literature review, organizing the scope, data collection, and the final presentation).

Table (1.1) Time Schedule for this semester.

Weeks Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project idea																
literature review																
organizing the scope																
Data collection																
Presentation																
Weeks Tasks	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
literature review																
organizing the scope																
Data collection																
Presentation																

1.5 Research Questions

Follow up to the above objectives, a few questions are raised.

1. What are the active runoff generation processes in arid and semi-arid regions?
2. What is the best hydrological model that can be used to assess the runoff generation process in arid and semi-arid regions?
3. Which data should be collected and how to acquire data in the fieldwork period? What is the quality of the data (spatial data and attribute data)? If data availability is insufficient, how to generate synthetic data?
4. How can we provide improved estimations of watershed initial conditions (e.g., soil moisture, infiltration rate, Manning coefficient, hydraulic conductivity)?
5. What is the optimal set of the input model parameters required to apply the HEC HMS and HEC RAS models?
6. What is the potential for the spatially distributed HEC HMS and RAS model set up for watershed outlet simulations to generate hydrographs at interior locations for flood forecasting?
7. How do we characterize the HEC HMS and HEC RAS models uncertainties?
8. How can we use the HEC HMS and HEC RAS models in assessing the runoff generation under land use and climate changes scenarios?
9. What are the proper water resources management options for the most efficient water use in both catchments?

1.6 Justification of the research

No laboratory experiment, and insufficient techniques available that can be utilized in which the difficulty and complexity of a natural hydrological system is enough replicated, so researchers focus on development of simulation models fit to arid catchments hydrology processing.

The problem in Rainfall–Runoff modeling appears from the combination of the complexity of a catchment system and the difficulty to properly and quantitatively collection the information that is available about it . Another, reason to model the rainfall runoff transformation is for forecasting purposes, in order to improve the quality of decisions related to flood risk management issues.

The purpose of this project is to improve understanding of hydrologic processes in the catchments of heterogenic soil type in the study area. The hydrological response, in such condition of catchments and the potential hydrology were not yet properly understood. Hence modeling the hydrology of watersheds is required for effective rainfall management purpose . Rainfall is the primary hydrological modeling input, but rainfall in arid and semi-arid areas is commonly characterized by extremely high spatial and temporal variability, while rainfall data for this study will based on radar data based (for both catchments).

Most records available are of relatively short length, and high intensity. Rainfall-runoff models are becoming an important tool for estimating flood hydrographs and discharge. There are several advantages to choosing the HEC-HMS and HEC RAS models for this study. The graphical user interface (GUI), . The models require different datasets including Digital Elevation Model (DEM), weather data, soil type, and land use.

HEC-HMS and HEC RAS models provides almost all of the same simulation capabilities, but has modernized them with advances in numerical analysis that take advantage of the significantly faster desktop computers available today. It also includes a number of features that were not included in other models, such as continuous simulation and grid cell surface hydrology.

Huge quantity of flooding water goes down to Dead Sea without any utilizing, despite of the importance of water resource management according to both neighbors Israel and Palestinian territories. Moreover, most flood generation studies and descriptions of watersheds generate them have not yet been conducted for several reasons: (i) Lack of awareness of the importance in monitoring floods (ii) cost of flood monitoring devices (iii) difficulty of securely installing measurement devices within the study area and (iv) the difficulties of access to those watersheds during the events it's self. Even in the rare cases where gauging stations exist, measurement problems may occur during intense flood events, reducing the quality and completeness of the data.

The main purposes of surface runoff and flood studies by applying modeling include:

- Protection of lives and catchment properties (wildlife, green cover and soil).
- Flood forecasting and risk management.
- Proposed suggestions for the optimized surface runoff/flood investigation.

1.7 Research Objectives

The main target of the project is to develop an integrated modeling methodology based on two watersheds monitoring and experimentation at two sites. The main components of the project are:

1. Geographical information system (GIS)-based rapid assessment of climatology parameters, catchments physical properties and soil hydrologic parameters,
2. Radar based rainfall data for both catchments
3. Integrated model development using watershed level parameters and distributed parameters
4. Estimate the water quantity that flow from surface runoff in the study area from each sub basin and from the outlet of each catchment towards the Dead Sea .

The study was intended to investigate the hydrology of each catchment using physically based, conceptual, computationally efficient and distributed model HEC HMS version 4.2.1 to access the heterogenic hydrological response from each catchment. Therefore, understanding the hydrological processes of each watershed is vital to make decisions on flood and surface runoff generation. Runoff is one of the major hydrological responses of the catchment which is related with rain water loss.

The aim of this study was to develop a new framework of rainfall-runoff model applications in such arid catchment with both models (HEC-HMS and HEC-RAS) input data include soil type, land use/land cover, and slope and other. The scientific objectives of the research plan are to develop a methodology of stream flow modeling in heterogenic watershed by investigating radar based rainfall data, tomography and other physical characteristics of each catchment. The specific objectives of the research plan are to:

1. Critically analyze the selected models' performance in the heterogametic hydrologically response of the heterogeneous soil type in each study area,
2. Develop relationship between rainfall- runoff processes.
3. Estimation of the surface runoff volume, hydrograph, rainfall hyetograph and flood peak for the study area.

Chapter Two

Lecturer Review

2.1 Kilsby et al, 2005

2.2 Mizyed, N., 1997

2.3 Dahan , etal ,2007

2.4 Kahana,et al,2002

2.5 Al-Kharabsheh et al ,2004

2.6 Yomtovian et al,1982

2.1 Kilsby et al, 2005

Illustrated that there are two obstacles have been raised according to changes in rainfall threatening the water resources of the West Bank. The first is the effects of global warming. Hence the current predictions from General Circulation Models (GCMs) are for significant decreases in annual rainfall over the region by the 2050s. The second concern was raised by recent studies of rainfall over Israel, which have shown evidence of a decreasing trend in annual rainfall.

The trend is characterized by a decrease in rainfall over northern Israel, and an increase in the more arid south. But it is not so clearly to consider this impact on west bank, where insufficient observational data from the West Bank have been used in the studies to date and the region lies between the zones of most marked increase and decrease. SUSMAQ program aims to estimate the impacts of possible changes in rainfall regime on groundwater resources, to build up guidance for the sustainable management of the groundwater resources of the West Bank. This needed many processing such as rainfall data Collection and analyzing and regional climate trends and variations relations and its impact on variable topography; and estimation this impact on variation on the rainfall trend in the area and GW recharge.

The researchers did not put forwards a real estimation or quantifying the amount of rainfall decreasing and evaluate the value of decreasing in surface runoff in West Bank. Rainfall in west bank exposed to different forms when reached the land surface evaporate, transpiration ,infiltrate to groundwater or participate in soil moisture besides to certain amount that runoff on surface.

2.2 Mizyed, N., 1997

In a study concentrated on springs discharging to the Dead Sea drainage systems which are fewer than those discharge to the Mediterranean drainage systems from west bank side . the interested on two main discharge areas are the Feshkha group and EinGedi. He studied the chemistry of water discharging from both sources ,the former is extremely complex involving recharge by local rainfall into the Quaternary Conglomerates bordering the Dead Sea, discharge from both the confined and phreatic sub-aquifers as well as from the much deeper waters of the Nubian Sandstone aquifer and from possibly juvenile or conante waters of sedimentation. Residency time in the phreatic aquifer is about 40 years from recharge in the

Hebron Mountains to discharge into the Dead Sea, with salinity increasing eastwards. There seems to be little intrusion by Dead Sea water. The more ancient waters, emerging from as deep as 2.5 km, making use of the major fault lines as conduits, may be about 25,000 years old, and thus significantly increase the salinity of the Feshkha discharge . While EinGedi, springs emerge above the clay/marl layer at the top of the Yatta Formation.

Residency time in the phreatic aquifer here is about half that of the system and maintains such a high quality that the water is bottled and sold as mineral water. The researcher focused on groundwater quality and explained the recharge processing method for both springs .One of EinGedi groups is fed from Ghar catchments and did not mentioned the surface water role in recharging of these springs. On the other hand Dayan et al,2006 discusses and explained the factors effect the flood formation and its impact on water of the study area such lows pass the area . He suggested that the drop in Dead Sea water level was caused by diversion of 90% of the total flow that would have reaches the Dead Sea from the Jordan River by Israel, Jordan, and Syria.

The annual evaporation of this lake is 1500 mm and varies with the salinity at the surface of the lake and freshening by the water inflow. The drainage area of the Dead Sea is 43,000 km2. Additional contributions come from both rift valley escarpments to the east and west of the basin and from the large southern part of this drainage basin. Intensive rainfall in the southern most parts of the drainage basin is generated yearly accounting for most of the major floods over the southern Dead Sea watershed, occurs mainly during fall and penetrates from the south. In extreme cases, rain intensities at the rain cell cores may exceed 100 mm h^{-1}, totaling up to a few tens of mm in rain depth, and cell core areas can reach hundreds of square kilometers.

The storm was accompanied by thunder, gale, and hail. The storm flooded several catchments within the Dead Sea basin. Although the convective storms are the typical fl ash flood–producing rainstorms in the region, there are cases in which a large amount of widespread, low intensity rainfall can cause floods as well. Wadi Al-ghar catchment at the western escarpment of the Dead Sea recorded the highest flow in twelve years (1983–1984 to 1994–1995). In this article, the authors describe the conditions that may affect flood formation in dead sea basin and insist that the main flood source is from southern area, in addition they don’t quantify the volume of each surface water sharing in each flood processing.

2.3Dahanetal ,2007

Puild up their study in the central Arava valley, this experiment was only ‘‘technical and qualitative’’,it is presented there because some of its results shed light on very important aspects of the infiltration process, and help to explain some of the results from the larger-scale infiltration experiment.

The infiltration and recharge were continuously monitored in all three hydrological domains participating in the infiltration process, the surface water, the vadose zone and the groundwater. Water level and EC were monitored in the groundwater while water content of the vadose zone was monitored using FTDR probes (detectors). Infiltration was estimated by various methods, including surface water loss, ring infiltrometers, waterfront propagation velocity through the vadose zone, and groundwater-level responses to the flood event. Major differences in flow velocities, fluxes and groundwater recharge rates were found between the various estimation methods and flooding conditions.

The infiltration rates and flow velocities estimated by the various methods in all monitored flooding events. This experimental system makes use of a new technique for installing flexible time-domain reflectometry probes for continuous monitoring of the vadose zone moisture profiles. Water infiltration was monitored in controlled infiltration experiments and during a natural flood. The monitoring setup allowed real-time tracking of the wetting- front propagation velocities and assessment of water fluxes through the vadose zone.

The results revealed a complex infiltration process that includes matrix and preferential flow together with lateral flow. This study quantifying the surface water loose by different hydrological processing in the area, and don’t mentioned the total surface water that remain to flow to Mediterranean sea, but techniques used in this study may be helpful in our study to estimate water looses throw surface water flow to dead sea in both catchment.

2.4Kahana,et al(2002)

Studied the meteorological data which has direct impact on flood formation and classified the atomospheric conditions that help in flood formation. Produced a large hydrologic database of the major floods in the Negev. This database dictated the selection of synoptic data and allowed to identify the atmospheric circulation associated with each extreme hydrological event. Categorized the floods into synoptic classes by manual classification, which yielded four 'synoptic types' each of which has unique characteristics in both weather elements and features of the resulting floods, such as their intensity, seasonality, and spatial distribution. data were collected from 37 hydrometric stations operated by the Israeli Hydrological Service.

The data were processed and displayed by the Grid Analysis and Display System (GrADS). The selected window, of 408 grid points, encompassing the eastern Mediterranean and the northern Red Sea areas, extends between 0–60 °E and 20–60 °N. A flood in which the recorded peak discharge reached the magnitude of a 5 year recurrence interval (20% annual probability) in at least one of the hydrometric stations was considered a 'major flood'. The determination of the 5 year discharge threshold for each hydrometric station is based on the event-based regional model of the Israeli Hydrological Service and was calculated for 23 stations which have been in operation for over 10 years. Fifty-two major floods were selected. GrADS.

Data were compiled and studied for 52 floods for the period 1965–94, with peak discharge above the magnitude of 5 year recurrence intervals (RI >5 years) in at least one drainage basin.

2.5Al-Kharabsheh et al (2004)

Claimed that there are two types of catchments, fan shape and fern leaf catchments. The fan shaped catchments give greater runoff, because tributaries are nearly of the same size and therefore, time of flow is nearly the same and is smaller. Whereas in the fern leaf catchment as in most of the studied catchments, the tributaries are generally of different lengths and the time of concentration is more as the discharge has to travel longer distance.

A number of major wadis drain into the Dead Sea without utilization. These wadis are characterized by narrow to wide shallow flow-beds with relatively high slopes. To monitor runoff five gabions were constructed and equipped with automatic water level recorders. The losses in precipitation are due to various causes, some of them evaporation, transpiration, and interception. Evaporation from water bodies and soil masses together with the transpiration from vegetation is termed as evapotranspiration.

There are three general methods commonly in use for measuring evaporation, which are mainly indirect methods: measurement from evaporation pans, such as Class A Pan, which is used in this study experiment, water budgets and corrections with climatic data (Experimental Formulas).

The rate and quantity of water that infiltrates into the ground is a function of soil type, soil moisture, permeability, ground cover, drainage conditions and duration of rainfall. It is well known that when water reaches the surface of a soil, a part of it seeps into the soil. This movement of water through the soil surface is known as infiltration and plays a significant role in the runoff process. Hence, infiltration is the primary step in the natural ground recharge. Sediment thickness and volume was measured in the area.

٢.6Yomtovian (1982)

Illustrated that simplified computational techniques of hydraulic analysis used to delineate flood plains with acceptable degree accuracy. The results indicated that when both the simplified manual and complex computer hydraulic computational techniques are applied to 3-creeks Apple, Burnt and Hay-in North Dakota the flood plain boundaries computed by both methods are preferred for determining the 10 to100 years flood evaluation.

The mathematical model such as HEC-2 or the national weather service Dam Breat model, are recommended for the detailed studies which require an accurate knowledge of the flood elevations.

Chapter Three

Materials And Methods

3.1 Study Area.

3.2 Maps.

3.3 Methodology.

3.4 Modeling.

3.5 Next Steps.

3.1 Study area

The study will be executed for two catchments located in the Judean Desert near the lake ofDead Sea, both generated surface runoff towards Dead Sea; they are Darga and Al-ghar catchments, with the total area 308.68 Km2. Both of them have variable climates according to the elevation and both are with an elongate elliptical shape, characterized by mountains and hilly area, narrow valleys and deep canyons.

The study area is divided into semi-arid, arid and hyperarid regions with more than six rainless months per year. Rainfall variables occur from season to season, and decrease from west to east, with times of many year droughts or near drought interrupted with intervals of heavy rain events (Zaide , CSD-16/17).

Some characteristics that describe the study area as mostly arid catchments are: Stream flow characterized by absence of base flow and flash-floods during infrequent high-intensity rain events, high evaporation rates, and highly-localized spatial rainfall distribution (Wheater et al1991), where the storm rainfall correlation coefficient decreases rapidly with downward eastern distance. (see the topographic map of the study area, map (1),)and finally, the area with sparse plant cover and organic matter (Pilgrim et al 1988).(Osborn et al 1979).

The area distinguished by topography with high gradient within short distance started from upper stream in west towards downstream in east, the rainfall, and decreased in the same direction, while the temperature increased.

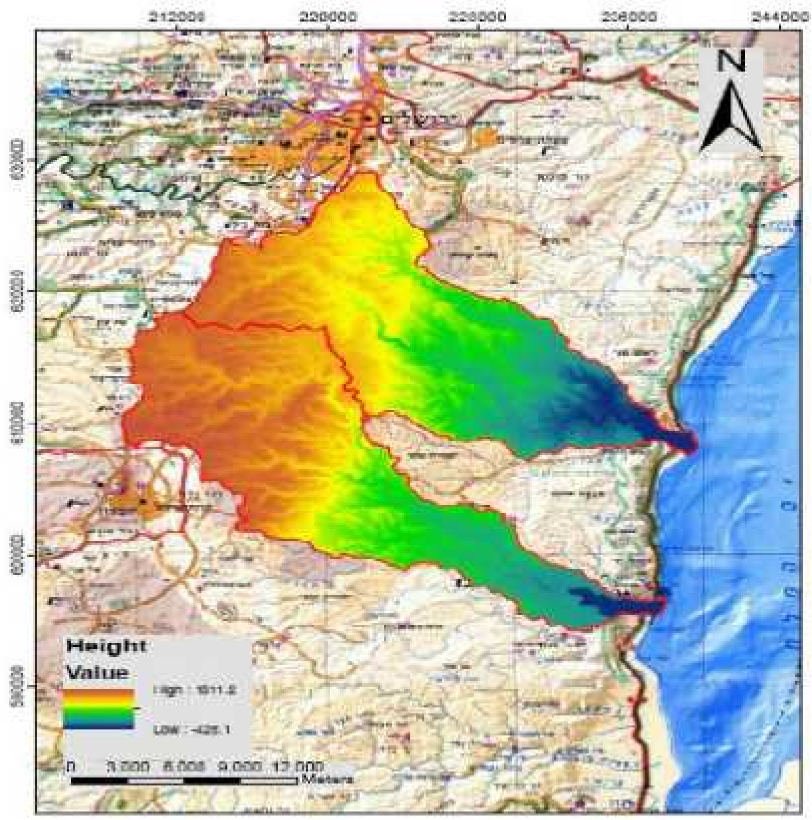


Figure (3.1)Topographic map of the study area

The land cover of the study area has a major impact on the surface runoff generation and the land use with low percent (housing, roads, and farming) in the upper headwater, while most of the land with spare plant covers within few weeks after rainy days and a little bit of pushes and trees distributed mainly around the channels of the streams.

The soil of the study area is subdivided in two types: mountainous soil and desert soil (Morin et al, 2006), The mountainous soil in both catchments covers the area 182.305 Km2 with percent of 59.06%, and most of it comes from Arugot, and the desert soil in both catchments is 126.38 Km2 , with percent of 40.94%. area. The soil structure can be categorized into: terra rossas, brown rendzinas and pale rendzinas is available in the upper catchments among the mountains of Hebron and Jerusalem.

And the mountains soil majority in the study area is brown rendzinas and pale rendzinas, with small spots of soil of pale rendzinas in the Darga catchment. In the middle distance of both catchments, the dominant soil is brown lithosols and loessialserozems. Finally at the foot hill of the downstream area near the shore of the Dead Sea there bare rocks and desert lithosols.

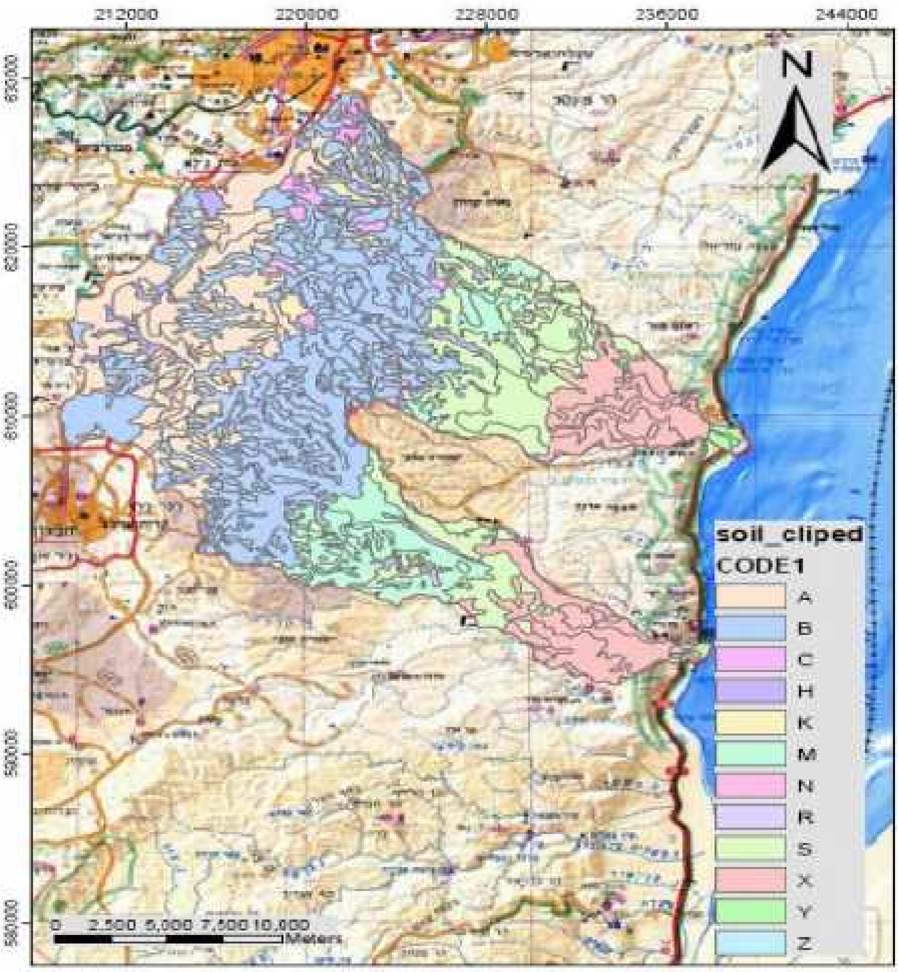


Figure (3.2)soil structure distribution among the study area

3.1.1Daraja

It is located in Judean Desert at the position of Elevation in the upper stream: 885 m above the sea level with coordinates x: 35.15, Y: 31.71 Decimal Degrees, and the elevation of downstream is – 413 m below the sea level with coordinates: X: 35.42 and Y: 31.56 Decimal Degrees. The upper North point limit border is located on 762.40 m above the sea level with Coordinates: X: 35.23 and Y: 31.75 Decimal Degrees.

