Scatec

Surface Water Analysis
Benban Solar Park, KomOmbo, Aswan

Prepared by:

Environics, SAE
Environment & Development Advisors

April 2016

Scatec

Surface Water Analysis
Benban Solar Park, KomOmbo, Aswan

Prepared by:

Environics, SAE
Environment & Development Advisors

6 Dokki St. 12th Floor, Giza 12311
Tel.: (+2010) 164 81 84 – (+202) 376 015 95 – 374 956 86 / 96
Fax: (+202) 333 605 99
Email: environics@environics.org
Website: www.environics.org

April 2016

Table of Contents

List of Figures

List of Tables

Executive Summary

The Surface Water Analysis Study of Benban Solar Park Area aimed at determining the potential flash flood hazards, and if needed, identifying adequate protective measures.

In order to achieve its aim, the study comprised the following Analyses:

- The **Topographical Analysis** using the Digital Elevation Model (DEM) of the study was a critical input to the **Morphological Analysis**, undertaken to understand the natural characteristics of drainage basins.
- The **Geological Analysis** to classify the types of rocks and surface soil as well as faults their distribution, was necessary to estimate the potential of water infiltration in the basins.
- The **Meteorological Analysis**, including the inventory of available rainfall data to estimate maximum rainfall quantities, recurrence and distribution is a critical input to estimate the flash flood hazards.
- The **Hydrological Analysis**, developing hydrographs of the drainage basins that affect the area and calculating maximum flood water flow and expected volumes.
- Finally, **Flood Plain Analysis**, extracting cross sections from the DEM at the streams intersecting the Park area, and evaluating the hydraulic safety of the cross sections as well as calculating water levels and velocities at these specific intersections. .

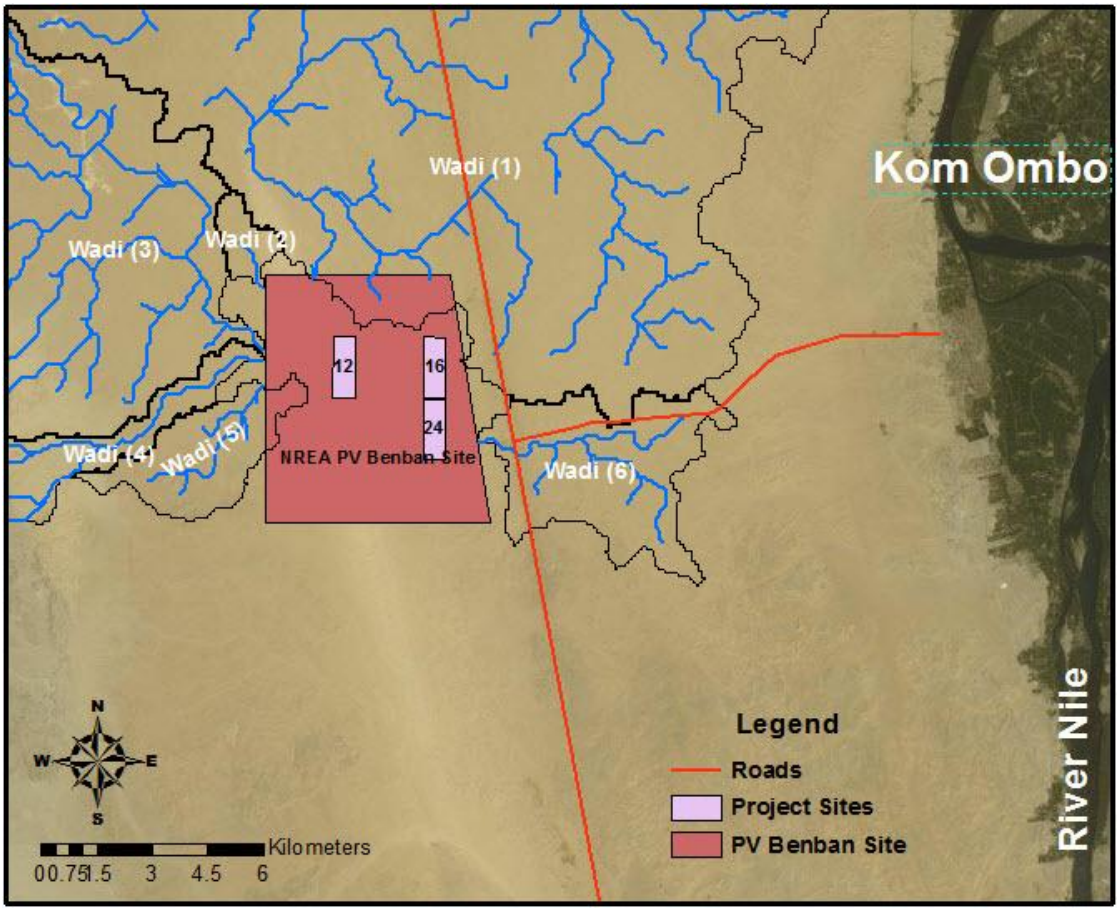
Methodology

The study reviewed available research, academic and statistical data, information and maps It is based on the DEM of the project area, rather than field topographic surveys. This was followed by comprehensive description and analyses of: land-use map around the project area; main tributaries; morphological characteristics; maximum rainfall depths, flood occurrence, and estimation of floods water levels/depths at intersection of watersheds outlets with the project area for different return periods. Watershed Modelling System (WMS) was then used for comprehensive hydrological analysis.

Topography and Morphology

The DEM was used to develop hydrographical features, illustrate elevations and slopes, and indicate flow directions, which were cross checked against topographic maps and satellite images. Land use of the study area and its surroundings was determined using satellite imagery. WMS model was used to identify watersheds affecting the project area, delineate boundaries of the drainage basins, and compute their geometric attributes.

Data analysis shows an extensive drainage network at the project area, with six drainage basins affecting the Benban Solar Park to different extents based on their areas and slopes. The six wadis affecting the park are of variable dimensions, with Wadi (1) and Wadi (3) collecting from watersheds having relatively larger areas and high slopes. As clarified in the figure below, Wadi (3), Wadi (4) and Wadi (5) hit the project area from the western side, while Wadi (2) and Wadi (1) hit from the north. Wadi (6) is the only watershed that hits the project area from the eastern side.
The figure below also shows the three sites of specific interest to Scatec, namely, plots 12, 16 and 24.