The longest distance between upper and lower point from east to west for Daraja is 29 Km and the longest distance of its width from south to north is 12 Km. The total area of Daraja is 74.32 Km2 , with 13 subbasins. According to Daraja catchment, the mountainous soil covers 34.63 Km2 with percent of 46.60%.

3.1.2Al-Ghar

It is located in Judean Desert the elevation of upper stream is located on 929.20 m above the sea level with coordinates X: 35.10 and Y: 31.65 Decimal Degrees ,and the elevation of downstream is -435.20 m below the sea level and the coordinates are: X: 35.40 and Y: 31.46 Decimal Degrees .

And the elevation of the south point border at upper limit is located at: 985.20 m above the sea level and with coordinates of X: 35.10 and Y: 31.57 DecimalDegrees. The longest distance between upper and lower point from east to west for Al-ghart is 35 Km and the longest distance of its width from south to north is 13 Km, and the total area ofAl-Ghar is 234.36 Km2 , with 15 subbasins.

The dominant soil type in Al-Ghar is the mountainous soil, which covers about 147.68 Km2 , with the percentage of 63.01%, and contains ten subbasins from 1 to 10, and the desert soil covers about 86.68 Km2 , with the percentage of 36.99% and contains 5 subbasins from 11 to 15.

3.1.3 Climatology of the study area

The western basin of the Dead Sea is span from the water divided through Hebron and Jerusalem Mountains in the west and the Dead Sea in the east. This basin is subdivided to many catchments discharge their surface runoff towards the Dead Sea , (Arad, 1964). The study area is described as mostly arid catchments (Wheater et al ,1991),where the storm rainfall correlation coefficient decreases rapidly with downward eastern distance, (Pilgrim et al 1988).(Osborn et al 1979), and decreased from north towards south in the study area. The temperature of the study area is going in opposite direction to rainfall pattern, decreased from west to east and from north to south.

Most of this region is classified as arid or semi-arid climate, while the basin headwaters experience wetter conditions of mountainous Mediterranean climate. Mean annual rainfall over the study region varies from 450 to 30 mm (Morin et al, 2012), but Tahal Group and Geological Survey of Israel and associates (2010), reporting that the upper stream areas with larger amounts (500 mm/yr - 600 mm/yr) with the approach to the Hebron and Jerusalem mountains in the west and the region of the downstream is characterized by a desert climate with a small amount of rain, about 100 mm/yr in the vicinity of the Dead Sea, (Tahal Group and Geological Survey of Israel and associates (2010)).The study area is characterized by a dry Mediterranean climate.(Laronne et al,2007).

In general, the climatic regimes of the Dead Sea basin, including the western tributaries span from a Mediterranean climate in the north and west at the upper headwaters of the tributaries, a semiarid climate among them, to an arid climate near the Dead Sea shores (Morin et al, 2006).

According to the information based upon the Israeli Hydrologic Service's measurements at various hydrometric stations in the region up to the years 2009, the total mean annual contribution of the western wadis (catchments) was estimated to be within the range of about 6 MCM as an annual average(Tahal Group and Geological Survey of Israel and associates ,2010). Larone et al (2007) wrote in their paper that in many cases theses catchments generate floods from events caused by Red Sea Trough and (RST) and cyclone system.

The major flood events caused by (RST) in Dead Sea catchments occurred in Daraja catchment in the hydrological year 1995/6 and 1998/9 with total flood volume 12.4x 106m3 and20.7x 106m3respectively. In contrast, some major floods are caused by cyclone systems in the study area for example in Al-Ghar catchment , in the hydrological year 1980/1 and 1992/3 with total flood volume 3.01x 106m3 and 2.44 x 106m3respectively and for Daraja catchment in the hydrological year 2001/2002 with total flood volume 0.399 x 106m3(Larone et al.2007).

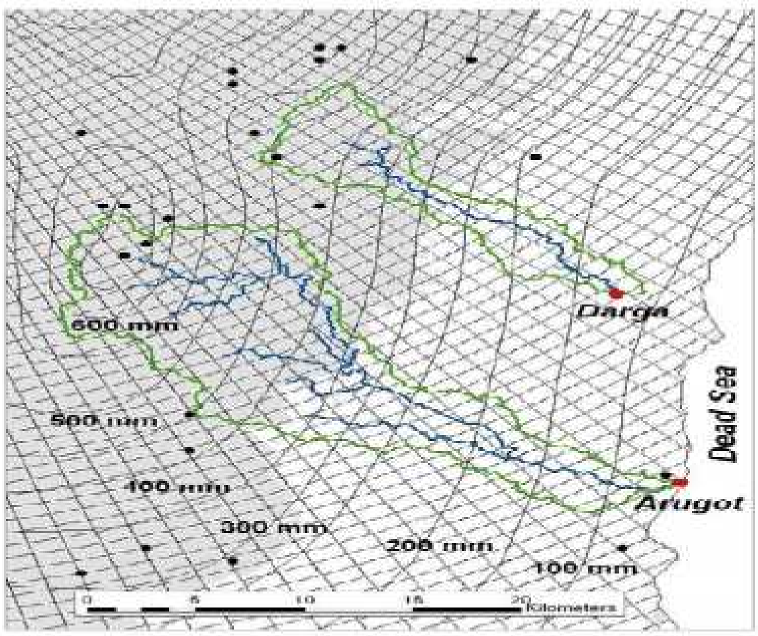


Figure (3.3) study area with rainfall distribution, rainfall stations (black dots), channels, and soil typein the area, after (Morin et al, 2009).

3.2 Maps

After getting data from the geomolg site for the region, we made the following maps using gis.

1. Geology ,The geology of the study areas consist of four different rock categories such as ailbian ,cenomanian, lower cenomanian, senonian, and Turonian stratifications, these rocks variant in rock structure hardness and configuration. Fig. (3.4).
2. Land cover , Land cover in the study areas is refer to terrestrial superficial which may cover by grass pushes, trees forests and water bodies and other biological living components, in addition to other bio classification that illustrated in the land cover map. Fig. (3.5).
3. Rainfall , Rainfall events is correlated to the quantity of rainfall per area. Rainfall in the study areas is variable temporally and spatially and this related to different aspects such as: the rainfall intensity and quantity is decreased from west to east and from north to south the trend in decreasing of rainfall related to the decreasing in the land elevation. The rainfall in the study areas extended from 0 mm to 1000 mm. Fig. (3.6).
4. Rocks ,Rthe study areas contains different sort of rocks and each rock consists of certain minerals and therefore there are sedimentary, metamorphic and igneous . Fig. (3.7).
5. Soil ,Soil available on the study areas above the rocks, the soil formed by rock fragmentation due to the weathering processing that affect the soil characteristics. In our study areas the soil can be classified into five soil groups as illustrated in the soil map . Fig. (3.8).
6. Strems ,the study areas are two catchments consist of water flow channels in stream channels from the upper stream. The water is flow through streams towards the outlet near the dead sea. Fig. (3.9).
7. Tempreture , the study area remarked by variability in temperature. It is various temporally and spatially through the study areas in both catchments. The temperature has trend to increase with respect to the land elevations, it increase from west to east and has the maximum value around the outlet near the Dead Sea peach. The temperature has maximum values during summer months mainly in July and august and minimum values during December and January average extended from 5 C to 35 C. Fig. (3.10).

8. Topography ,It is an expression concern with the land superficial including valleys, mountains, hills, flat plains and plateaus.it has essential roles in defined the site characteristics such as rainfall, temperatures, grazing lands and agricultural regions, the study areas have been classified and subdivided into zones based on the elevations, the elevations extended from 127 m below sea level to more than 990 m above sea level. Fig. (3.11).
9. Wells ,The source of water in both catchments is rainfall, which offer water to the area. The hydrological cycle in the study areas can go into different forms. Some of the water will evaporite and back again to atmosphere, some will go into surface runoff and generate stream channels flow and may compose flood. While the rest will percolate to groundwater through the rock layers to feed groundwater basin in the area. Recently the groundwater utilized through construct groundwater with 5 wells in Daraja and 6 wells in Al-Ghar. Fig. (3.12).

3.3Methodology

The research methodology will try to achieve the research purposes and reply to the research questions. The methodology involves collection of primary and secondary data. The secondary data would be derived from books, journals (literature review), archival satellite images andInternet literature review. Many scientific articles from scientific journals, and some books and Master theses have been collected. All of them are about surface runoff hydrology and modeling processing discussed some methodologies and results of these studies.

The primary data will include field observation in order to draw up cross sections in selected points among the stream down ward and estimate discharge during general surface flow and the discharge at that point during the flood processing.

We will measure and calculate the bankfull area and floodplain area per event by determination of the wetted area and radius of the channel, beside to determine the water velocity among the channel. The amount of runoff and the discharge of streamflow are related to the rainfall distribution, the rainfall rate and the duration of high rainfall rates in the drainage basin (NRC, 2005).

The methodology would be divided into the following steps:

- Radar based rainfall data collection and analysis,
- Discharge data is required for model calibration and verification.
- Soil data collection, measurements and recording data, photos and images.
- Manning's roughness constants for both channels and hill slopes, manning's equations and othermathematical equations needed, Excel document.
- Satellite imagery processing and analysis(Geomolg, and GIS),
- Field observation and visits to monitoring the stream down ward each catchment, measurementsfor stream channels factors to sketch out cross sections in certain selected locations among bothstream channels.
- Software of both programs (HEC HMS, and HEC RAS): training, calibration, validation andapplication.
- GIS data for modeling and for collection the physical parameters of each catchment.
- Applications of model processing, analyzing, comparison, modified, and results.
- Finally , discussion, conclusion, recommendations, and printing out of the dissertation as aresearch.

Chapter Four

Modeling

4.1 Work data

4.2 The software used

4.٣The methodology of the study

4.1 Work data

The work data is divided into three types: the information on the study area, the geographical data of this area and the data on the software used.

4.2 The software used

We have the HEC software family (HEC-HMS, HEC-RAS and HEC-GeoRAS) which are free products from the Hydrology Engineering Center within the US Army Corps of Engineers.

4.2.1 HEC-HMS

HEC-HMS is designed to simulate rain-flow processes. It is designed to be applicable in a wide range of geographic areas to solve as many problems as possible.

Figure (٤.١) HEC-HMS logo

HEC-HMS is a semi-spatial model that subdivides a watershed into several parts, called sub-basins, which are considered to have homogeneous characteristics. It is particularly well suited to simulate the hydrological behavior of non-urban watersheds. HEC-HMS also makes it possible to simulate and incorporate tanks and bypasses.

The HEC-HMS hydrologic model includes a graphical interface, capabilities for data manipulation, management and storage, as well as display and printout capabilities. It follows the hydrologic model HEC-1, the Flood Hydrograph Package developed during the 1970s, which is still today the most widely used hydrological model in the United States (EL JAKANI, 2011).

The HEC-HMS hydrological model was developed by the U.S. Hydrologic Engineering Center (HEC). Army Corps of Engineers (USACE). A detailed description of HEC-HMS and its complete documentation can be found on the USACE website (http://www.hec.usace.army.mil).

The Tool has a special module to manage the calibration operation very satisfactorily:

- By allowing to select the sets of parameters and their domains of variations.
- Providing graphs and tables of comparisons.

4.2.2 HEC-RAS

HEC-RAS, the Hydrologic Engineering Centers River Analysis System, is a computer program that models water flow hydraulics in natural and man-made streams.

Figure (٤.٢) HEC -RAS logo.

The model used by HEC-RAS is one-dimensional. This means that there is no direct modeling of hydraulic variations due to changes in cross-sectional shape, elbows, or other aspects of a 2D or 3D flow.Like HEC-HMS, HEC-RAS was developed by the US Department of Defense (United States Army Engineers). The purpose of its elaboration is to manage the rivers, ports and other public works under their jurisdiction.

HEC-RAS has been widely distributed around the world since its publication in 1995. It allows hydraulic engineers to analyze flows in river beds and determine flood zones. It integrates many data entry methods, hydraulic analysis components, data storage, table and graphical report editing. (Wikipedia, 2013)

HEC-RAS has extensions on other programs:

- AutoCAD, RiverCAD: functions for importing Digital Terrain Model (DTM) files from AutoCAD.
- HEC-GeoRAS: Data import / export module compatible with ArcGIS software. In the following paragraph we will present this extension that we will use in the case of our study.

4.2.3HEC-GeoRAS – ArcGIS

HEC-GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a graphical user interface.

Figure (٤.٣) Extending HEC-GeoRAS on ArcGIS 10

The HEC-GeoRAS interface on ArcGIS allows the preparation of geometric data for import to HEC-RAS and allows the display of the simulation results of the processes exported from HEC-RAS to ArcGIS.

We will use this extension to represent the elevation data calculated on HEC-RAS. The final result of this representation is the flood hazard map which is the objective of this study.Subsequently, we will present the methodology followed to arrive at our results.

4.3The methodology of the study

The objective of this work is to establish a system that can model and map the future hazard, from the rain forecast. To do this, we will follow a well-defined methodology. We begin by giving a general presentation of this methodology which will outline the major steps that we will follow. Then we will explain in detail each of these steps.

4.3.1 General presentation

For this study, we chose hydrological rainfall-flow models to model the flood formation process. This step will be followed by the calculation of the altimetry level of the waters in the area concerned. This will map the flood areas where the risk is increased.

As we explained in the previous chapter, several hydrological models exist depending on the study area, the data available to us, our experience, etc.

In the case of this work, hydrological rainfall-flow modeling was chosen. It will be performed by the HEC-HMS software, which gives access to several modeling possibilities.

As for hydraulic modeling (flow-elevation), it will be performed by the HEC-RAS and ArcGIS software (via the HEC-GeoRAS extension).

In order to achieve these objectives, this study will be conducted according to 3 stages:

1. The preparation of the data:
2. Hydrological rainfall-flow modeling by HEC-HMS.
3. Hydraulic rate-elevation modeling by HEC-RAS / HEC-GeoRAS.

4.3.2 Presentation of the methodology

In this paragraph we will present in detail the 3 steps mentioned in the general presentation. Namely, data preparation, rainfall-flow modeling by HEC-HMS, and finally the rate-elevation modeling by HEC-RAS of floodwater levels.

4.3.2.1 Preparation of data

The data available to us can be classified into two categories: data from the global hydrological area (watershed) that will be used in step 2; and local data specific to the study area (the flood zone) that will be used in step 3.

1) The data of the global hydrological space

These data are the morphological data, the runoff coefficient, and the concentration time.

a) Morphological data of the hydrological space

As we explained below, the term hydrological space refers to the geographical space affecting the studied hydrological phenomenon, in our case, this space concerns the watershed that feeds the catchment.

The delineation of this watershed is the first step of this study. A watershed is defined relative to a point on a watercourse, such as all lands drained by the hydrographic network located upstream of that point. Thus, a drop of rain falling on this surface will eventually pass to the considered point of the river, unless it is evaporated or it infiltrates to too deep layers.

The definition of basin contours is an essentially topographic operation. For this study, it consists of defining, on a georeferenced topographic map, the ridge lines (water separation line) to delimit the surface that feeds the same outlet.

The delimitation of the basin will allow us to calculate several parameters:

- The basin surface (S).
- The average slope of the largest stream (P).
-The length of the longest stream (L).

The operations to be carried out consist firstly in the georeferencing of the maps, in the digitization of the contours, in the delimitation of the watershed and in the extraction of information useful for the study (Figure 4.4) .

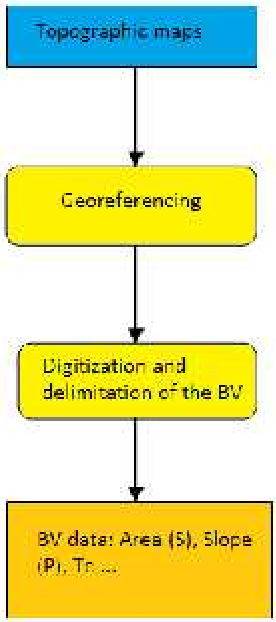


Figure (٤.4) Extraction of BV data.

Note: All these operations will be performed on ArcGIS 10.2, which is an essential tool for this type of work.

b) The runoff coefficient.

The runoff coefficient (Cr) is defined as the ratio of the amount of water flowing (ie, flowing) to the soil surface (Es) and the amount of rainfall (P).

$$C\ r = \frac{Es}{p} \quad (4.1)$$

The Cr coefficient depends mainly on the land use studied, the size of the watershed and its slope. Cr values are recoverable from special tables.

Table IV (APPENDIX) shows some values of the runoff coefficient for watersheds with an area less than 10 Hectares.

The calculation of the runoff coefficient for a given area at several land uses a formula weighted by the areas occupied by each land occupation.

c) Calculation of Concentration Time.

The concentration time makes it possible to know the hydrological reaction time of the watersheds. It can be calculated using the preceding characteristics. Physically, it corresponds to the time taken by the drop of water furthest from the outlet to reach this one. The estimation of this concentration time is obtained using several empirical formulas such as the formulas of Turraza, Ventura, Kirpich and Giondotti:

Turraza: $Tc=\frac{0.1^3\ \overline{(S.L)}}{\sqrt{p}}$(4.2)

Ventura: $Tc=0.1272*\frac{\sqrt{S}}{p}$(4.3)

Kirpich: $Tc=32.5x10^{-5}\,.\,(1000.L)^{0.77}\,.\,(\frac{D}{L.1000})^{-0.385}$(4.4)

Giondotti: Tc=(4x$S^{0.5}+1.5xL$ / (0.8x($(H_{max}-H_{min})^{0.5}$) (4.5)

Where :-

- Tc: Concentration time in hours.
- S: basin area.
- P: average slope of the largest thalweg.
- L: length of the longest thalweg.
- D: The maximum height difference.

2) Local data of the flood zone

Data from the flood zone mainly include data from the topographic survey per total station of the Shabat, and the satellite image of the area.

These two data will be used to extract the DTM from the flood zone, and to assign the Manning "n" coefficients to land use (Figure4.5).

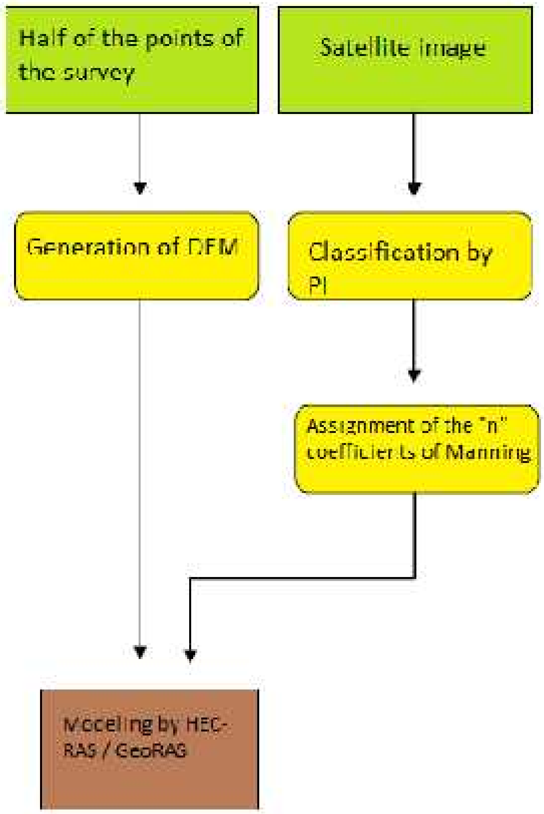


Figure (٤.5) Preparation of local data for the flood zone

- DEM extraction

The numerical model of the terrain is generated from (1m) counter map obtained from geomolg

The software used to generate the DTM is ArcGIS via the 3D tool Analys Tools -> Create TIN

- Assignment of Manning "n" coefficients

The classification of this area into different regions with different Manning "n" coefficients is obtained as a photo interpretation of a Google Earth TM image.