Land Use

The Catchment areas of the wadis are barren land with no evident land use. However, wadi (6) and a tributary of Wadi (1), intersect with the main access roads to the Park.

Meteorology

Rainfall data is used to determine the runoff volumes for each drainage basin affecting the project area. Rainfall design storm characteristics, hydrological calculations, estimated rainfall storm durations, hydrograph representations, and storm distributions are used to deduce rainfall intensity.

According to the Flood Atlas of the Wadis of Aswan Governorate, the frequency analysis of statistical distributions of rainfall data at Kom Ombo, which results in highest confidence of error, is the General Extreme Values (GEV):[1]

Flood return period (Year)	**2**	**5**	**10**	**25**	**50**	**100**
Rainfall values using GEV distribution (mm)	4.82	7.22	10.9	19.4	29.1	43.7

[1] *Flood Atlas of the Wadis of Aswan Governorate*, Ministry of Water Resources and Irrigation, Arab Republic of Egypt (Cairo, 2012), 17.

Geology

Geological analysis of the region around Benban Park shows that it is generally characterized by sand or lime stones with medium potential of cracks or faults. Therefore, there is a high potential for rainfall losses to infiltration, which reduces the volume of flood runoff.
Rainfall losses via infiltration and runoff are estimated using the Soil Conservation Service Curve Number (SCS-CN) method, so as to calculate the surface runoff in the drainage basin system.

Expected water losses to infiltration are generally high, but flash floods often occur in a day subsequent to mild rains that are enough to saturate the soil and increase runoff. The study, therefore, took the conservative assumption of such sequence of events.

Hydrology

Hydrological analysis was based on the results of the meteorological, morphological and geological analyses to estimate the amount of flood water and the disposal and maximum time for the arrival of flood peak times. WMS model was applied to determine the drainage basins that have direct effect on the area, calculate their hydrological properties, and produce the required hydrographs according to their complexity. Synthetic unit hydrograph of the Soil Conservation Service (SCS-UH) method was used to calculate surface runoff characteristics and estimate the required hydrographs for the drainage basins, given the absence of runoff measurements in the study area.

Rainfall data, flood volumes, peak discharges, time to peak and runoff volumes for 25, 50 and 100 year return periods were analyzed and results are shown in the table below. It is clear that the Park is safe from flash flood hazards in the 25 year return period, and only Wadi (1) represents a potential hazard in the 50 year return period.

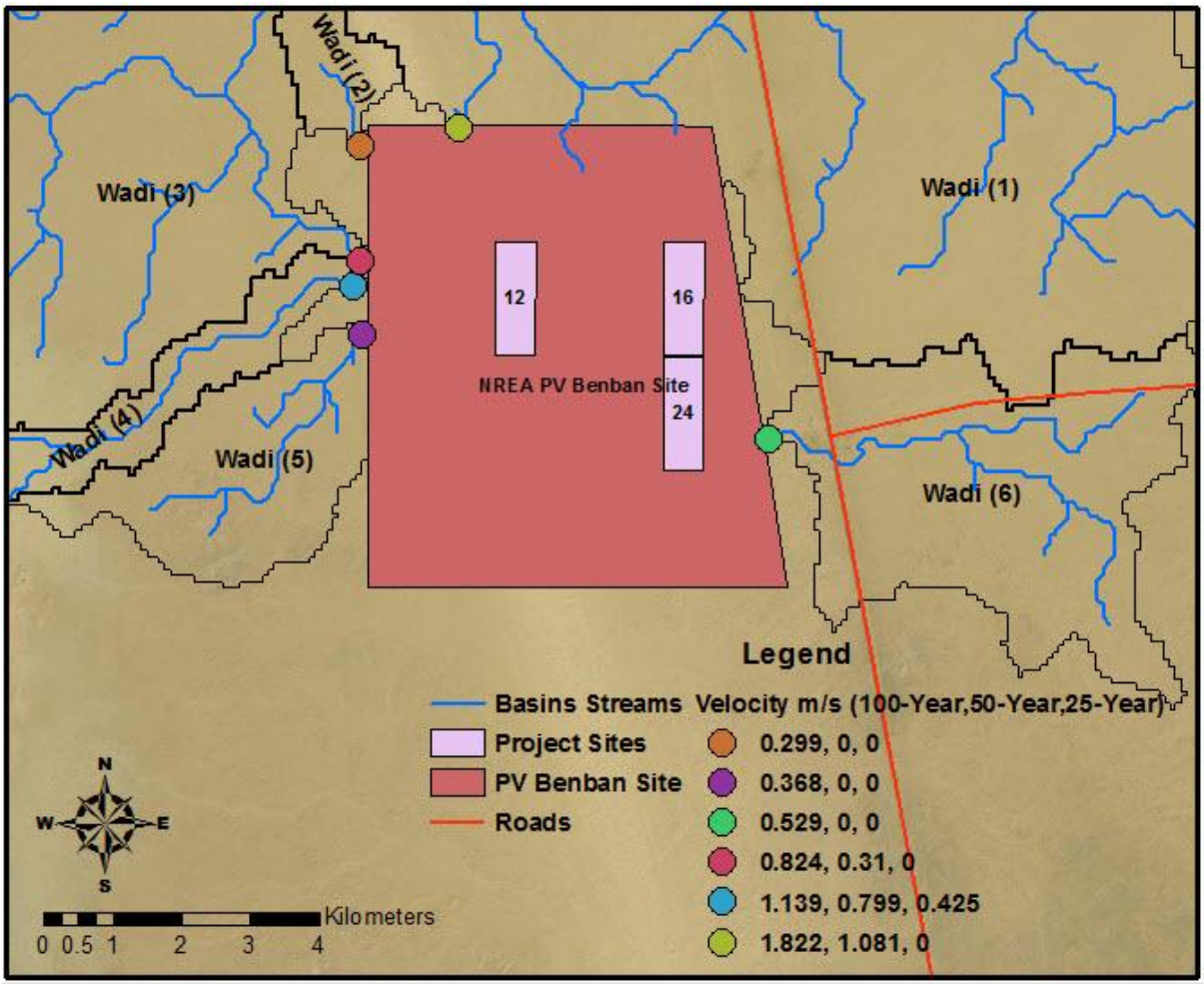
Drainage Basin	Flood Volume (m3)			Peak Discharge (m3/s)			Time to peak (min)
	25-Year	50-Year	100-Year	25-Year	50-Year	100-Year	
Wadi (1)	-	879,361	7,298,644	-	9.80	80.89	1695
Wadi (2)	-	-	3,120	-	-	0.35	255
Wadi (3)	-	16,093	340,060	-	0.54	11.33	510
Wadi (4)	2,844	34,644	131,097	0.39	4.54	16.02	210
Wadi (5)	-	-	12,897	-	-	0.89	315
Wadi (6)	-	-	24,260	-	-	1.36	360

Flood Plain Analysis

Ground elevations for the six cross sections at intersection of watershed outlets are extracted from the DEM and used for estimating flood water depths. Runoff discharges estimated by the hydrological analysis and extracted cross section areas are used to determine the flood

volume containing capacity. Expected water depths at each cross section for different flood return periods are analyzed to identify suitable flood protection methods. Velocities of flood water at each cross section for different flood return periods are studied to determine the destructive effect of potential floods on the Park. Roads around the project area are investigated to ensure accessibility and predict any possible isolation hazard during a flood event.

Locations of Cross Section	Water Depth (m)			Velocity (m/s)		
	100-Year	50-Year	25-Year	100-Year	50-Year	25-Year
Wadi (1)	1.59	0.72	0.00	1.8220	1.0810	0.0000
Wadi (2)	0.16	0.00	0.00	0.2990	0.0000	0.0000
Wadi (3)	0.25	0.06	0.00	0.8240	0.3100	0.0000
Wadi (4)	0.42	0.25	0.10	1.1390	0.7990	0.4250
Wadi (5)	0.16	0.00	0.00	0.3680	0.0000	0.0000
Wadi (6)	0.27	0.00	0.00	0.5290	0.0000	0.0000



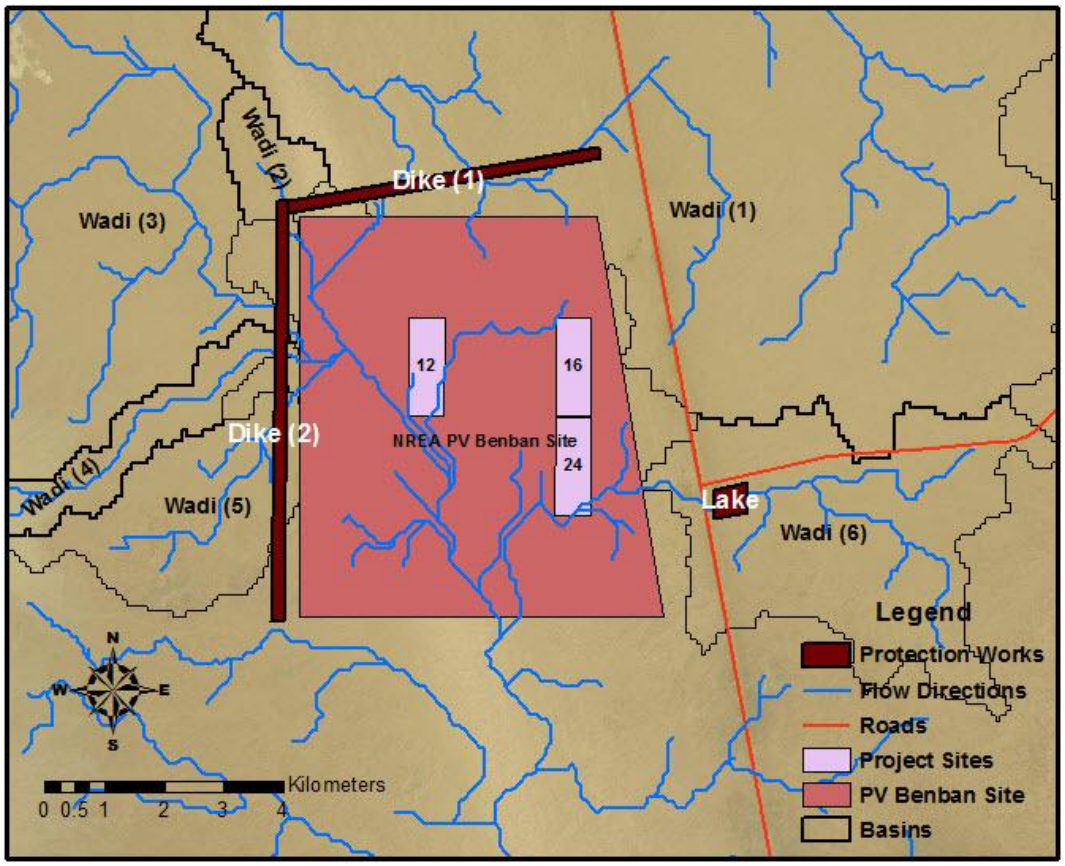
Conclusions

Surface water analysis of the study area has reached the following conclusions:

- Six watersheds affect the project area, two of which would potentially produce the maximum volumes of flood water because of their relatively large areas.
- All Scatec sites are positioned in flow directions, although of different flood paths of various level of hazards. Project sites 12 and 16 are subject to being affected by watersheds 1, 2, 3, 4 and 5, while project site 24 may only be affected by watershed number 6. Nevertheless, in case of high flood volumes and peaks, the entire park will be affected.
- Analysis of the rainfall data, flood volumes, peak discharges and time to peak for 25, 50 and 100 year return periods have indicated that there are no hazards associated with the first and minimal hazards for the second.
- For 100 years return period, most water velocities are within safe range and water depths are mainly below one meter, with an exception of one wadi. Although, the velocity of water flowing from this wadi is within the non-destructive range, it still holds the risk of ponding.
- During potential floods, all roads leading to the park will be accessible. However, if left without protection, the road surrounding the park expected to be constructed by NREA will be isolated from the north during a flash flood of 50 year return period and from the north and the west during that of a 100 year return period.