The Manning "n" coefficients (or roughness coefficients) represent the resistance to flood flow in floodplain canals and plains. It is determined by formulas special mathematics and listed in tables. Table V (APPENDIX) presents the Manning "n" coefficients in natural watercourses. In this part of our study, we have prepared all the data we need for the rest of the study.

In what follows, we will use these data for hydrological rainfall-flow modeling, and hydraulic modeling of water levels (step 2 and 3).

4.3.2.2 The hydrological rain-flow modeling by HEC-HMS

The HEC-HMS software is designed to be applicable in a wide range of geographical areas and to solve as many problems as possible. The following table represents the main features of this software:

Categories	HEC-HMS
Deterministic or Stochastic?	Deterministic.
Empirical or Physical?	Both.
Global or distributed?	Global.

The HEC-HMS software offers a multitude of possibilities for rain-flow modeling. These differ according to the sub-models chosen for the production function, the transfer function and the basic flow. These sub-models are listed in Table VII (ANNEX).

In what follows, we will present the sub-models adopted for this study.

- **The basal rate sub-model**

Base flow is the component of the flow that returns to the stream from underground storage. His knowledge is important to model the recession of the hydrograph after the peak flow, as well as to estimate the volume of the flood.

The HEC-HMS software has three submodels for the base flow: constant monthly, linear reservoir and recession:

The monthly constant submodel is a very simple approach that is not suited to the semi-arid context where large variations in basin saturation conditions can be observed in a single month.

The linear reservoir method can be used only with a continuous SMA loss sub-model.

The recession method is an approach that uses a sub-model of exponential base rate recession. This commonly used approach is used in this study, it is suitable for basins where the volume of floods is strongly influenced by rain events (USACE., 2010).

In the exponential recession model, the base flow Bt:

$B_{t=B_iR_c^t}$ (4.6)

Where:-

- Bi is the initial base flow at time t0 [m3 / s].
- Rc the exponential decay constant [0,1].

The constancy of exponential decay is determined by several experimental and statistical methods such as the analysis of ancient flood hydrographs.

For our study, we will take the value Rc = 0.8 .

- **The model of the production function**

In the HEC-HMS model, the pond area can be divided into impervious zones and permeable zones. In impervious areas, water flows without interception, evaporation, perspiration or infiltration. In permeable areas, flow is subject to losses (USACE, 2010).

The HEC-HMS software has different methods (submodels) for the production function: initial and constant loss sub-model, initial and constant deficit sub-model, sub-model Green and Ampt model, SCS sub-model and the continuous Soil Moisture Sub-model (SMA).

As part of this study, the SCS Loss Sub-model (USDA-SCS, 1985) was selected. Indeed, many studies have successfully used this sub-model in the semiarid Mediterranean context (Brocca et al., 2009, Tramblay et al., 2010).

In addition, this submodel is applicable on watersheds ranging from 0.25 ha to 100 km². It is adapted to account for the initial moisture conditions of watersheds at the event scale.

The CN (or S) parameter can indeed be linked to different soil moisture indicators, measured in the field, from models or satellite data.

In the SCS sub-model, excess precipitation (net rainfall) is estimated as a function of accumulated precipitation over the episode:

$$p_e = \frac{(p-Ia)^2}{p-Is+s} \quad (4.7)$$

Where:-

- Pe: refers to excess precipitation.
- P: total precipitation.
- Ia: initial losses.
- S: the maximum retention potential.

The initial losses (Ia) are given by the relation:

$$I_a=0.2S \quad (4.8)$$

The retention potential S is connected to the Curve Number (CN), which can itself be estimated by tables describing the different soil types and / or by calibration with observed data:

$$S=(25400-254xCN)/CN \quad (4.9)$$

- **The model of the transfer function:**

Once excess precipitation (net rainfall) is known, it is converted to direct runoff. The HEC-HMS platform has several transfer functions: Clark, Snyder and SCS unit hydrographs, user defined hydrographs, Modclark transformation and kinematic wave.

Among these methods, Clark's unit hydrograph is frequently used for event modeling. This method is particularly effective for reproducing complex hydrographs, in basins with a varied topography and land use.

The unit hydrograph method of Clark represents two processes: translation and attenuation.

The translation is based on a synthetic time-surface histogram with a concentration time Tc. The histogram represents the area of the pond that contributes to the flow at the outlet as a function of time.

Attenuation is modeled by a linear reservoir. The reservoir represents the basin-wide stock noted as St.

The average outflow of the tank during a period t is given by:

$$O_t=C_A I_t+C_B O_{(t-1)} \quad (4.10)$$

Where:

- It: the flow entering the reservoir at time t.
- CA, CB, coefficients calculated by the relation (Δt is the computation time step):

$C_A=\Delta t/(S_t+0.5\Delta t)$ (4.11)

$C_B=1-C_A$ (4.12)

The parameters required by the Clark method are: Concentration time, Tc [hours], St storage coefficient [hours]. These two parameters can be estimated by calibration when rain and flow records are available.

4.3.2.3 Hydraulic modeling by HEC-RAS / HEC-GeoRAS

The study we are conducting is largely hydrological. However, the flow-elevation modeling part is completely hydraulic.

As mentioned above, HEC-RAS is a software program that models the hydraulics of water flow in natural and artificial streams. This software is based on a very complicated mathematical arsenal.

In this paragraph we will highlight the main formulas and some principles used by HEC-RAS and its extension on ArcGIS, HEC-GeoRAS, to model the hydraulic flow.

HEC-RAS allows the representation of two regimes: the permanent regime and the non-permanent regime.

The steady state describes the conditions in which the depth and speed of water in a given location do not change over time, unlike the non-steady state where the depth and speed of water are variable.

In our study, we will use the steady state for the peak flow, and then we will explain the principles of hydraulic calculation used by HEC-RAS in this regime.Indeed, to model the hydraulics in a given point of the studied channel (water height) HEC-RAS is based on an iterative solution of the following energy equation:

$H=Z+Y+\frac{\alpha V^2}{2g}$ (4.13)

Where:

- H: total energy in any rental along the studied canal.
- Z + Y: the potential energy.

The parameters of this energy equation are illustrated in Figure (4.6).

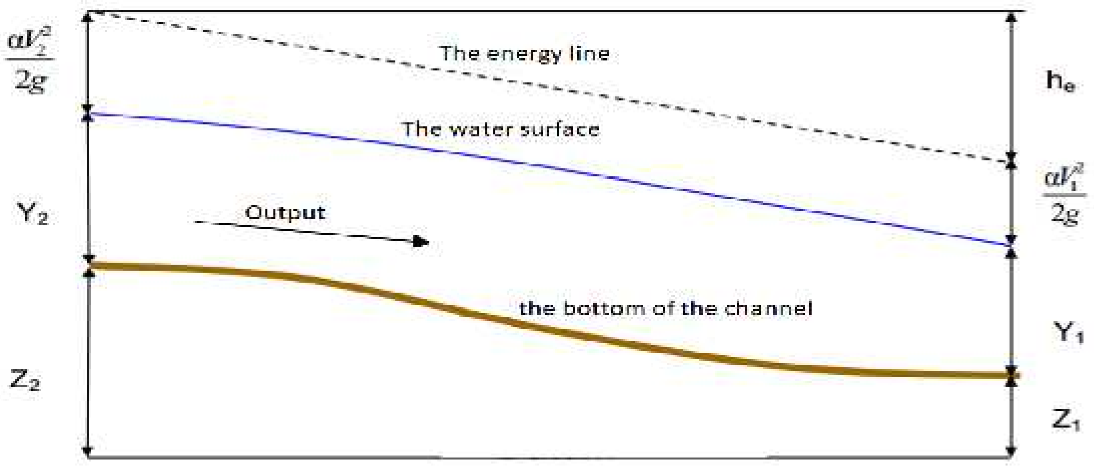


Figure (٤.6) The energy equation for a flow between two sections

In order to graphically determine the sections of the channel we will use HEC-GeoRAS which allows the preparation of geometric data for import into HEC-RAS.

In this part we have presented the methodology and physical basis of the current study, which focuses on three stages:

- The preparation of the data that will be used later in the work.
- Hydrological rain-flow modeling.
- Hydraulic modeling of water elevation.

In the next chapter, we will implement these three steps, present the results and perform an analysis of these results.

The primary data will include field observation in order to draw up cross sections in selected points among the stream down ward and estimate discharge during general surface flow and the discharge at that point during the flood processing. We will measure and calculate the bankfull area and floodplain area per event by determination of the wetted area and radius of the channel, beside to determine the water velocity among the channel. The amount of runoff and the discharge of streamflow are related to the rainfall distribution, the rainfall rate and the duration of high rainfall rates in the drainage basin (NRC, 2005).

Chapter Five

APPLICATION, RESULTS AND ANALYSIS

5.1 Application and results

٥.٢Results analysis

5.1Application and results

After the definition of the methodology to follow in chapter 4, we go in this chapter

present the application of this methodology.

As we have already explained, our work will follow three steps:

1) The preparation of work data.
2) Hydrological rainfall-flow modeling using HEC-HMS software.
3) Flow-elevation hydraulic modeling by HEC-RAS software and its extension on ArcGIS (HEC-GeoRAS).

Subsequently, we will present the application made for each of these steps

5.1.1 Data preparation

We have classified the data at our disposal according to two categories:Global Hydrological Space (to be used in Step 2) and local dataspecific to the study area (to be used in step 3).

1) The data of the global hydrological space

As a reminder, the data of the global hydrological space, for our case, are the data

Morphological, the Cr runoff coefficient and the Tc concentration time.

- Digitization of contour lines

The digitization of contour lines will allow us to produce the digital model offield of the zone. This step will be useful to delimit the lines of ridges more

Figure (5.1) countor map for daraga and ghar

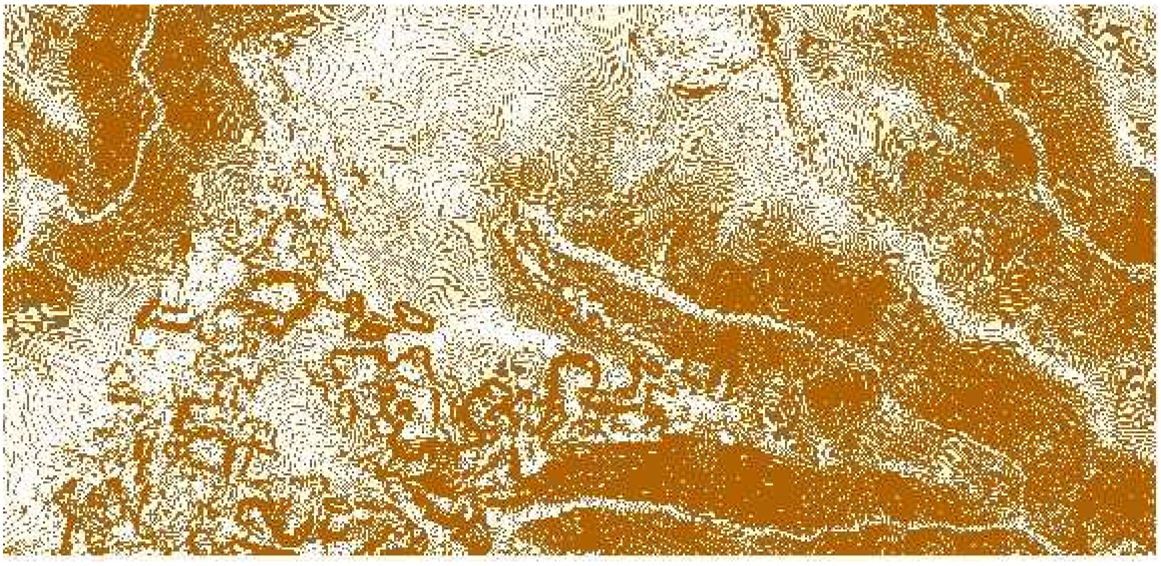


Figure (5.2) countor zoom in ghar

- The coefficients Cr, CN and Tc

For this study, the runoff coefficient and concentration timeis shown in the following table :

Table (5.1)Cr and TC for daraga catchment

subbasin	TC(HR)	Cr
1	0.998667	0.87881
2	0.391983	0.280121
3	0.388163	0.28277
4	0.266133	0.203529
5	0.11496	0.078896
6	0.160967	0.111127
7	0.519833	0.402446
8	0.050983	0.035683
9	0.447648	0.354809
10	0.814667	0.640929
11	2.3795	4.197681
12	0.568565	0.434232
13	1.001262	0.844534

Table (5.2)Cr and TC for Ghar catchment

subbasin	TC	Cr
1	0.38	0.262239
2	0.62	0.433512
3	0.38	0.264841
4	1.25	0.965701
5	0.47	0.33343
6	0.94	0.746745
7	0.5	0.35976
8	2.06	1.866472
9	1.34	1.202533
10	0.57	0.433928
11	2.27	3.484745
12	0.22	0.160406
13	0.8	0.656816
14	2.12	2.218093
15	1.33	1.28613

The calculation of the concentration time is done by the Kirpich formula. This formula proved its robustness for wooded and cultivated land.

The area contains a soil and poorly maintained, so we took for Daraga and Ghar:

CN = 67

2) Local data of the flood zone

As we explained in the methodology section, the targeted data of the area inundable are the DTM of the area and the "n" coefficients of Manning.

- DEM extraction

The digital terrain model is generated from the countor map.
The software used to generate the DTM is ArcGIS from the Create TIN tool in the 3D Analyst Tools feature.

Figure 3and 4 shows the generated DEM for Daraga and Gharcatchment .

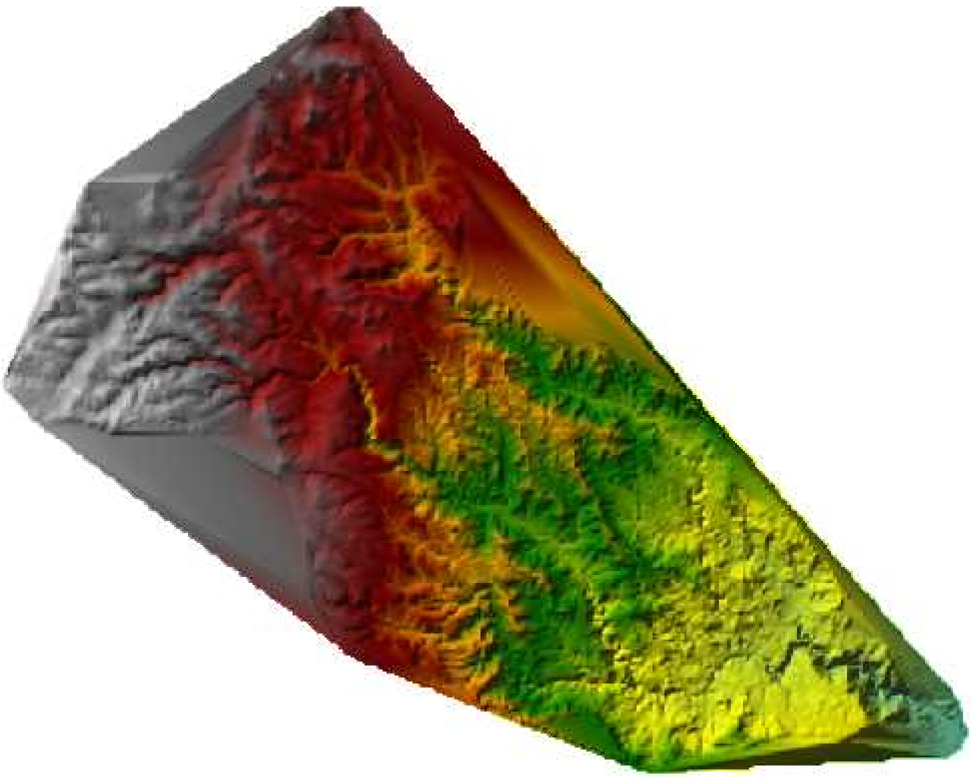


Figure (5.3) DEM of the ArcGIS Generated Area for daraga catchment

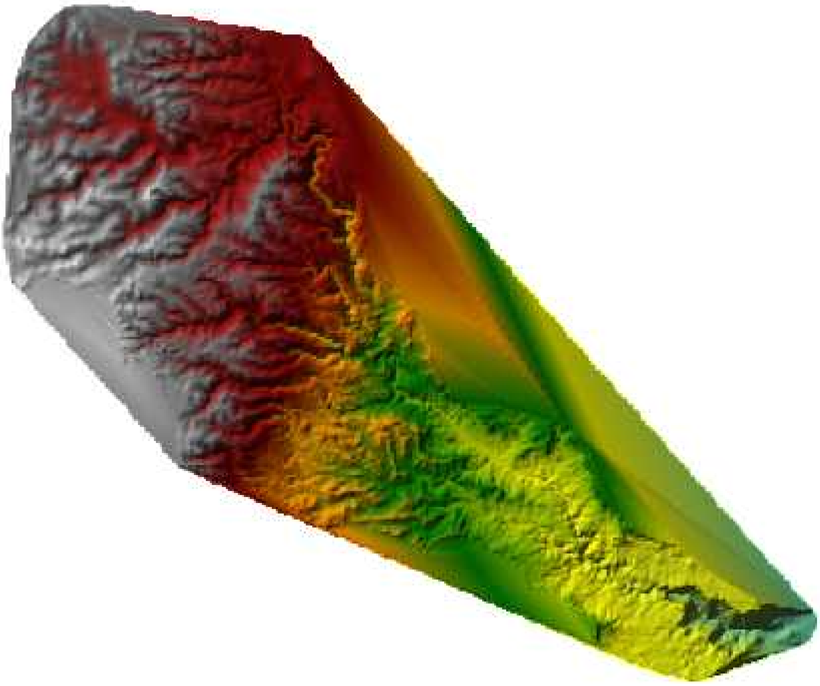


Figure (5.4) DEM of the ArcGIS Generated Area for daraga catchment

5.1.2 Application of the hydrological rain-flow model by HEC-HMS

The HEC-HMS platform allows rain-flow modeling through four stages:

- The first step is to specify watershed parameters and sub-models of the flood formation process (sub-model of the watershed function).

  production, submodel of the transfer function, and the flow sub-model ofbasis) which will be used later in the calculations.

- The second step is to set the meteorological stations of the zone and, mainly, to determine the input weight of each station on the data rainwater input.
- The third step is the input stage of the precipitation data and their parameters (unit, interval between data, etc.).
- The fourth step is the final step before simulating the training process of raw, it consists in determining the control parameters of the simulation (date ofstart, end date, time interval, ...)

But before explaining the work done on each step, let's wait a little bit on

sensitivity analysis, calibration and validation of our model.

5.1.2.1 Sensitivity analysis, calibration and validation

The HEC-HMS software, through the selected sub-models (The recession method, the SCS loss model and Clark's unit hydrograph), involves severalsettings. A sensitivity analysis is essential for the robustness of the model because it defines the most sensitive parameters of the model whose uncertainty significantly affects the results at the exit.

These coefficients will therefore be the subject of particular attention, the determination of theirvalues by calibration will give more accurate results.

Subsequent studies, which used the same sub-models as those in our study, showed that the most influential parameter is the Curve Number (CN) This coefficient depends directly on the permeability, the land use and the conditions of its humidity and its precise determination requires a calibration.

Unfortunately, the area of this study has no record archive or flow measurement data, the calibration of the CN coefficient and the validation of the modelso are not possible at the moment.

5.1.2.2 The modeling of the flood formation process

This step is the first step of the rainfall flow modeling in the HECHMS platform, it has two objectives:

- The entry of watershed parameters.
- The input of the parameters of the rain-flow modeling (the sub-models).

1) **Watershed parameters**

To determine watershed parameters, the HEC-HMS platform allows us to contain all the elements of this basin (sub-basins, rivers, ..) that participate infeeding of the studied area.

For our study, a simplified scheme has been established that represents the watershed that collects rainwater to the flood zone (Figure 5.5/6).