Recommended Protection

The potential total volume of flood water for 100 years return period requires adequate protection works. Because land plots are already allocated to specific developers to install a set capacity of electricity generation, the option to respect flood paths and allow for their free flow towards their destination does not seem to be feasible.



As clarified in the figure above, the study recommends establishing common protection works for the whole Benban Solar Park, instead of separate ones for each site. Protection is especially required at the northern and western eastern sides, via constructing two short dikes, as well as the eastern side, where a small pond should be excavated.

Protection works for individual sites will be less cost efficient and can hardly account for the different interventions undertaken by each developer in its allocated site. Without joint planning, it will be hardly possible to ensure protection of the individual sites. However, without coordination between developers and their agreement on cost sharing of common protection works, the only option left for an individual developer with be to protect its own site.

Uncertainties

The major uncertainty to which the results of this study are sensitive is its reliance on the DEM analysis of topography and morphology. Although the DEM results were cross checked with maps and satellite imagery, the limitations resulting of its resolution as compared to topographic site survey has a direct impact on the depth of water flow and its velocity, and accordingly the sizing of the protection works recommended.

Next Steps

The first step would be to consult with the developers' association of Benban and NREA to confirm the willingness and the mechanism to cooperate in establishing the needed protection works. It is understood that this step might hold some difficulties, namely:

1. Flash flood hazards are obviously counterintuitive given the dry nature of the area; and
2. Committing to cooperation is difficult without a clear vision of what this would entail in terms of costs. At the current stage, a cost estimate could be provided but its accuracy and its sensitivity to the field survey might make this step premature.

The next steps are typical of this type of recommended engineering activities, and would be:

1. Refine calculations based on limited field survey focused on the intersection of wadis with the Park. This could also be limited to that of Wadi (1), as the depth of water flowing from it is the governing factor for the dike design
2. Complete preliminary design accordingly, and provide a cost estimate
3. Finalize design and bill of quantities
4. Call for bids from qualified contractors

1. Introduction

1.1 Background

The topographic nature of many areas of Egypt, characterized by mild slopes and flatness, encourages investments that do not always take into account potential flash flood risks. With growing development and rarity of flash flood recurrence, urban life has overlapped with several drainage basin outlets. Egypt is currently witnessing a boom in new and renewable energy projects, due to the country's dedication to using all possible resources for efficient energy production. Solar power projects constitute a large percentage of these projects and typically require flat planes. The new solar park in Benban, Aswan, has invited 40 international investors. This mega project requires a detailed study to evaluate the potential risk and volume of flood water, and provide suitable suggestions for protection and mitigation.

1.2 Description of the Study Area

Figure (1) shows the location of the project area (PV Benban Site) within Aswan Governorate, near Kom Ombo City, to the west of the River Nile and within the Western Desert. Three projects sites are also illustrated (areas (12), (16), and (24)). The project area lies parallel to the Upper Egypt Desert Road that connects the northern governorates to Aswan Governorate. This road is connected to Kom Ombo City via a side road of approximate length of 12 Km. No activities exist at any significant proximity to the area.

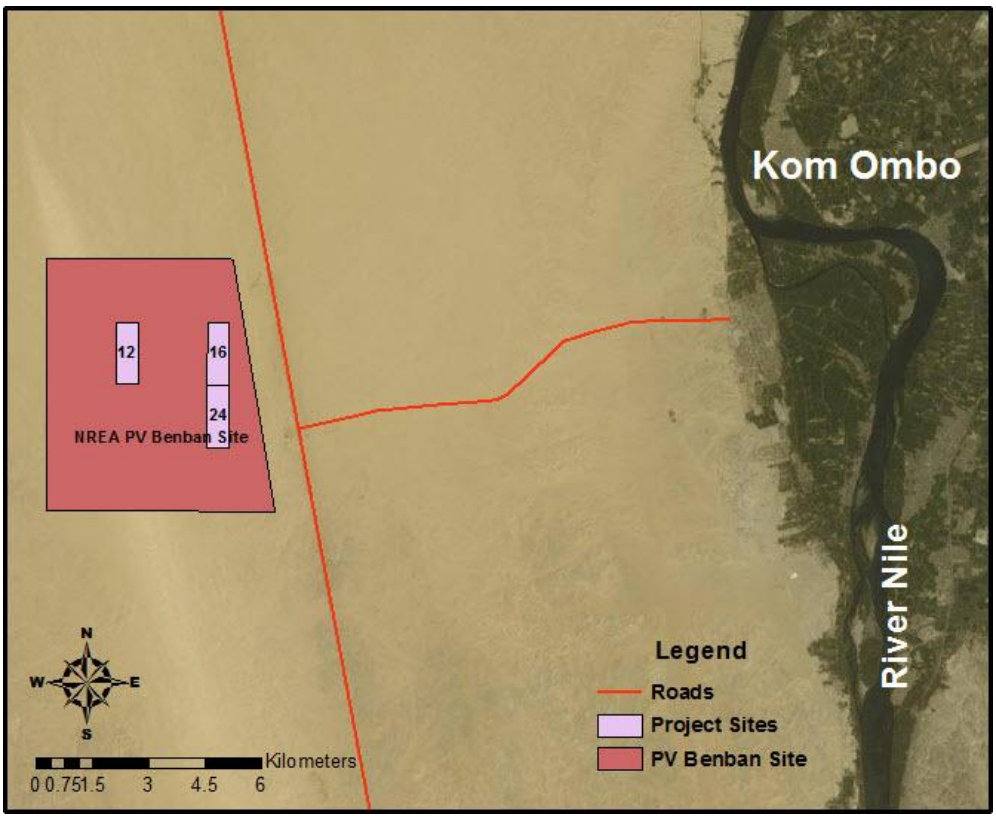


Figure (1): Location map of the project area

2. Scope of Work

2.1 Surface Water Hydrology Analysis

In order to evaluate the water volumes of flash floods that may affect the project area, the analysis of surface water hydrology in the project area includes:

- Topographical Analysis: It describes the topographic features which are concluded from the Digital Elevation Model (DEM) of the study area.
- Morphological Analysis: It concentrates on estimating the natural characteristics of the drainage basins that affect the study area.
- Geological Analysis: It is concerned with the classification of the study area from a geological perspective and determines the types of rocks and faults, distribution and geological map of the area.
- Meteorological Analysis: It is concerned with an inventory of available rainfall data from the nearby areas to estimate the amount of maximum rainfall quantities and their time of recurrence and distributions around the region of interest.
- Hydrological Analysis: It is concerned with the conclusion the hydrographs of the drainage basins that affect the area of interest and calculation of the maximum of flow of flood water and expected volumes.

2.2 Floodplain Analysis

Floodplain analysis is used to estimate water levels, discharge and velocities for the cross sections at the streams that intersect the project area. Floodplain analysis of the project area includes:

- Extraction of the cross sections from the DEM at the streams that intersect the project area.
- Hydraulic Analysis, evaluating whether the cross sections are hydraulically safe by calculating water levels and velocities inside these cross sections.

The analyses listed above provide an assessment of flashfloods around the project area, indicating their potential hazards in terms of flood velocities and water depths.

3. Methodology

The investigation of surface water hydrology around the project area is based on the analysis of available data, which is acquired from various sources, mostly earlier reports in the area and verified scientific and academic websites. The following sections highlight the data collected and the types of analyses. Section (3.3) provides a brief background on the software package, which is used to perform these analyses, while section (3.4) lists the limitations governing the report's findings.

3.1 Data Collection

To investigate the occurrence of the possible flash floods that may affect the project area, as well as the analysis of floodplain, the following data was obtained.

- Available topographic and geologic maps of the project area;
- Digital Elevation Model (DEM) of the project area;

- Available satellite images of the study area to describe the land-use;
- Statistically analysed rainfall data for available ground stations nearby the project area;
- Ground elevations for the cross sections of the streams at intersection of watersheds outlets with the project area were extracted from the DEM.

3.2 Data Analysis

Using the available information and data, a comprehensive description of the hydrologic system is provided, including:

- Land-use map around the project area (domestic, touristic, agriculture, industrial…etc.);
- Main tributaries (streams) that might affect the project area;
- Morphological characteristics of the drainage basins and tributaries (area, basin slope, stream length, stream slope…etc.);
- Maximum rainfall depths at different return periods based on the results of the statistical analysis;
- Calculation of flood occurrence for the project area at the different return periods.
- Estimation of floods water levels/depths at intersection of watersheds outlets with the project area for the different return periods.

3.3 The Watershed Modeling System (WMS)

The WMS is a comprehensive environment for hydrologic analysis. It was developed by the Environmental Modeling Research Laboratory of Brigham Young University in cooperation with the U.S. Army Corps of Engineers Waterways Experiment Station.

It allows using the graphical user interface to set up any of the supported hydrologic models. Once boundaries have been created, geometric attributes such as area, slope and runoff distances can be computed automatically. A topological tree representation of the watershed is created, and all data necessary to define hydrologic model can be entered by selecting basins and outlet points.

Several models (HEC-1, TR-55, TR-20, Rational, and NFF) are supported within WMS with the additions of a complete HMS interface and an interface to the Orange County (California) hydrologic models and updates to the Los Angeles County methodologies. Many display options are provided to aid in modeling and understanding the drainage characteristics of terrain surfaces. HEC-1 Model is the model used in this report and it is developed by the U.S. Army Corps of Engineers.

3.4 Constraints

Data on geology and surface water was collected from available maps, reports made available by the Ministry of Water Resources and Irrigation (MWRI) and research institutes. Raw data of rainfall series is not accessible; instead, analysed rainfall data published on Aswan Flood Atlas (Aswan, 2012) was used. Surveying data for streams ground elevations was not available; therefore, DEM was used to extract the needed ground elevations of the streams cross sections.

4. Previous work and flood incidents

The most important earlier work covering the region is the Flood Atlas for Aswan Governorate, which was published by MWRI (Aswan, 2012). This Atlas is a useful guidance tool for decision makers and water resources planners, which allows for the integration of proper water resources management in development planning and ensures avoidance of flood prone areas. The Atlas includes the geomorphological and hydrological characteristics of all wadis and drainage basins, estimated flood water volumes and rates for different return periods (50 and 100 years) and mapping of the flood hazard and risk areas.

The outlets of the drainage basins in the Atlas are usually placed near the closest water body (sea or river) to the streams of these basins. Hence, the various hydrographical features (areas, length, slope…etc.) are usually calculated with respect to the total area of these watersheds. Unlike studying the flood effects on a small project area, the aim in this case is identifying the outlets of the watersheds at the intersection with this project area.

According to the Atlas, the project area (PV Benban Site) is located within Wadi El-Qobbaniya drainage system, which is considered one of the biggest watersheds in Aswan Governorate (about 4700 square kilometers). The system starts at high elevations (about 520 meters above sea level) then its small branches are connected together to form this watershed. The estimated volume of flood water for this watershed is 5 and 21 million cubic meters for 50 and 100 return period years, respectively. The degree of risk inside this basin is classified in the Atlas as from medium to weak.

Most of the flood incidents recorded in Aswan Governorate initiated from the Eastern Desert, due to the higher elevations of mountains and the much higher effect of the Red Sea. The most recent flood incident, recorded in 2010, resulted in catastrophic consequences, destroying about 33 houses and displacing around 1500 families. In 1981, floods that occurred north of Edfu City and El-Nubaria disrupted the railway line in the region and cut the land route between Cairo and Aswan. In 1979, floods hit Aswan City, collapsing more than 300 houses, and leaving many more in need of necessary repairs before being inhabitable again, without resulting in any casualties. Floods also swept some areas in Kom Ombo Center, cutting some roads and the railway. However, there are no records of flashfloods west of the Nile, where the project area is located.