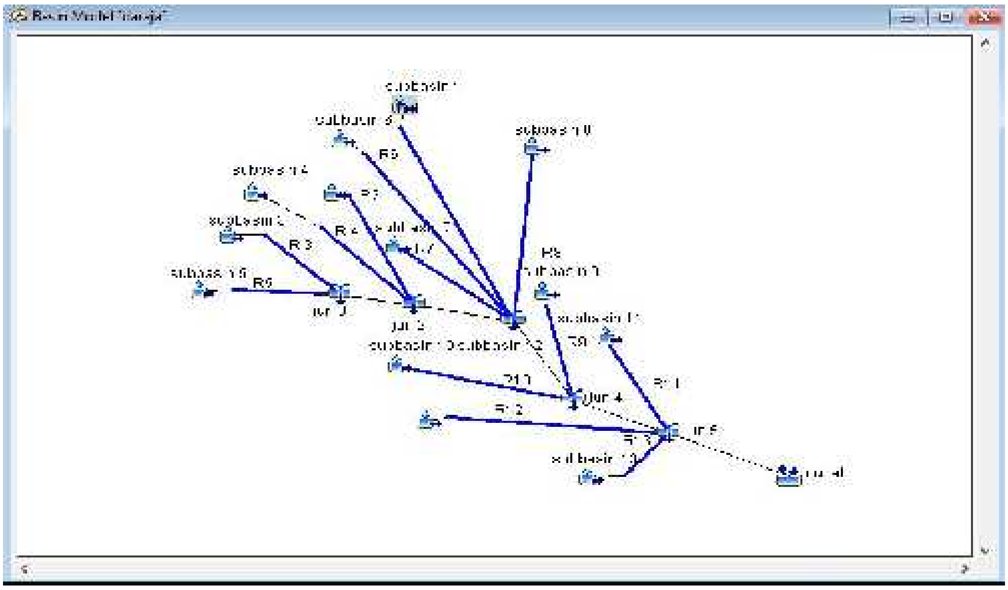


Figure (5.5) Diagram showing the watershed and the flood zone for Daraga catchment

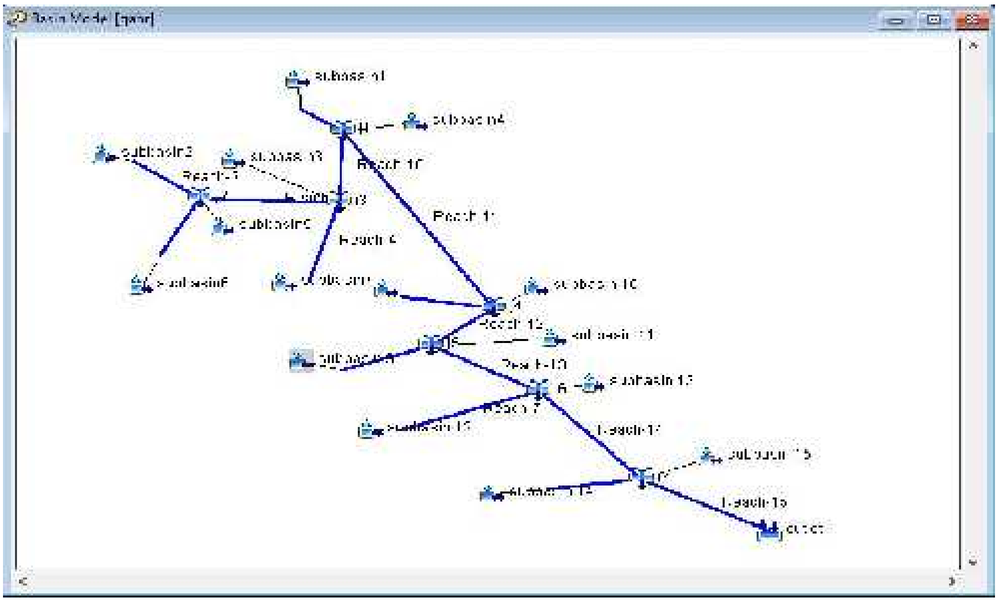


Figure (5.6) Diagram showing the watershed and the flood zone for Ghar catchment

2) **Parameter of the rain-flow modeling**

In this step, we will introduce the sub-models chosen in the previous chapter, as well as their parameters and the surface of the B.V. (Figure 5.7)

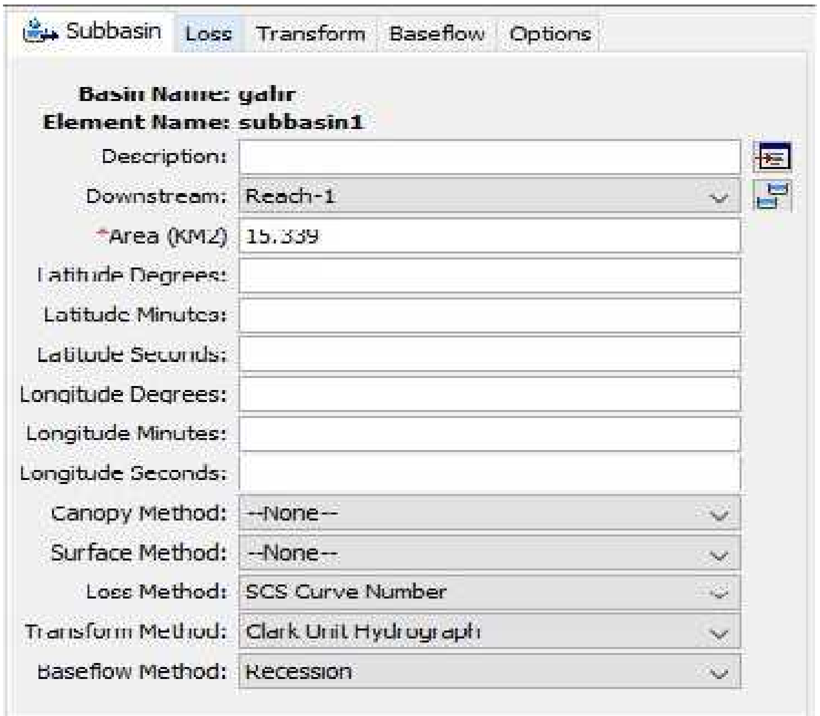


Figure (5.7) Entering Basin Data(subbasin 1 in ghar) and Models to Use We will present the parameters introduced for each submodel selected for this study

- The basal rate sub-model

The recession base flow sub-model introduces three parameters.

The initial flow (taken equal to 0), Rc the exponential decay constant ([0,1]) taken equal to 0.8 and the ratio equal to 0.1 (Figure 5.8)

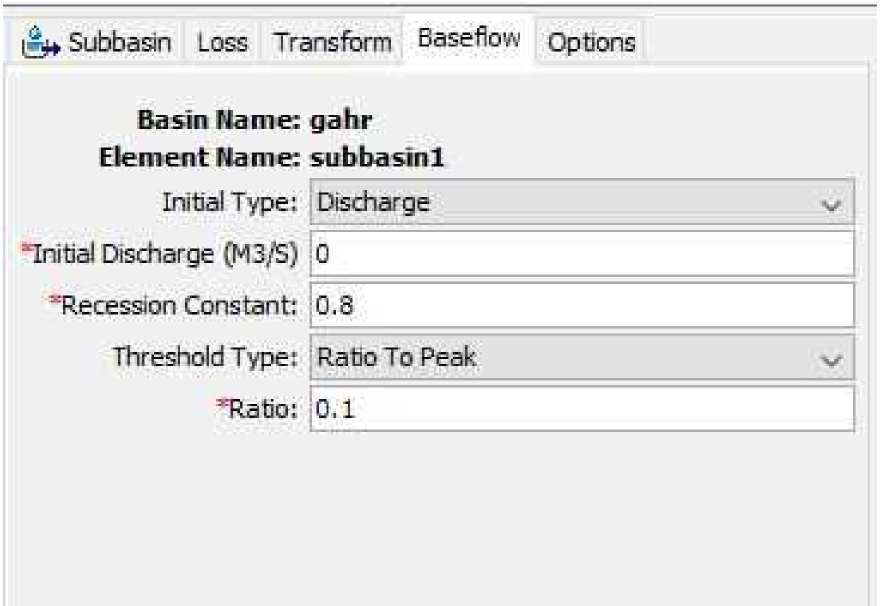


Figure (5.8) The basal rate subbasin.

- The sub-model of the production function

The sub model of the selected production function is SCS Curve Number, this one ownsthe CN coefficient and impervious as the main parameter (Figure 5.9)

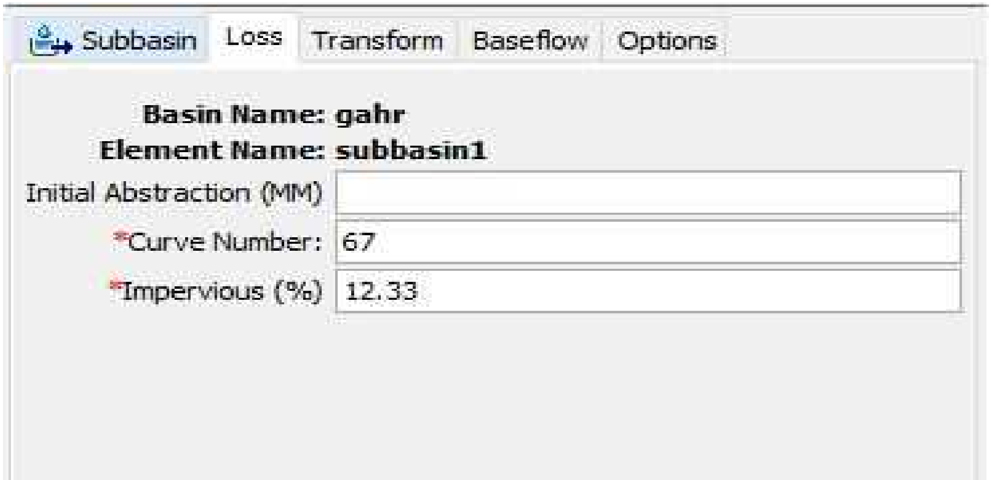


Figure (5.9) The submodel loss.

Table (5.3)impervious data for Ghar catchment

subbasin	area	building	impervious
1	14264617	4745811	33.2698105
2	19456291	8047534	41.3621185
3	1897481	23674	1.24765413
4	18631231	666479	3.57721404
5	7932576.9	1520581	19.1688152
6	9576879.1	2098705	21.9142894
7	24031405	7528383	31.3272698
8	12685847	428477	3.37759863
9	21730064	1896500	8.72753993
10	565368.33	0	0
11	4112005.3	0	0
12	11714936	967641	8.25989152
13	20744292	0	0
14	41428191	967641	2.33570661
15	25407993	0	0
total	234179177	28891426	12.3373164

Table (5.4)impervious data for Daraga catchment

Subbasin	area	building	impervious
1	29129763.12	3706331.935	12.72352239
2	6313924.786	1630655.487	25.8263369
3	8105902.299	2738054.6	33.77852951
4	782150.9492	146150.0228	18.68565434
5	15843162.73	1717578.15	10.84113178
6	3110996.768	525679.9743	16.89747735
7	2506931.544	385282.8272	15.36870156
9	1276036.673	163261.8795	12.79445042
10	30893811.59	3666048.909	11.8666125
11	55006400.69	385399.1844	0.700644251
12	71515897.52	817563.0557	1.143190653
13	11266843.6	63320.42098	0.562006745
Total	235751822.3	15945326.45	13.43235487

- **The model of the transfer function:**

As we explained in the methodology chapter, we opted for Clark's unit hydrograph sub-model. This submodel requires two parameters: Tc the concentration time and St the storage coefficient. Figure ١0 shows the valueschosen for these two parameters.

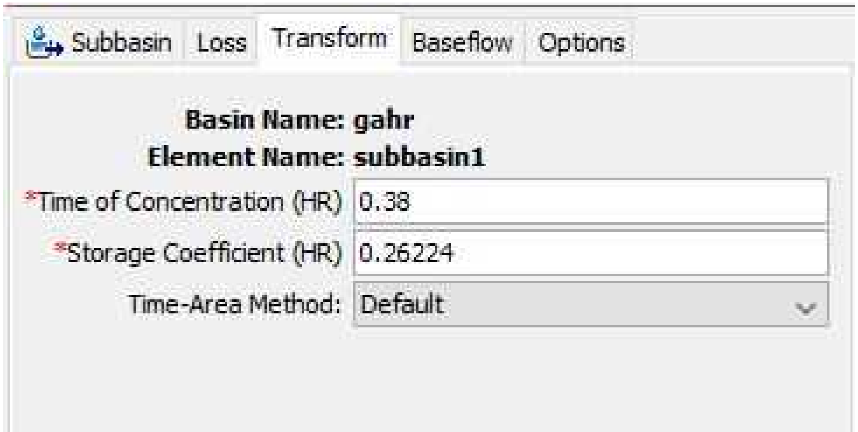


Figure (5.10) The submodel of the production function

5.1.2.3 The model of weather stations

This stage of the work aims at parameterizing the meteorological stations of the study area and atdefine their weights according to their contribution in the model.

In our case, we model the existence of a single meteorological station who serain data are identical to those of the studied hydrological space.

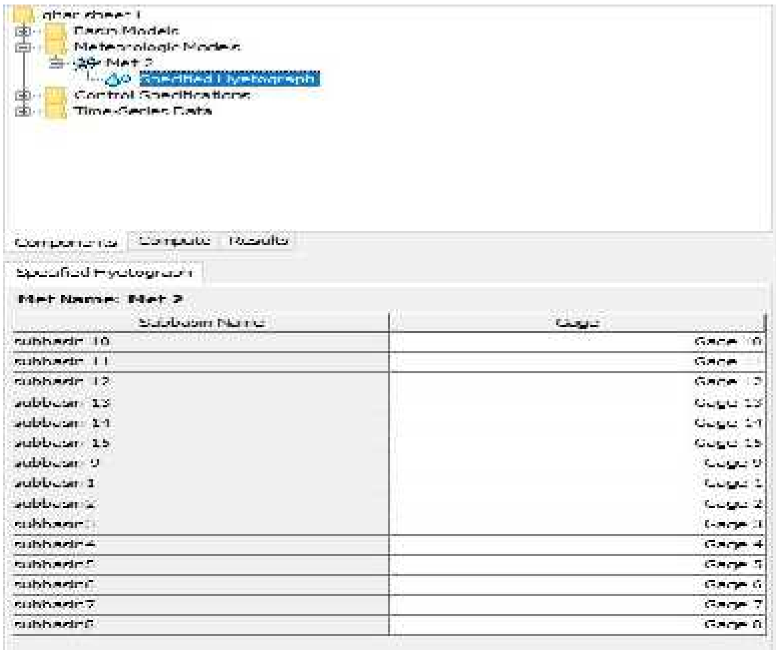


Figure (5.11) Parameterization of the weather station

5.1.2.4 Rainfall forecast data

In this step, we have introduced the precipitation parameters, the dates, theacquisition intervals, the unit used and the input mode of these data (manual orautomatic) (Figure 5.١2).

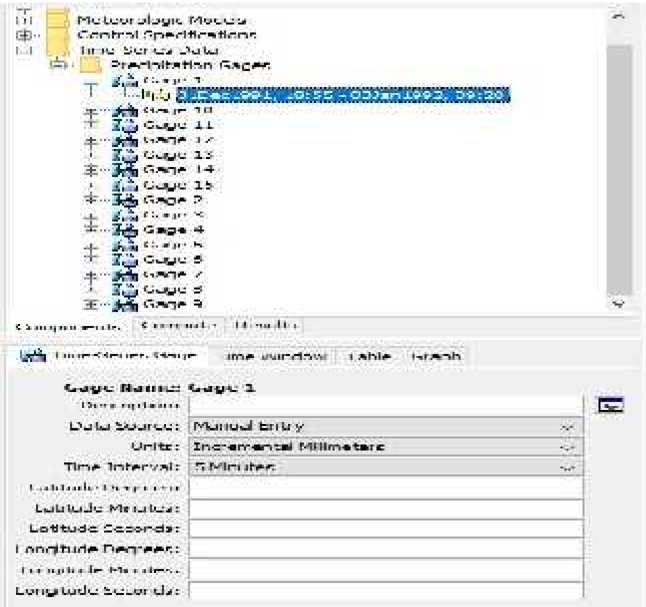


Figure (5.12) Setting the precipitation and intervals data

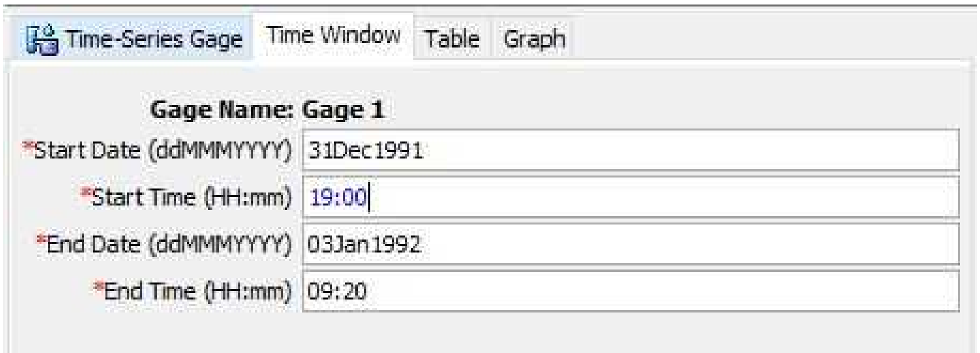
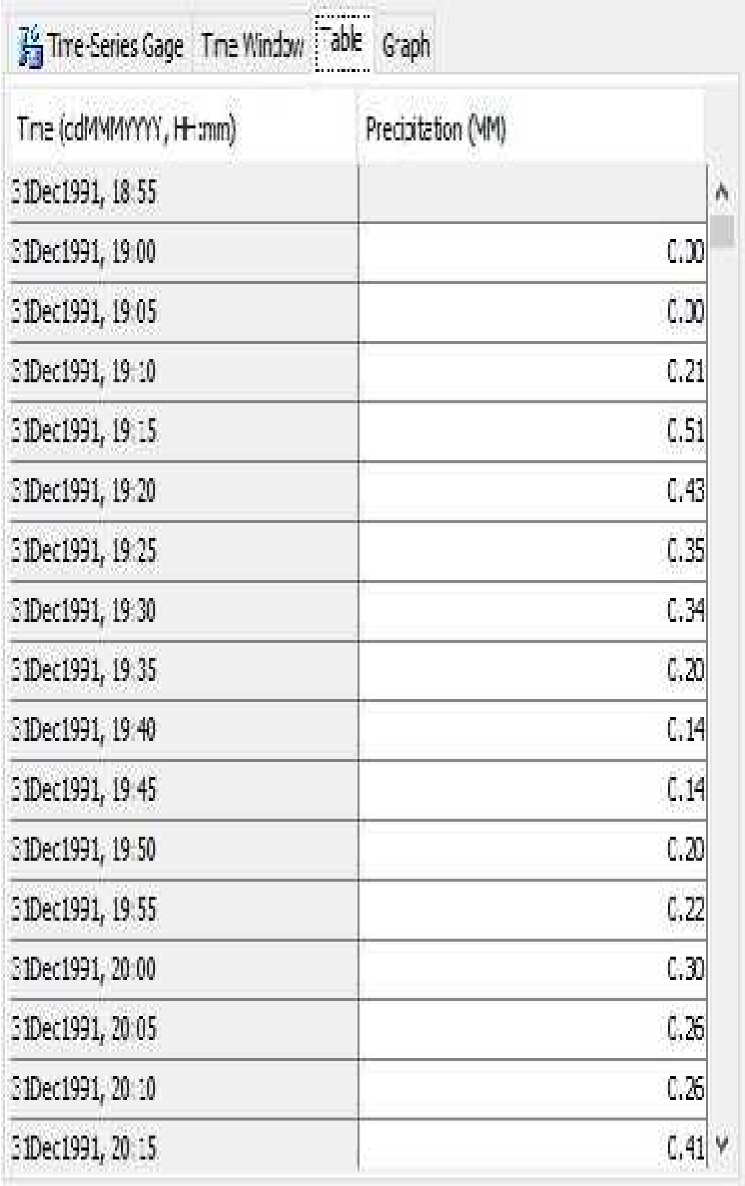


Figure (5.13) Setting the time data for sheet

After setting the rainfall data, we insert the rainfall data for 5 minute interval . These data come from radar.