5. Surface Water Analysis

5.1 Topographical analysis of study area

5.1.1 DEM, Slope and Flow Directions Maps

The various hydrographical features that are required for the hydrological analysis are developed using 90-meter resolution DEM. Figure (2) shows the DEM around the project area, illustrating the elevations of the ground surface ranging from 73.5 meters to about 500 meters above mean sea level. Figure (2) clearly shows that the project area is located in area of low ground elevations.

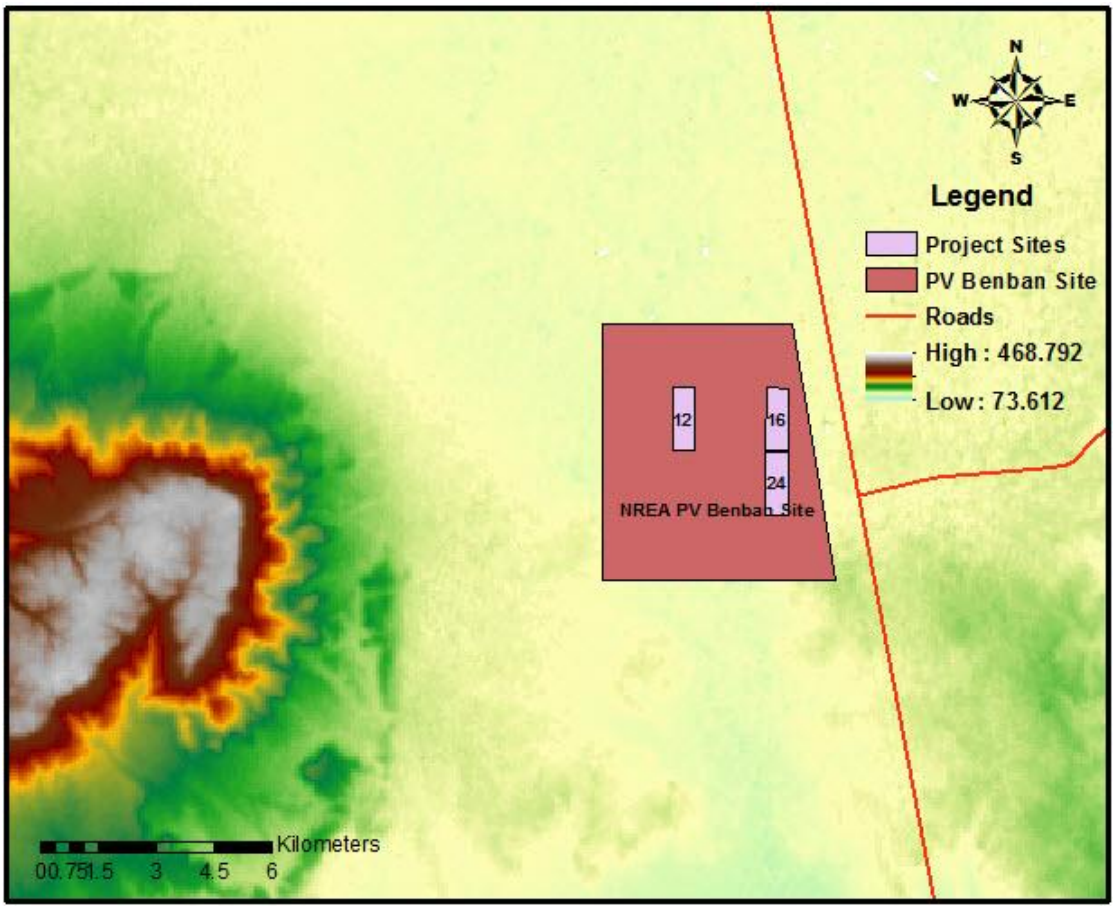


Figure (2): DEM of the project area

Figure (3) shows the slope map of the area, which is also developed using DEM. The figure illustrates that the maximum slope around project area is about 2 %, which is considered a mild slope. Flow direction map (Figure (4)) is also developed using the DEM, and it combines slopes and ground elevations to represent the paths of flow streams (blue arrows). These flow paths are cross checked using topographic maps and satellite images.