Time (ddMMMYYYY, HH:mm)	Precipitation (MM)
31Dec1991, 18:55	
31Dec1991, 19:00	0.00
31Dec1991, 19:05	0.00
31Dec1991, 19:10	0.21
31Dec1991, 19:15	0.51
31Dec1991, 19:20	0.43
31Dec1991, 19:25	0.35
31Dec1991, 19:30	0.34
31Dec1991, 19:35	0.20
31Dec1991, 19:40	0.14
31Dec1991, 19:45	0.14
31Dec1991, 19:50	0.20
31Dec1991, 19:55	0.22
31Dec1991, 20:00	0.30
31Dec1991, 20:05	0.26
31Dec1991, 20:10	0.26
31Dec1991, 20:15	0.41

Figure (5.14) Input of rainfall data

5.1.2.5The control data of the simulation

The last step before starting the simulation is to determine the parameters of the simulation control (start date, end date, time interval, ...) (Figure 5.15)

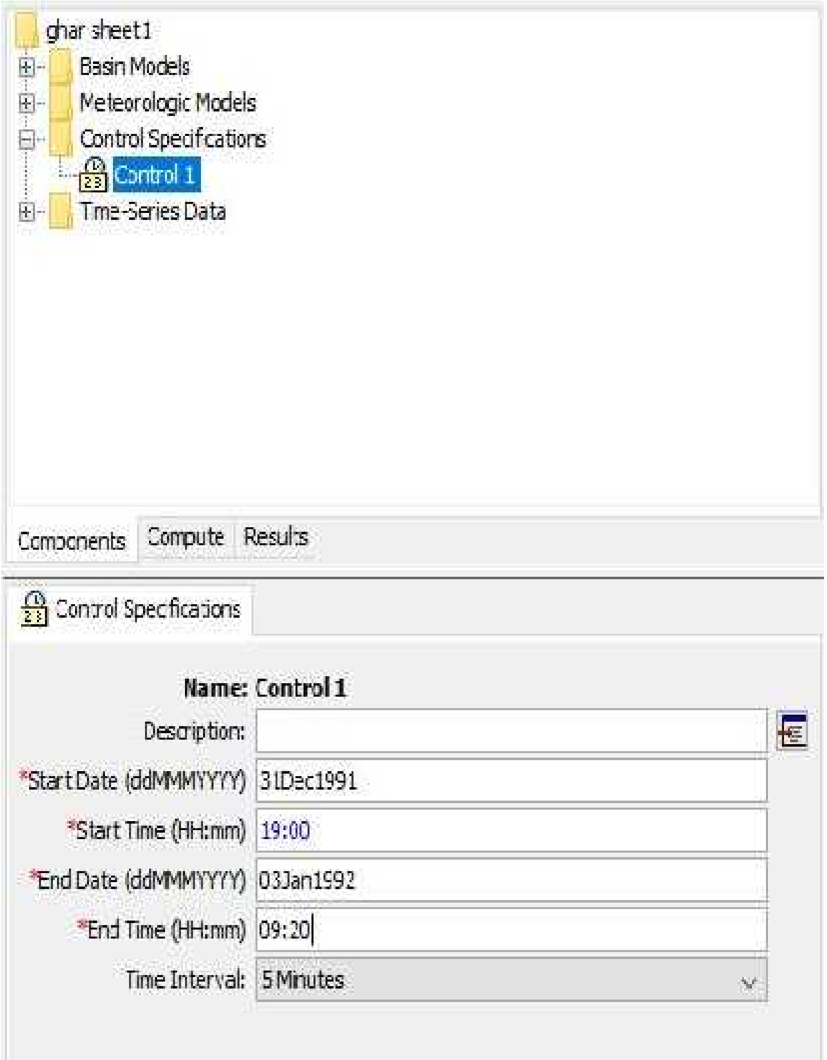


Figure (5.15) Entering simulation time parameters

After determining all the necessary parameters for the rain-flow modeling, we started the simulation. Figure (5.16) shows the results obtained.

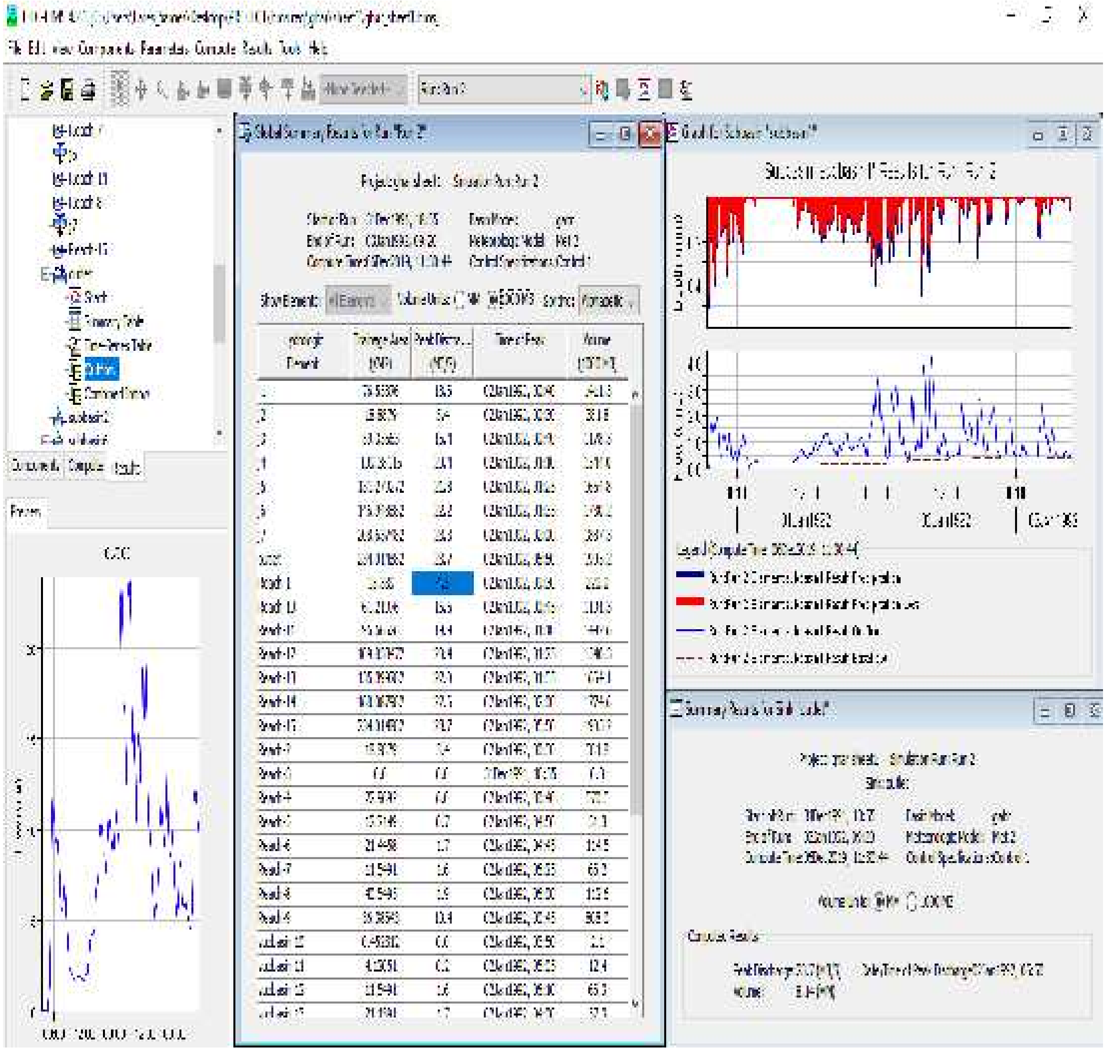


Figure (5.16) The results of the hydrological simulation

5.1.2.6 Results and Analysis

The rainfall and runoff data recorded in Al-Draga and Ghar catchment have been used to calibrate and validate the developed model. Figures (17)and (18) illustrate a comparison between the observed and simulated flows at the out let for both Ghar and Al-Daraga sub-catchments for the events of 31Dec1991 to 03Jan1992 (for Ghar) and 05Nov1994 to 06Nov1994 (for Al-Daraga), respectively.

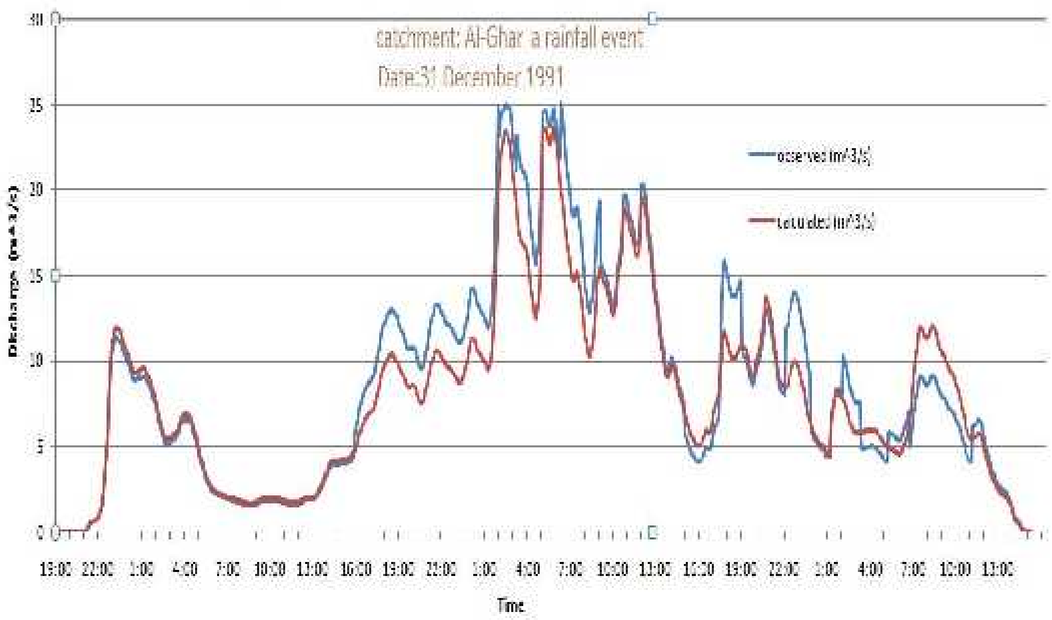


Figure (5.17) Observed and calculated flows for Ghar catchment

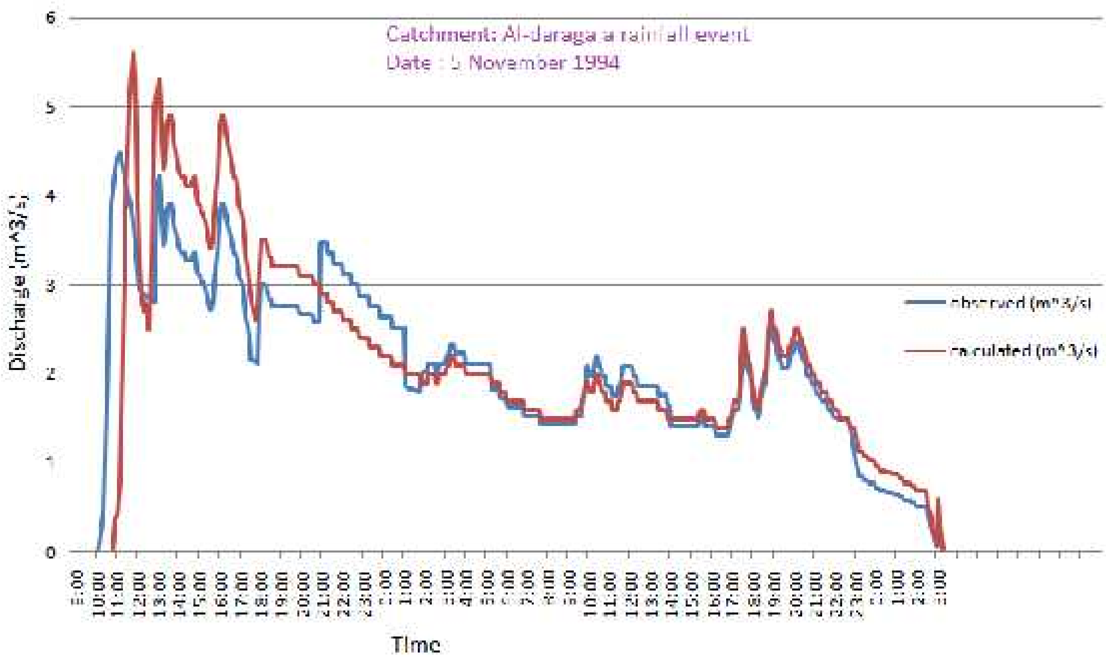


Figure (5.18) Observed and calculated flows for Al-Daraga catchment

R^2 and Nash-Sutcliffe coefficients where used to judge the calibration/validation the model for both catchment (Daraga and Ghar). Its obvious from fig.(5.17-5.18) that the simulated is mostly fitted the observed data for Daraga sub catchment , the obtained R^2 =0.888 and Nash-Sutcliffe=0.811 as shown in the fig.(5.19)

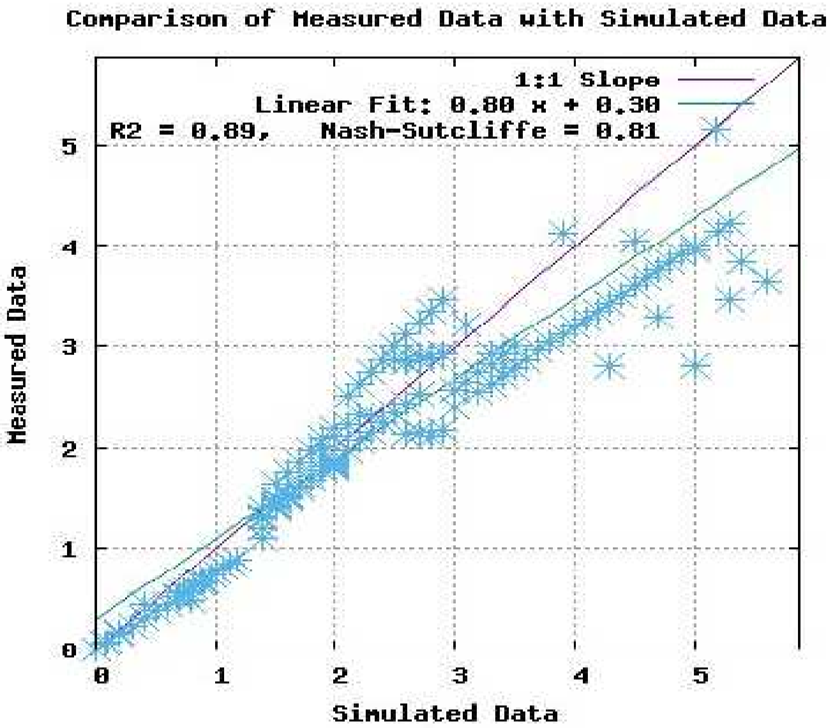


Figure (5.19) correlation between simulation result Vs observed data for Daraga catchment

while R^2 =0.94 and Nash-Sutcliffe=0.918 for Ghar sub catchment as shown in the fig.(5.20)

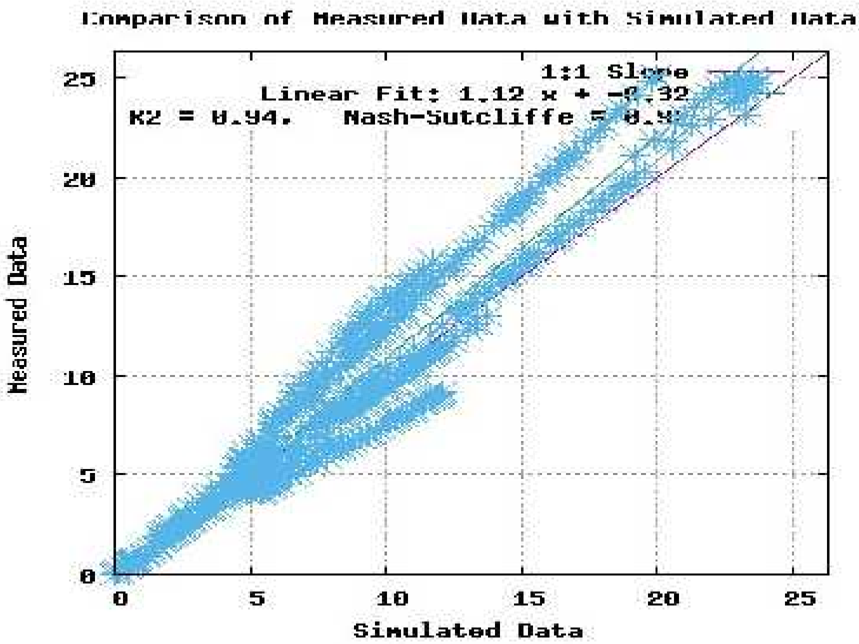


Figure (5.20) correlation between simulation result Vs observed data for Ghar catchment

5.1.3 Application of the hydraulic lift-elevation model by HEC-RAS and HEC-GeoRAS

The main role of HEC-RAS in the case of our study is to model the hydraulics ofthe flow of water in the watercourse of the studied Al-Daraga and Ghar.

HEC-GeoRAS represents the set of procedures, tools and utilities for processing geospatial data in ArcGIS using a graphical user interface.

The interface allows the preparation of geometric data for import into HEC-RAS and the representation of the simulation results of the exported HEC-RAS processes.

Flow-elevation hydraulic modeling will be done in three steps:

1. The first step is to prepare geospatial data on ArcGIS from the extension HEC-GeoRAS (DEM, center and edges of the Al-Daraga and Ghar, coefficients "n" ofManning, perpendicular sections, etc.). This step will finish by exporting the results to HEC-RAS.
2. The second step will allow us to enter the flow data and the parameters of flow-elevation simulation on HEC-RAS. The final result will be re-exported to ArcGIS.
3. The third step is the final step. It consists of determining the flood zone on ArcGIS which is the goal of this study.

5.1.3.1 Preparation of geospatial data with HEC-GeoRAS

The work on HEC-GeoRAS consists in defining the DTM of the zone, the center and the banks of the

Al-Daraga and Ghar, the Manning "n" coefficients corresponding to each region, and the sectionsperpendicular to the Al-Daraga and Ghar which must traverse the entire flood zone.

Figure (21/22/23/24) represents the result obtained after completing all of these steps

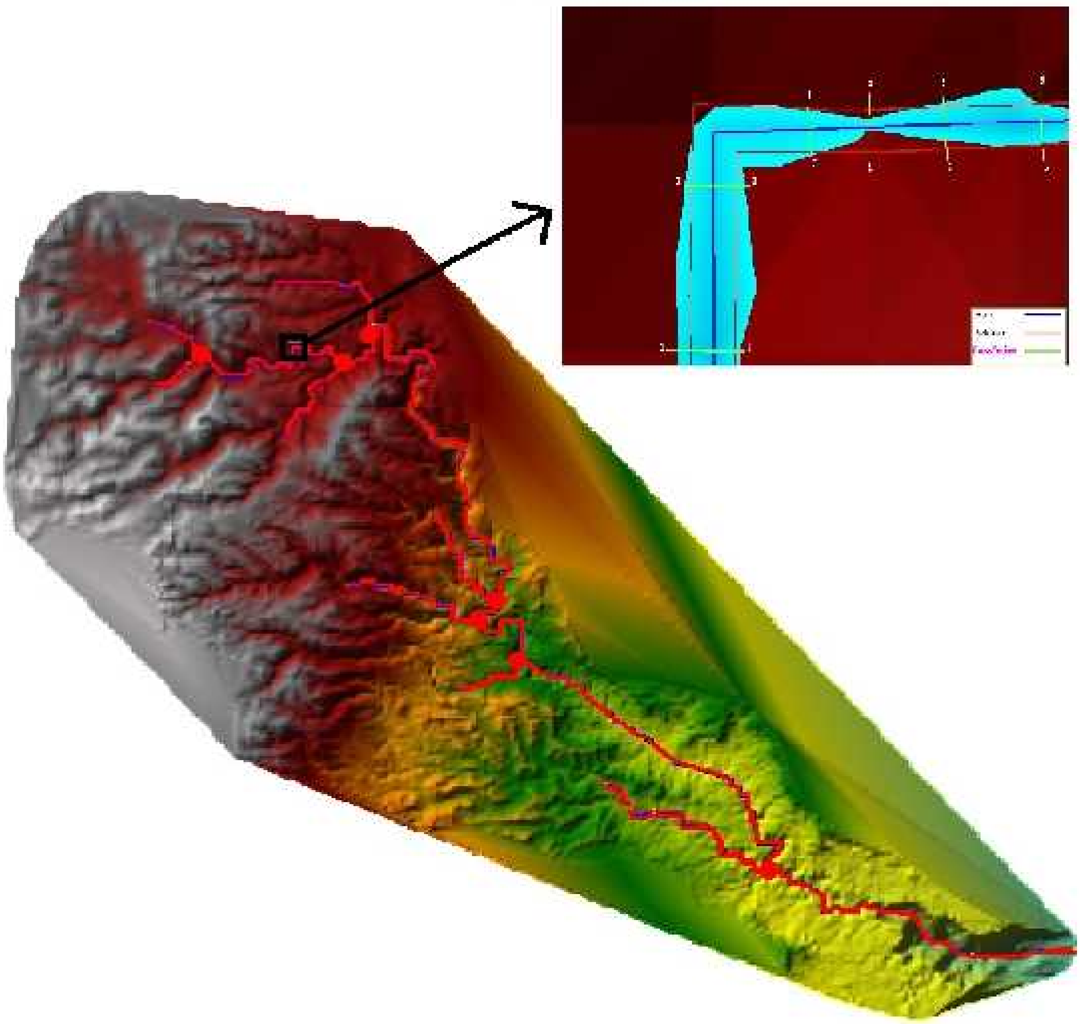


Figure (5.21) Determining the elements of the Ghar in ArcGIS by HEC-GeoRAS

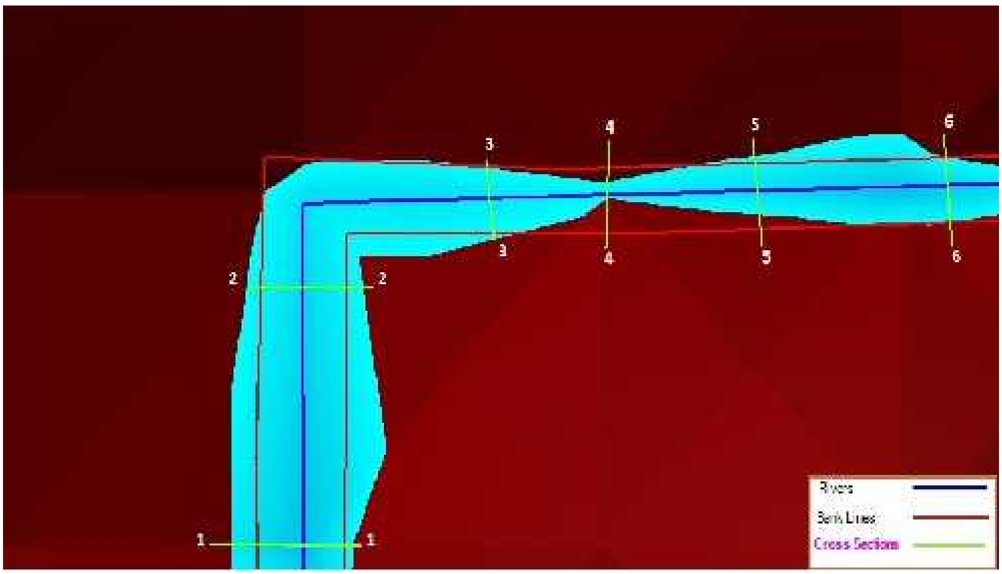


Figure (5.22) zone for Determining the elements of the Ghar in ArcGIS by HEC-GeoRAS

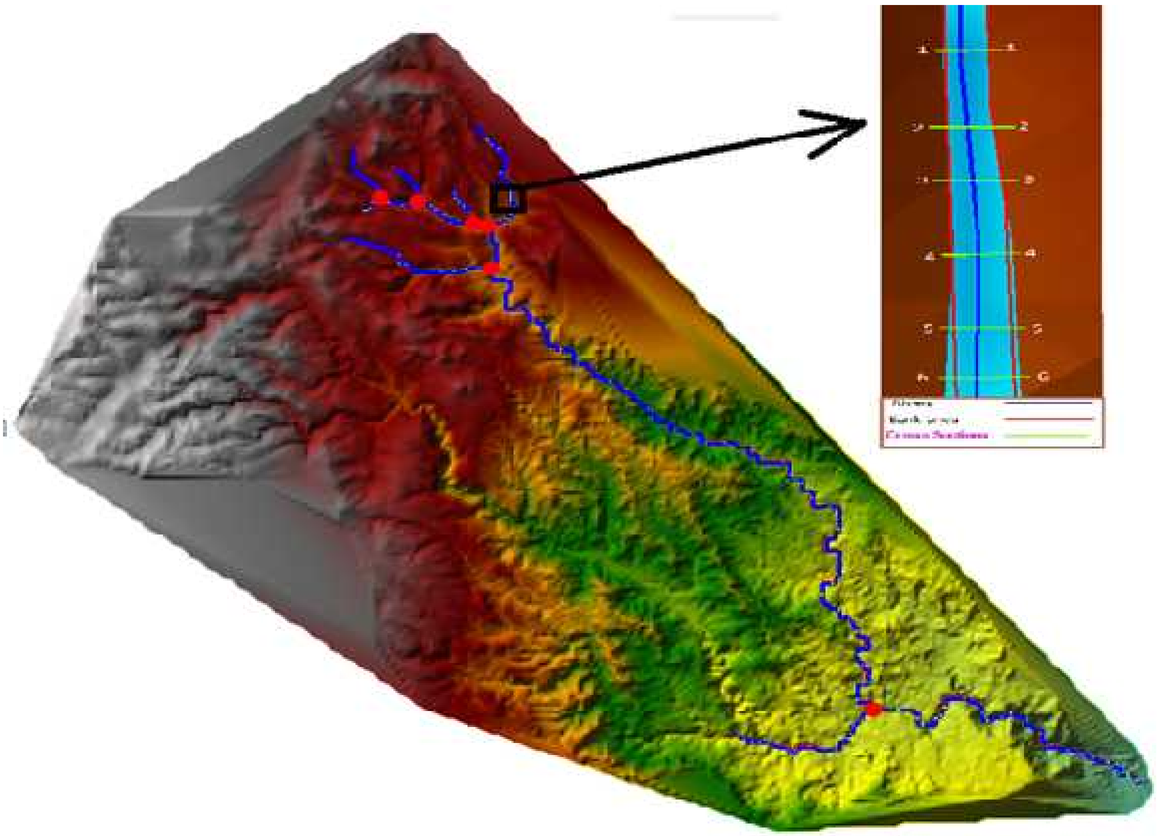


Figure (5.23) Determining the elements of the Al-Daraga in ArcGIS by HEC-GeoRAS

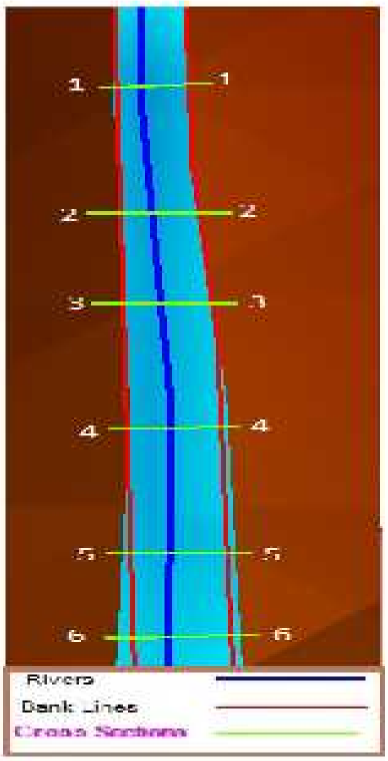


Figure (5.24) zone for Determining the elements of the Al-Daraga in ArcGIS by HEC-GeoRAS

5.1.3.2 Data processing and flow introduction by HEC-RAS

After determining the geospatial elements of the Al-Daraga and Ghar on ArcGIS, we export theresulting file to HEC-RAS.Figure (25/26) shows the file obtained after export.

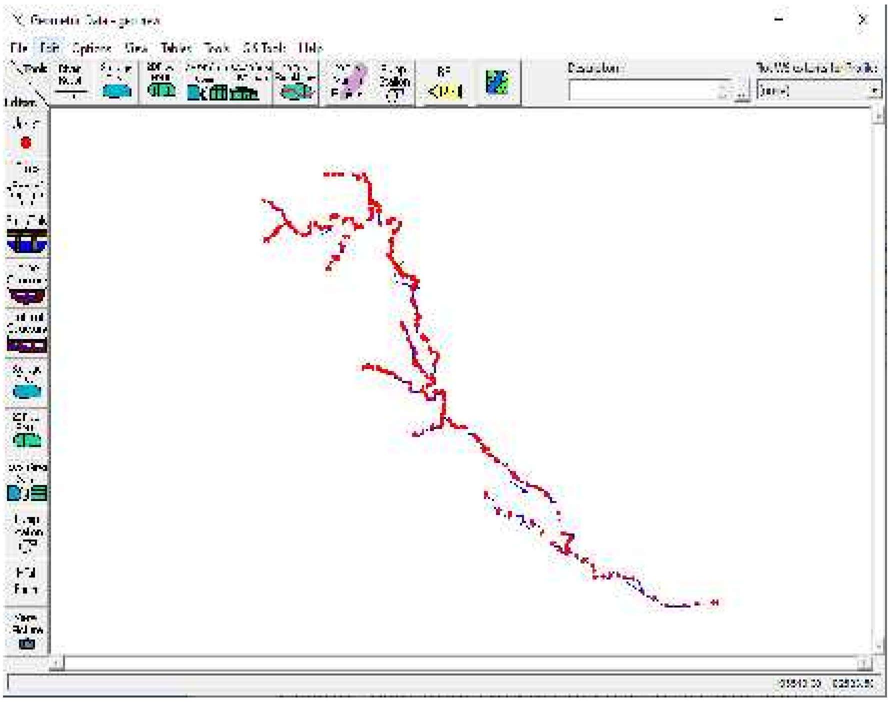


Figure (5.25) File exported to HEC-RAS. Loading data from ArcGIS to HEC-RAS for Ghar catchment will allow us to edit this data.

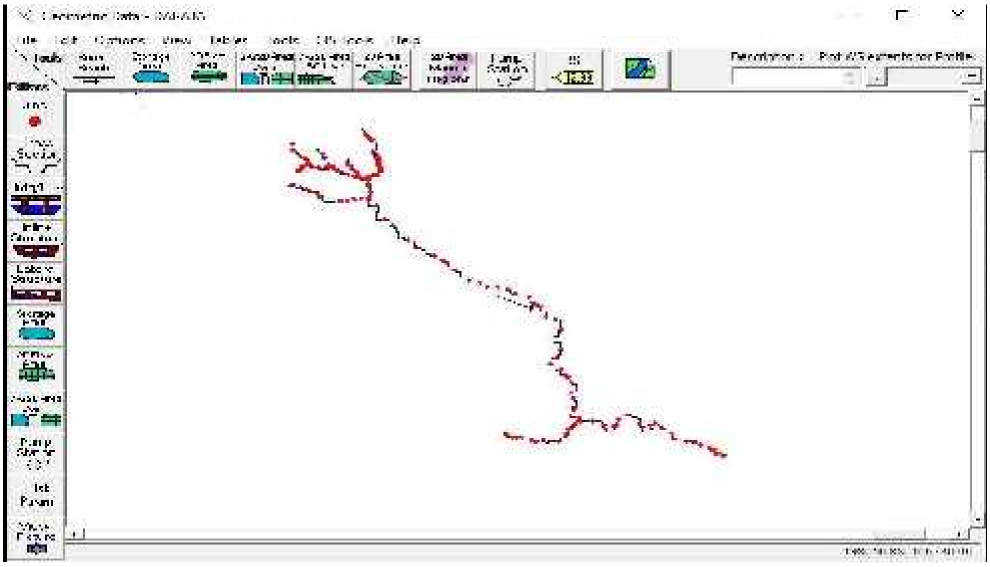


Figure (5.26) File exported to HEC-RAS. Loading data from ArcGIS to HEC-RAS for Ghar catchment will allow us to edit this data

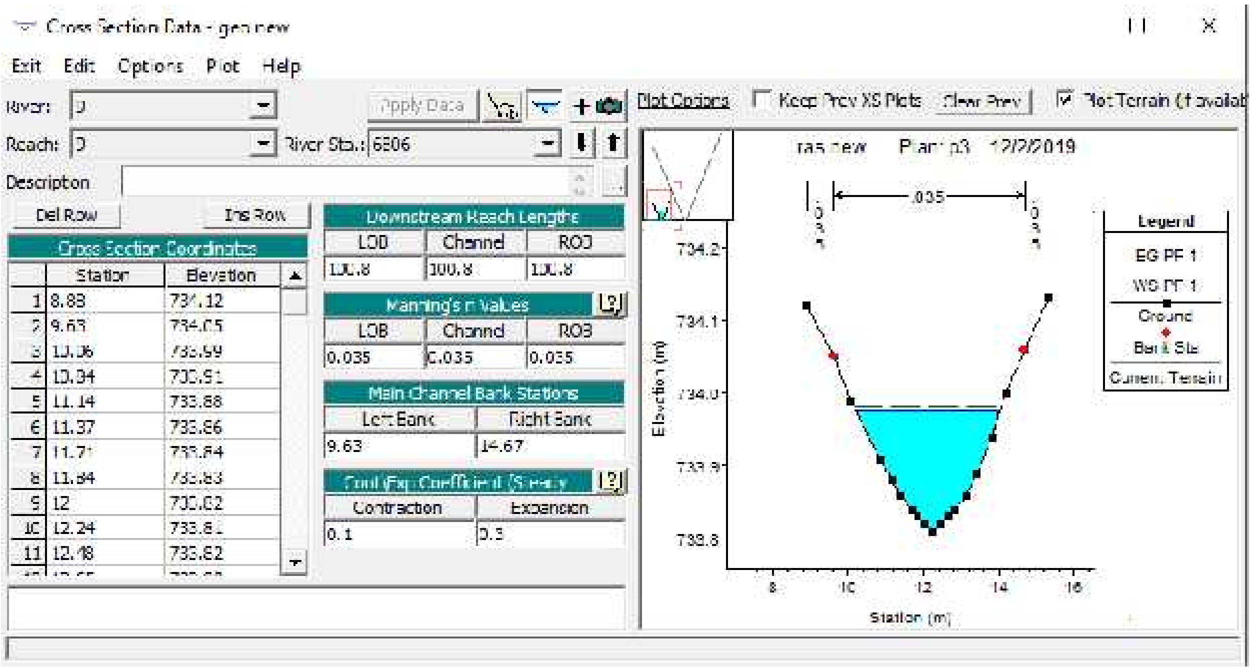


Figure (5.27) Example of editing a perpendicular section in Ghar catchment.

The last step is to enter the previously calculated flow rate on HEC-HMS. The value chosen, corresponds for our case, to the peak of the flow which represents the critical phase of the hazard. Figure(5.28/29).

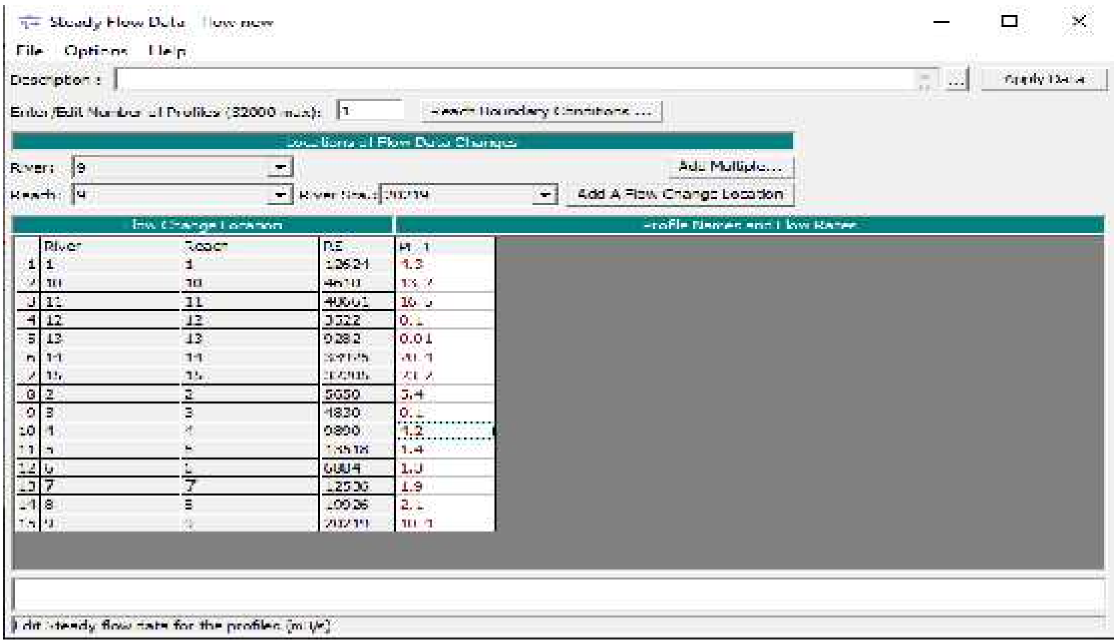


Figure (5.28) Flow input calculated on HEC-HMS for Ghar catchment.

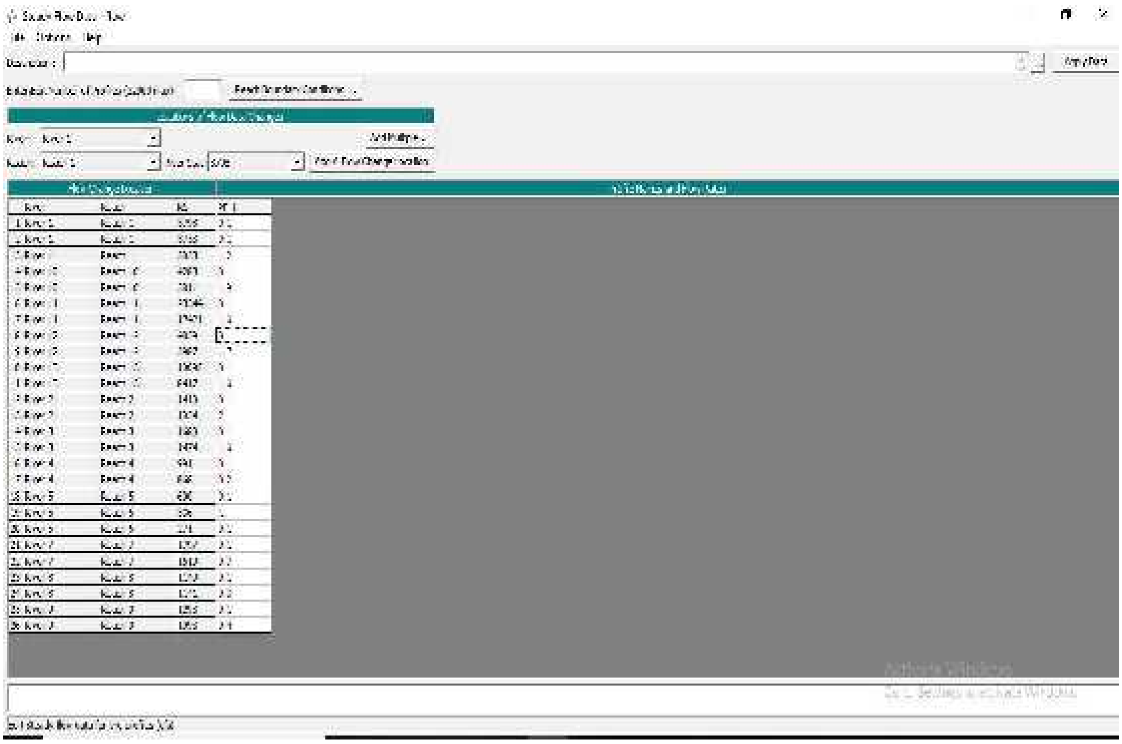


Figure (5.29) Flow input calculated on HEC-HMS for Al-Daraga catchment.

5.1.3.3 Visualization of hydraulic results on ArcGIS from HEC-GeoRAS

In order to visualize the graphical result of the flood zones, we re-export the result to ArcGIS Figure (5.30).