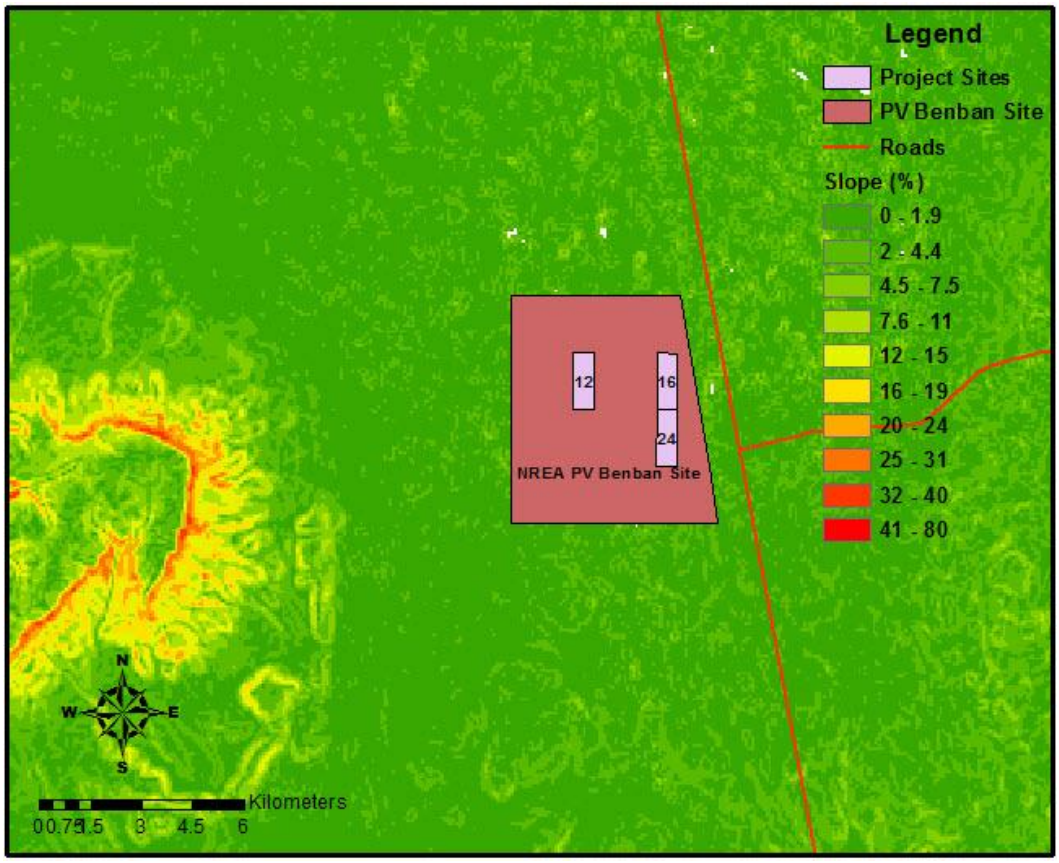


Figure (3): Slope map of the project area

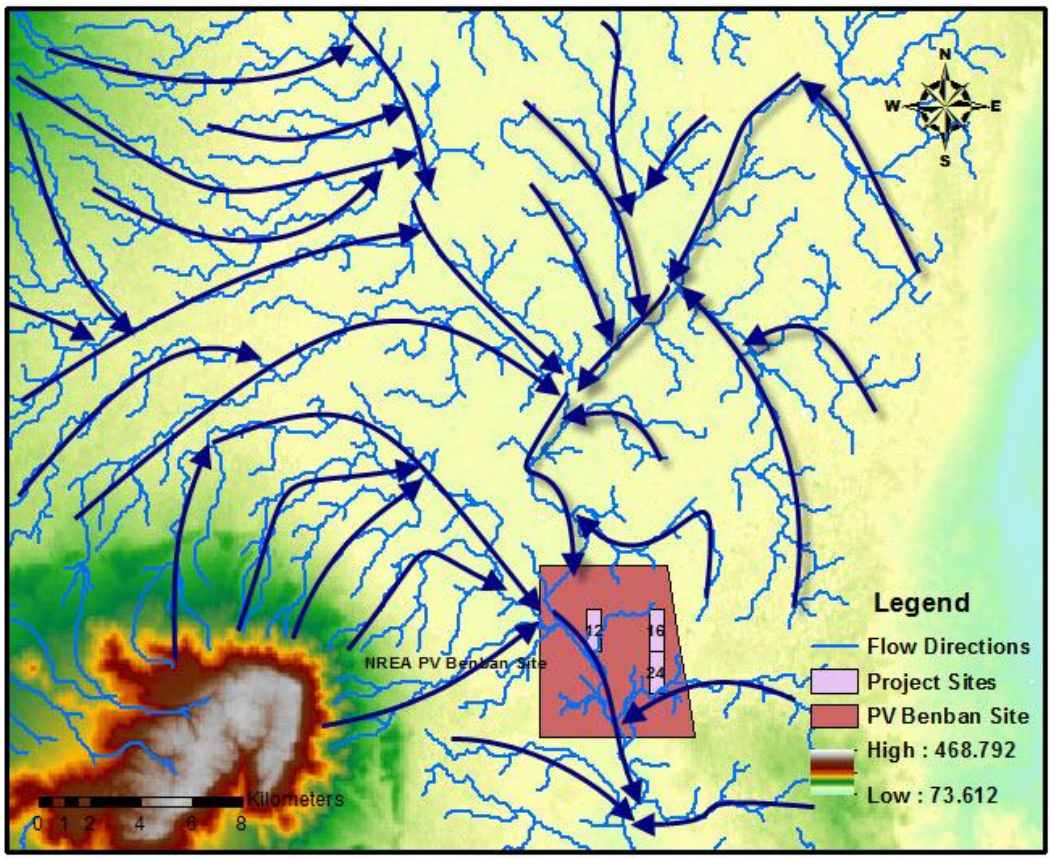


Figure (4): Flow Direction map around the project area

5.1.2 Land-use map

Land use of the study area and its surroundings was determined using a satellite image. Figure (5) shows the main features in the area and the drainage basins that affect the project site, clearly showing no activities in proximity or around. Most areas inside the drainage basins are classified as remote; therefore they can be considered empty natural locations. The map also shows the flow directions that intersect the project area, which are drawn using the DEM after identifying the outlets of the drainage basins at intersection locations. The flow paths determined by DEM were confirmed using the satellite image. This map is also used to estimate the rainfall losses during the storm event, as will be explained later.