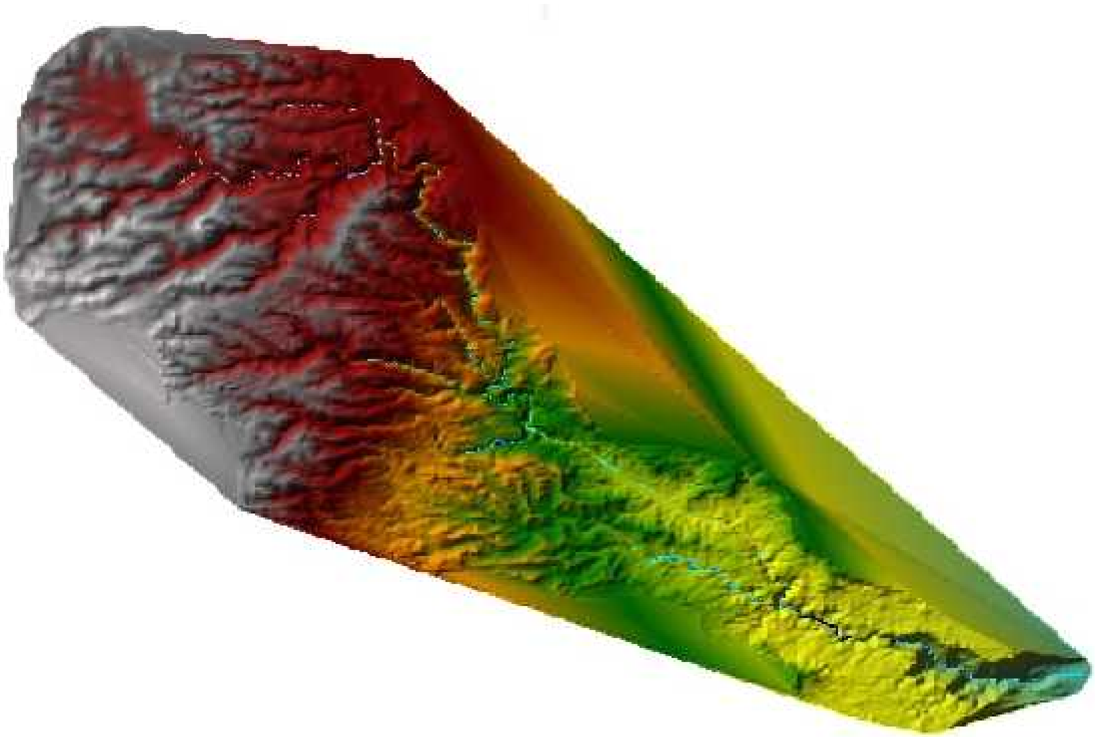


Figure (5.30) Result showing flood map in Ghar catchment

The result is a file in raster format, which represents the location of raw for the flow entered.

The output file also contains information on the water depth in each point.

This information is retrievable from the legend or by the information icon for the selected pixel.

The cross sections for the selected zoom zone are illustrated through section 1-1 to section 6-6 for Daraga and ghar as shown:

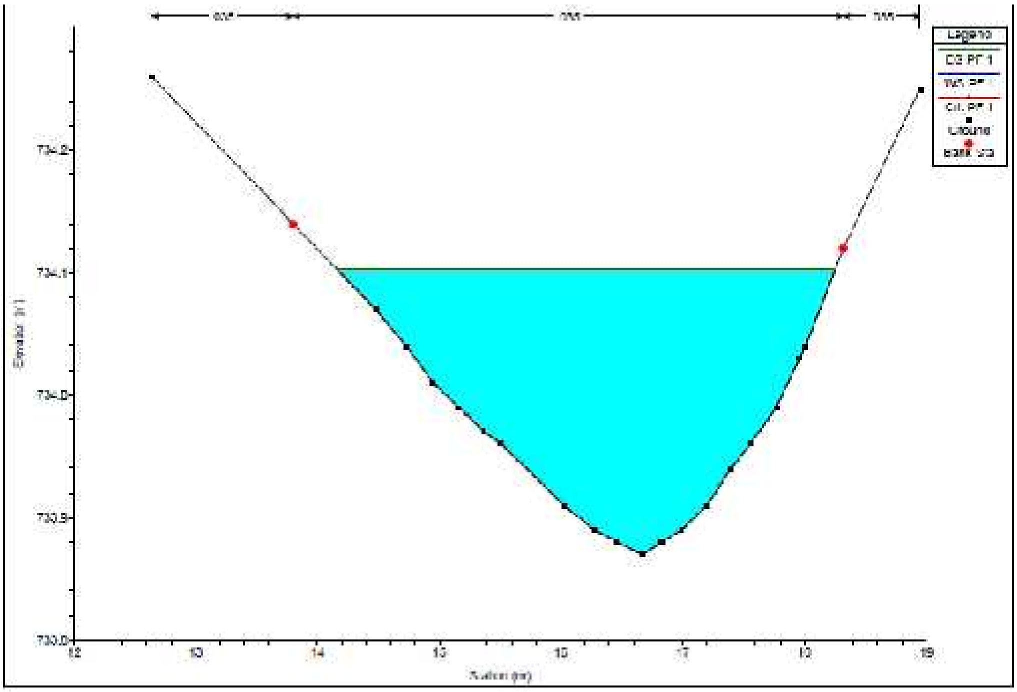


Figure (5.31) section (1-1) in zoom zone for Ghar catchment

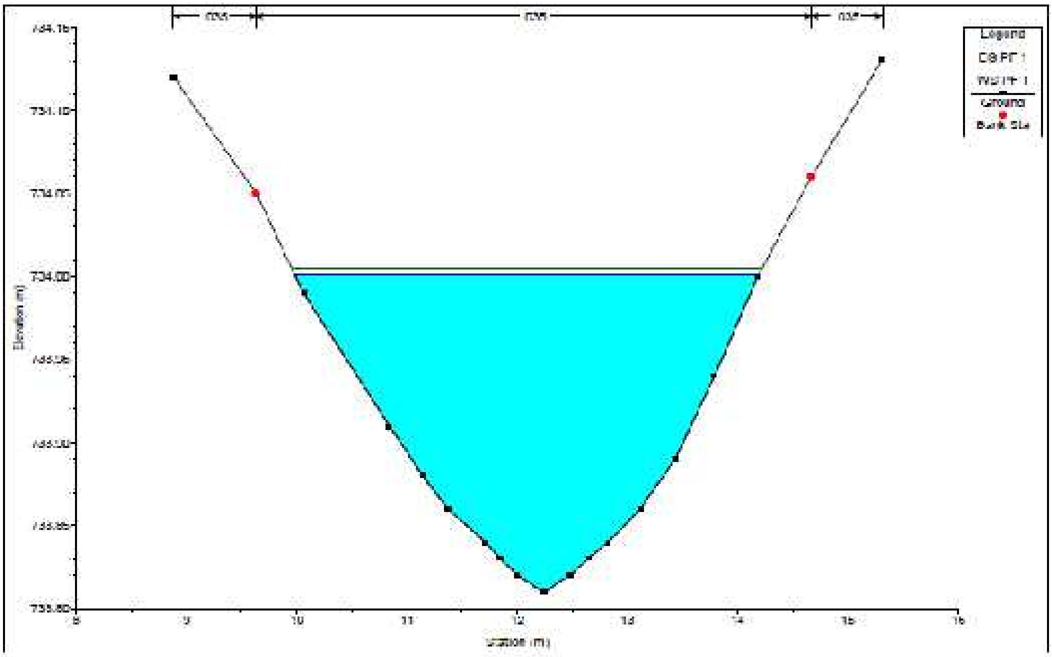


Figure (5.32) section (2-2) in zoom zone for Ghar catchment

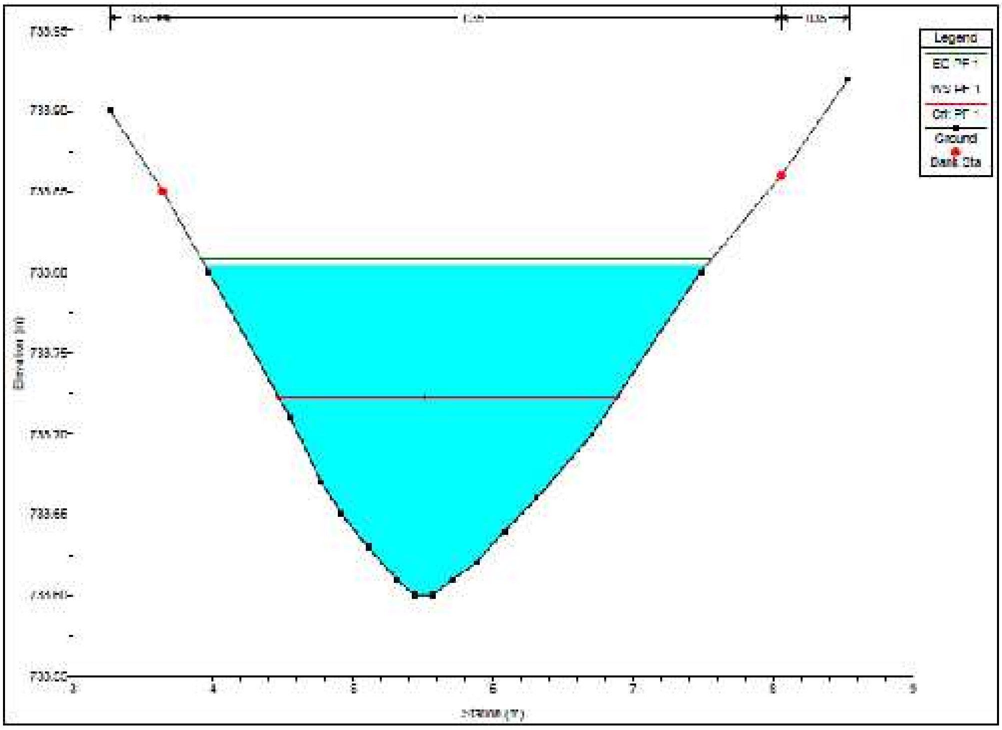


Figure (5.33) section (3-3) in zoom zone for Ghar catchment

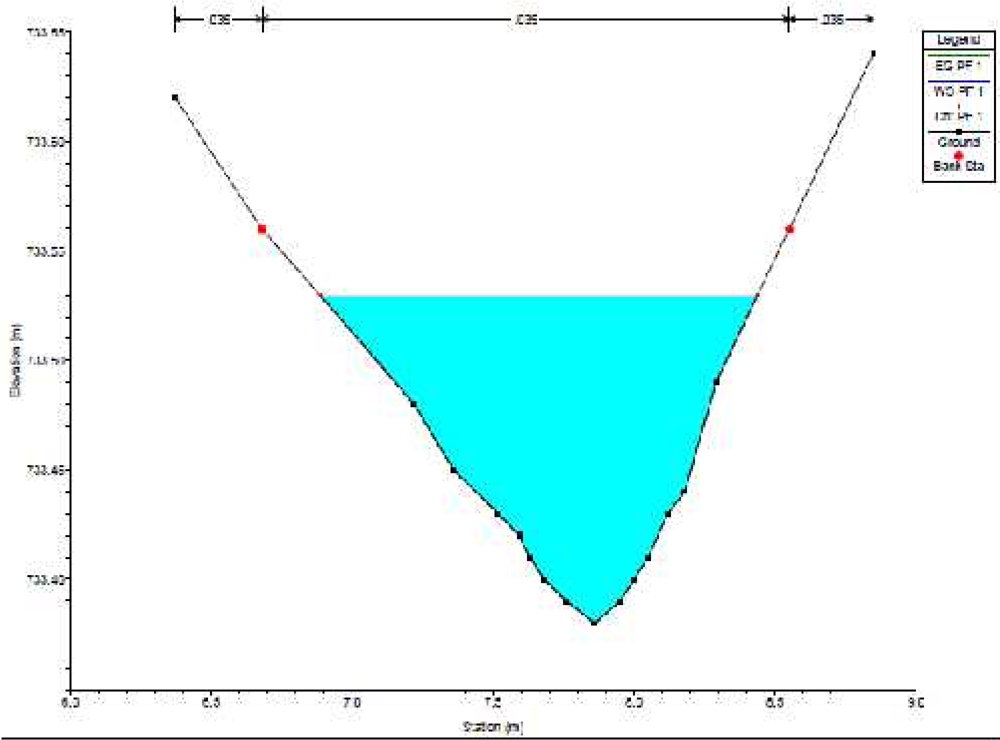


Figure (5.34) section (4-4) in zoom zone for Ghar catchment

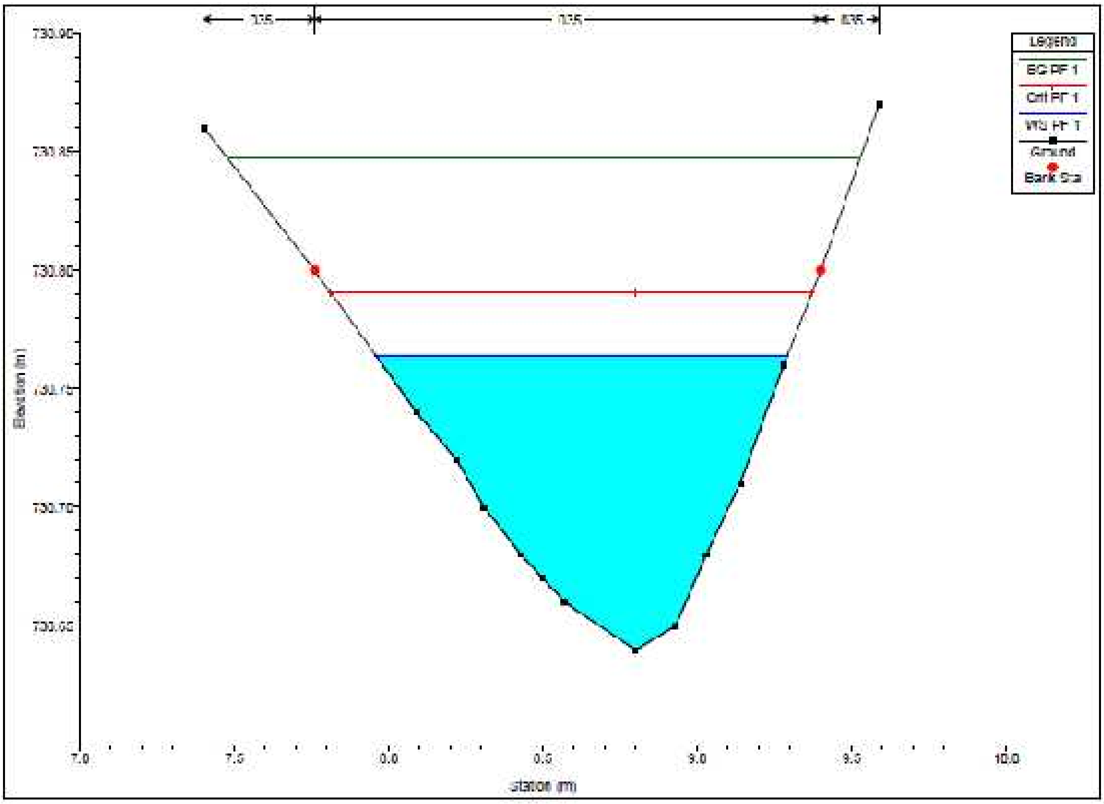


Figure (5.35) section (5-5) in zoom zone for Ghar catchment

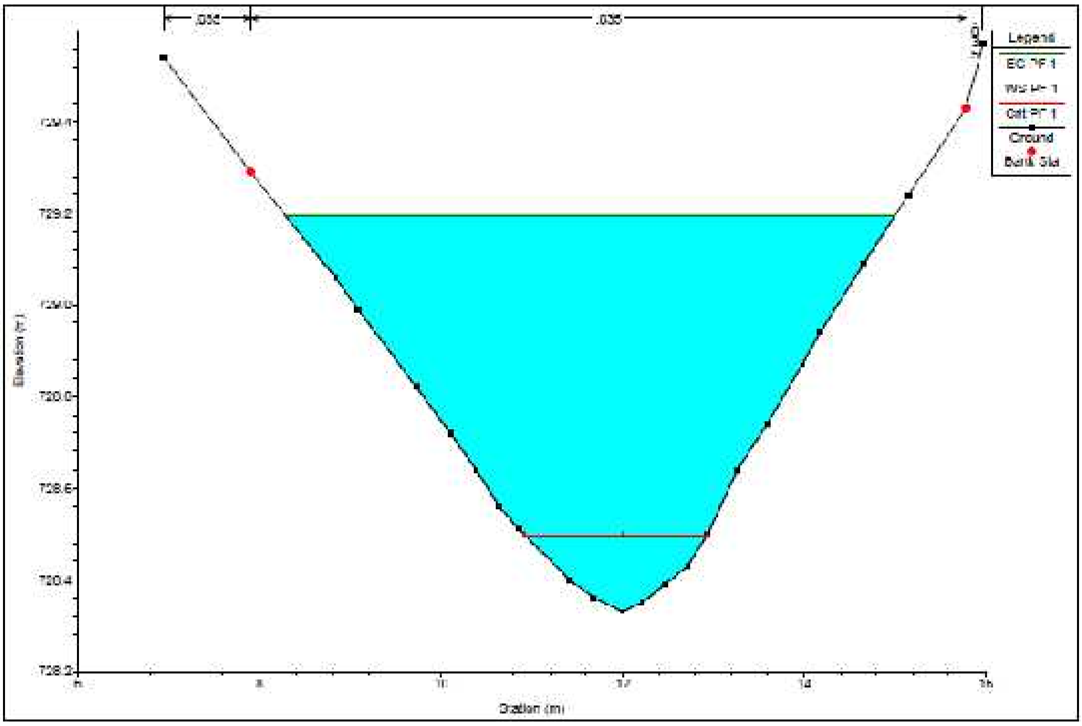


Figure (5.36) section (6-6) in zoom zone for Ghar catchment

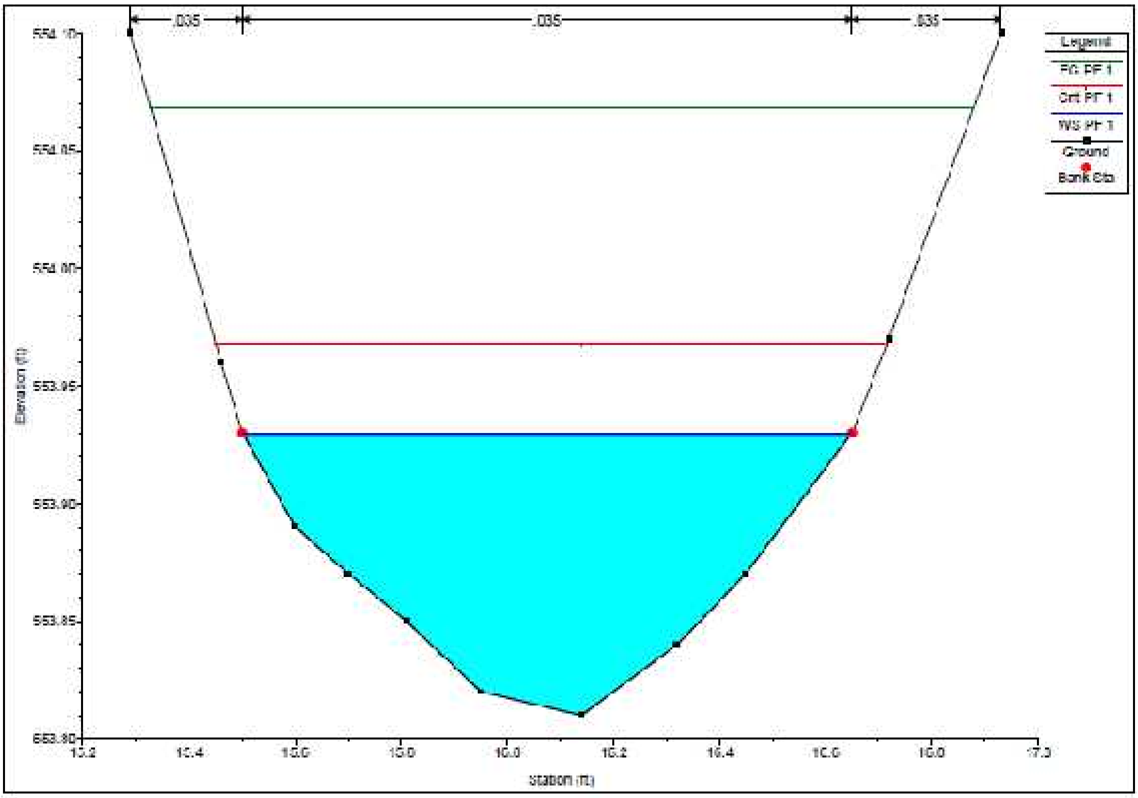


Figure (5.37) section (1-1) in zoom zone for Daraga catchment

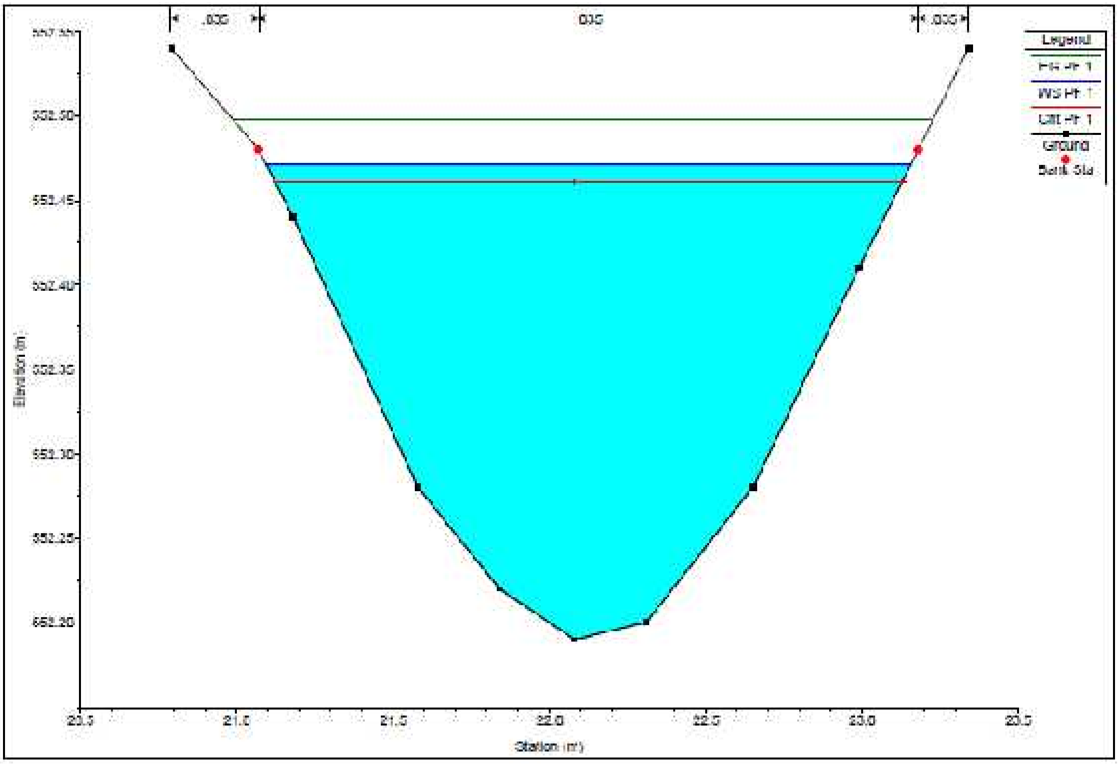


Figure (5.38) section (2-2) in zoom zone for Daraga catchment

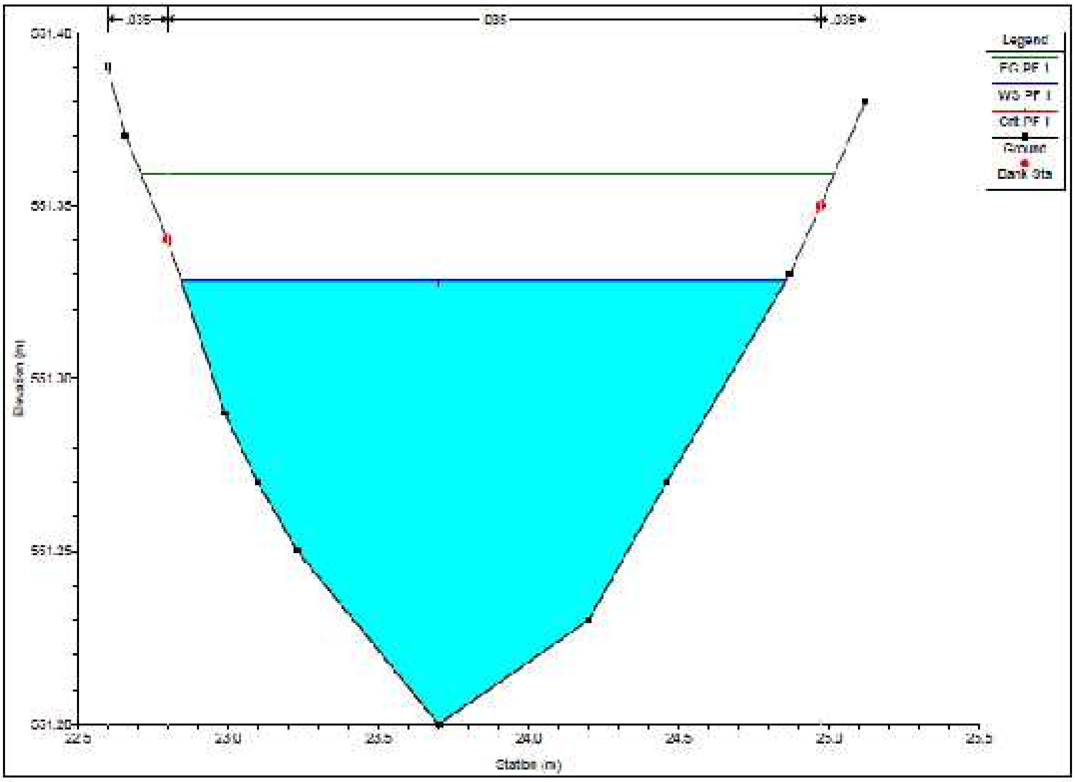


Figure (5.39) section (3-3) in zoom zone for Daraga catchment

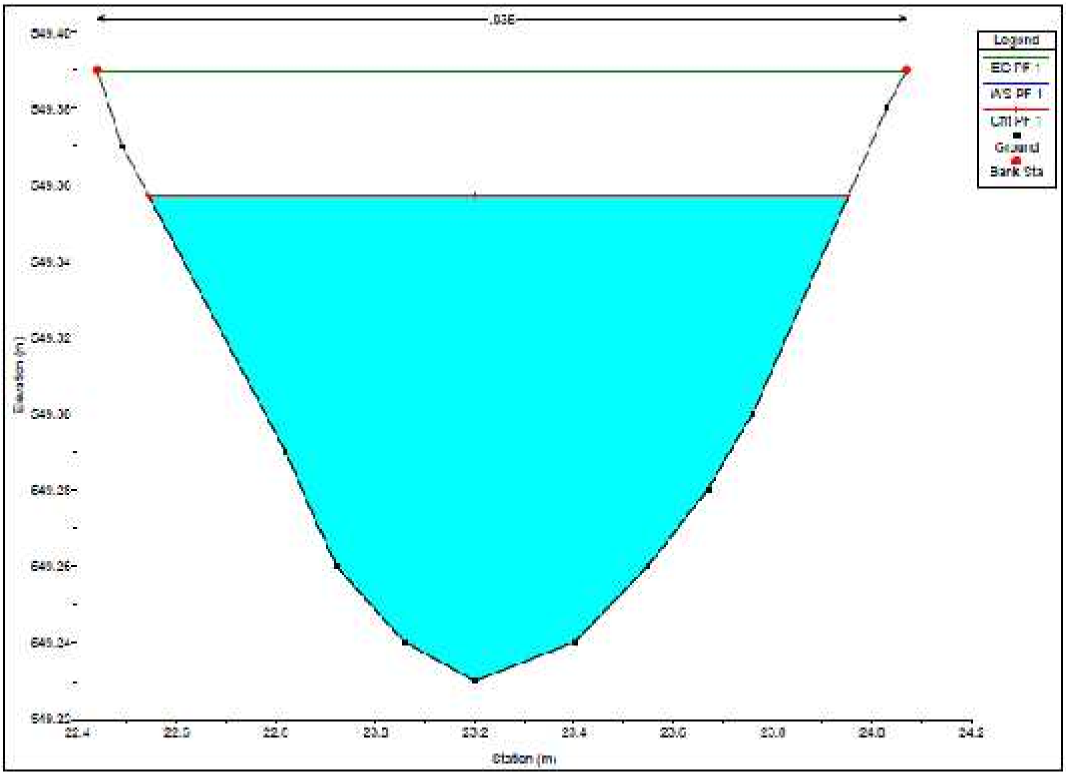


Figure (5.40) section (4-4) in zoom zone for Daraga catchment

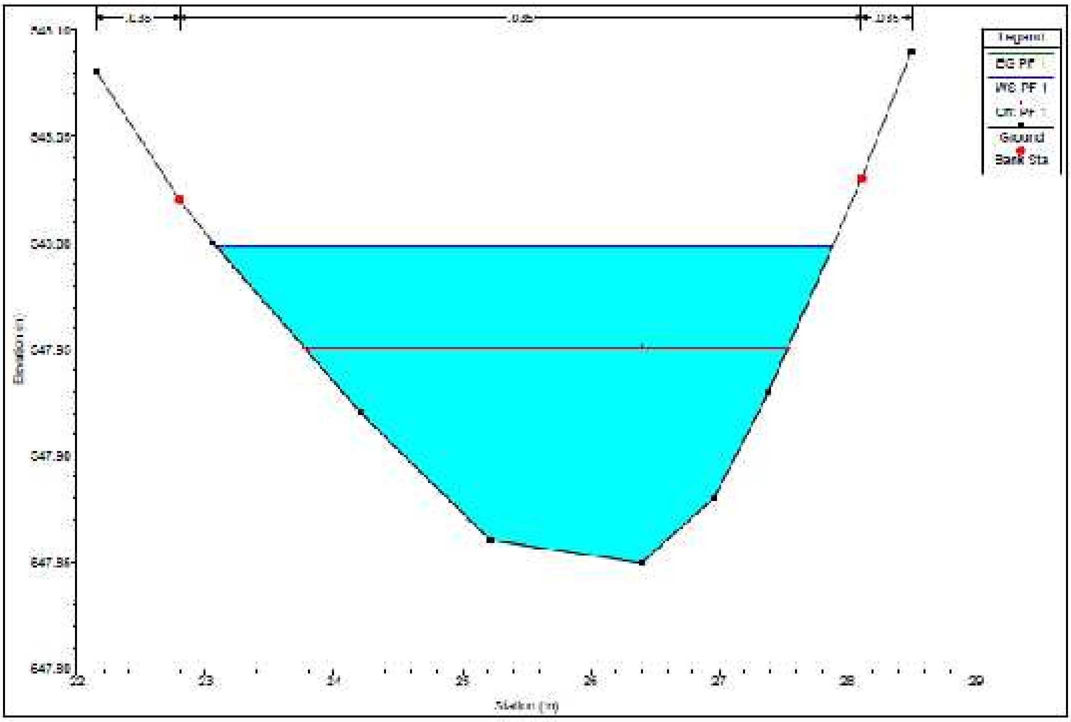


Figure (5.41) section (5-5) in zoom zone for Daraga catchment

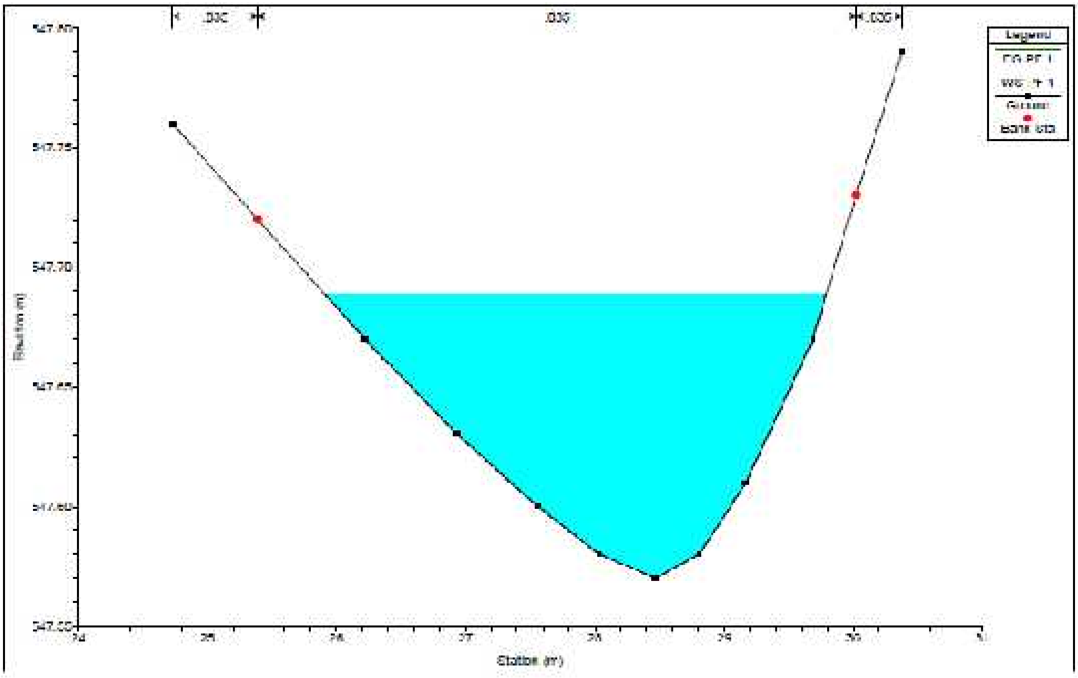


Figure (5.42) section (6-6) in zoom zone for Daraga catchment

While the water depth vary between 15cm to 90cm in zoom zone for Ghar catchment , and vary between 12cm to 30cm in zoom zone for Daraga catchment .

5.2 Results analysis

This study allowed us to pass a series of rain forecast data, the flow generated, then the map of water levels.

The final file obtained is a raster file, whose pixels represent the information on the location and depth of flood waters .

In addition to the delimitation of the floodplain, the application made allows the determination of predicted water depths for each point (pixel). This is very meaning to determine the degree of danger of the hazard .

These two data (coverage and depth) can be used later for other purposes:

- Preparation of an evacuation and rescue plan: for example, by exploiting very shallow areas for vehicles and animals; and high areas depth for the zodiacs of the civil security, etc.
- Integration on a GIS for the realization of a risk map: this map requires first, the production of a vulnerability map of the region according to factors technical and socio-economic. Then the risk map is achievable from the sum or the product of the two hazard and vulnerability maps from GIS software .
- Storage of data on a map server: the final file obtained is a raster format file, its publication on a map server by the Web mapping techniques will make this information available to a large number of users.
- Reflection on future structural measures to reduce the vagaries of the same scale.

The originality of this work lies in the fact that it is trying to find a solution to the problem flood forecasts under very specific conditions:

- A study area where for the first time a hydrological study of this kind is conducted.

This last point posed a great constraint for our study:

Indeed, we have chosen rain-flow modeling as the essential tool for modeling of the flood formation process. Calibration and validation of this modelare very important to ensure the quality of our results.

To minimize errors, we tried to choose the model and the parameters used, in particular the CN parameter judged sensitive by the sensitivity analysis.

From this point of view, we judge that the results obtained after modeling are satisfactory, because they rely on a good choice of the model and its parameters, and give a general idea to decision makers about the dimension of future hazard to make decisions required. However, this does not exclude the need for a means of verification of results obtained.

For this reason, we propose to make observations of rain and traces of water flooding by topographic survey at several points in the study area.

This we compare the results obtained and the observations collected, and will allow us to therefore, to make a judgment on the quality of our work.In addition to the problem of calibration and verification, our study suffers from other constraints:

On the one hand, we opted for an event model to use a few days before a rain event. This choice poses the problem of the initial conditions of the basin (initial flow in the Al-Daraga and Ghar, base flow, etc.). The absence of a flow measurement station on the Al-Daraga and Ghar initial conditions are unknown and, therefore, the use of the model will bevery coarse. Except in the case where these initial conditions are zero (after a dry period for example.) or in the case of using the model in a continuous way.

On the other hand, throughout this study, we did not discuss the data point storm. However, these meteorological data are a great source of uncertainty for the model that must be taken into account. The degree of accuracy of these to a fallout direct on the accuracy of the overall results. Moreover, this rain data plays determining role in determining the model's projected scope (one day, one week, a fortnight, etc.).

That's why the sources of these rain-weather data and techniques used for their acquisition deserve special attention.

By this study, we estimate that we have initiated a flood forecasting system, in the goal of arriving at a complete system, which takes into consideration the following points:

- the calibration of the model used: by observations rain flow or rain-elevation (traces of water).
- the continuity of operation: towards an automatic system that works in permanently.
- the democratization of information: by a real-time display of forecasts of chance on a website.

5.3 CONCLUSION AND RECOMMENDATIONS

Radar rainfall data are collected and listed in volume (mm) per five minutes are then applied rainfall as input to a hydrological oriented GIS model. A set of HEC programs (HMS, GeoRAS and RAS) and ArcGIS were used for runoff and water level simulation and generating the flood inundation maps. In conclusion, integration of Hydrologic and Hydraulic Models, RS and GIS can be a helpful strategy for Flood Early warning.

The current study is summarized with the following points. The main intent behind the study was to develop a rainfall runoff model to generate the flood inundation extent for the known precipitation event. Future precipitation predictions can be used in the current model for the generation of future flood inundation maps and assessing the peak flood in future. The model is not region sensitive, similar model can be developed for other catchments for the assessment of flood magnitude and its extent.

The transformed runoff with the help of HEC-HMS are used for flood plain mapping with HEC-RAS. The generated inundation map is the model prediction for the peak flow . The region is expected to flood to greater extent if the rainfall event is more intense and of shorter duration as compared to the considered event. To mitigate the flooding and reduce the flood extent, best management practices such as low impact development can be adopted.

No model is complete and there is always scope of refining the model. Current model can berefined by incorporating higher resolution data, and including recent data and scenarios.

The current model was calibrated based on the land use data , thus more recent land use data incorporation can further refine the model.

References:

[1] Abushandi, Eyad Hamad,2011,(PhD thesis), Rainfall-Runoff Modeling in Arid Areas .

[2] Arad, A. (1964). The geology and hydrogeology of the lower cretaceous of the northern Negev and Judea Mts. Geological Survey of Israel Report HYDRO/3/64.

[3] Laronne, Jonathan; Shentsis, Isabella; Alpert, Pinhas,2007, Hydrological Sciences Journal.(9).

[4] Morin E, E. Shamir, L. Ben-Moshe, A. Rone, T. Grodek, Y. Enzel, K. Georgakakos (2012) Geomorphology-based index for detecting minimal flood stages in arid alluvial streams, Hydrol. Earth Syst. Sci. Discuss., 9, 12357–12394.

[5] Morin ,Efrat ; Yael Jacoby, ShiloNavon, Erez Bet-Halachmi, Towards flash flood prediction in the dry Dead Sea region utilizing radar rainfall information, Advances in Water Resources 32 (2009) 1066–1076

[6] Morin, Efrat;Dayan, Uri (2006) Flash flood–producing rainstorms over the Dead Sea: A review, Geological Society of America Special Paper 401, p. XXX–XXX, doi: 10.1130/2006.2401(04).

[7] NRC, 2005. Flash Flood Forecasting Over Complex Terrain: National reearch Council, with an Assessment of the Sulphur Mountain NEXRAD in Southern California, The National Academies Press, Washington, DC, pp. 206.

[8] Osborn, H. B., K. G. Renard, and J. R. Simanton, 1979, Dense Networks to Measure Convective Rainfall in the Southwestern United-States: Water Resources Research, v. 15, p. 1701-1711.

[9]Overeem, Aart (2009),Climatology of extreme rainfall from rain gauges and weather radar.

[10]Pilgrim, D. H., T. G. Chapman, and D. G. Doran, 1988, Problems of Rainfall-Runoff Modeling in Arid and Semiarid Regions: Hydrological Sciences Journal-Journal Des Sciences Hydrologiques, v. 33, p. 379-400.

[11]Reshma T, Venkata Reddy K, Deva Pratap, Venkata Reddy K, Deva Pratap (2013): Simulation of Event Based Runoff Using HEC-HMS Model For an Experimental Watershed, International Journal of Hydraulic Engineering 2013, 2(3): 42-46.

[12]Scharffenberg, W. A. 2001. Hydrologic modeling system HEC−HMS user’s manual. Washington, D.C.: U.S. Army Corps of Engineers.

[13]Wheater, H. S., A. P. Butler, E. J. Stewart, and G. S. Hamilton, 1991, A Multivariate SpatialTemporal Model of Rainfall in Southwest Saudi-Arabia.1. Spatial Rainfall Characteristics and Model Formulation: Journal of Hydrology, v. 125,p. 175-199.

[14]ABU-IZIAH, I. (2010). Modeling soil erosion and sediment transport under different land management options in a semi-arid watershed of southern italy. Thèse Master of science Land and Water Resources Management : Irrigated Agriculture. Collection Master of science n.583, 139p.

[15]USACE. (2010). Hydrologic Modeling System HEC-HMS. Technical reference manual version 3.5. Davis, CA: Hydrologic Engineering center US Army Corps of Engineers.

Sites web:

PRM. (2013). Retrieved from Prévention des risquesmajeurs (http://www.risques.gouv.fr/)

LA PREFECTURE DE L'AUDE (2013) :Prévention des risquesmajeursdans le département de l'Aude.: (http://www.aude.pref.gouv.fr/ddrm/@@Aude00.htm)

I.TIMILLA (2013) : Orange Risk (www.orangerisk.net/tl@@9skh00nch3@lda00.html)

UCL. (2013). Valeurs des coefficients n de Manning. UCL : universitécatholique de Louvain .(http://sites.uclouvain.be/gce/~hydraulique/enseignement/didacti/lecon02/manning.html)

Wikipedia. (2013). HEC-RAS (http://fr.wikipedia.org/wiki/HEC-RAS)