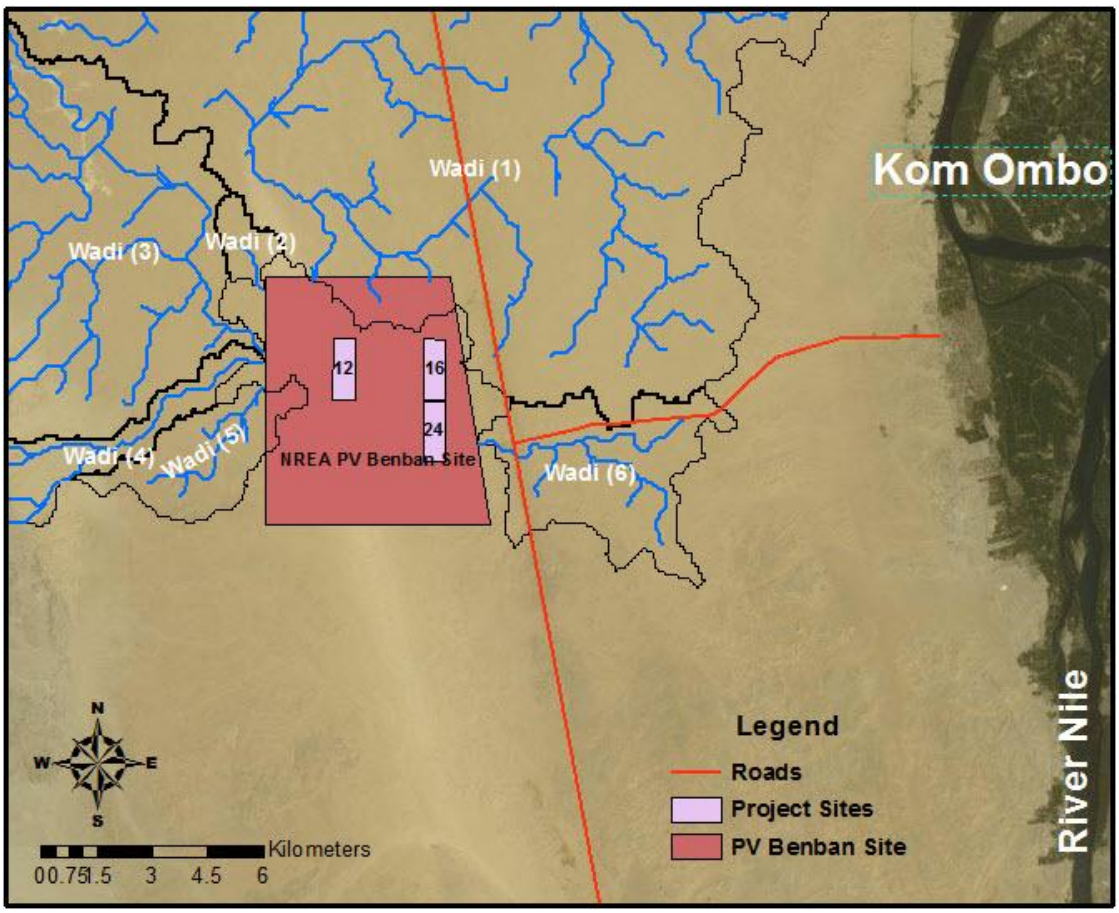


Figure (5): Land-use map of main features around the project area

The analysis of the DEM revealed an extensive drainage network, which originates from the high lands (Gebel El-Barqa) that reach an elevation of about 500 meters above mean sea level. Furthermore, the project area is affected by six drainage basins; the effects of these basins vary according to various features, such as basin area and slope. Wadi (1) and Wadi (3) are classified as having larger areas and high slopes compared to the other basins. Wadi (3), Wadi (4) and Wadi (5) hit the project area from the western side, while Wadi (2) and Wadi (1) hit from the north. Wadi (6) is the only watershed that hits the project area from the eastern side.

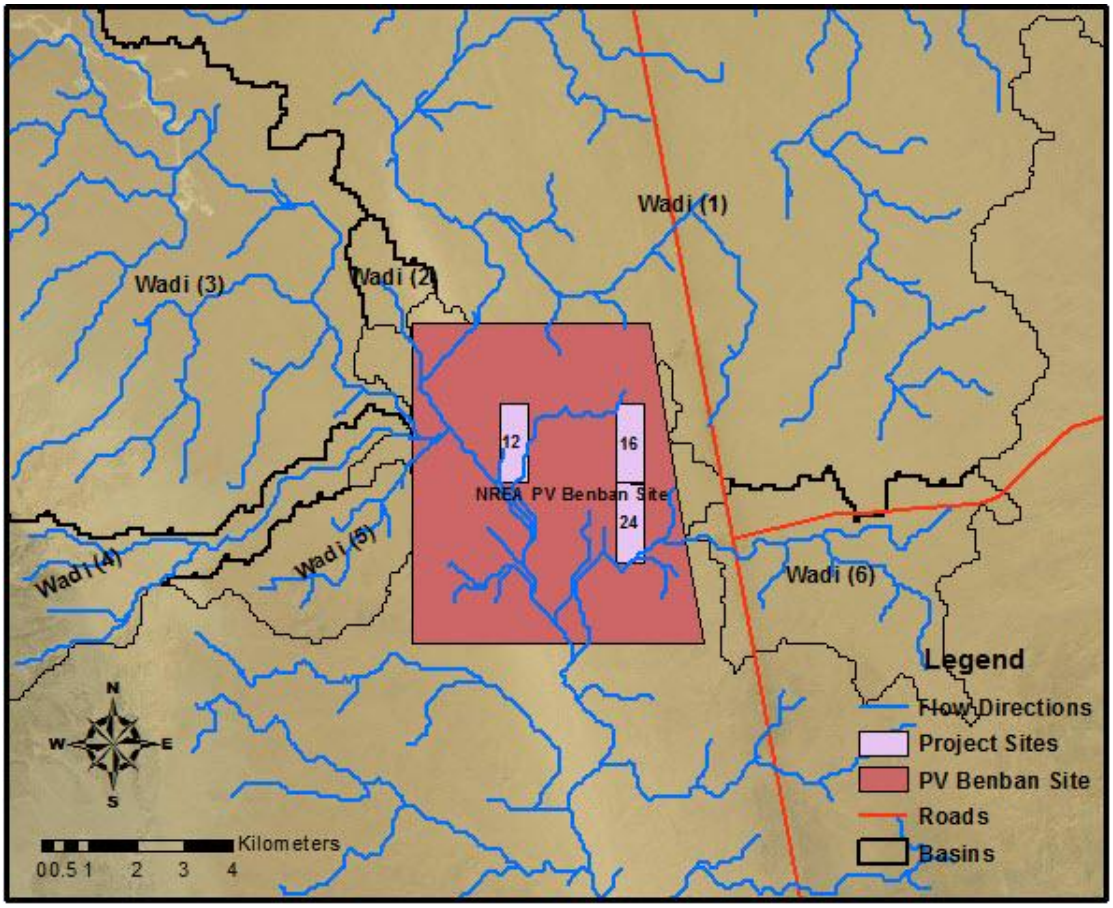


Figure (6): Drainage streams inside the project area

Figure (6) shows the drainage streams inside the project area, which subject the project location to potential floods. All project sites are positioned in flood flow direction. Project sites 12 and 16 are subject to being affected by watersheds 1, 2, 3, 4 and 5, while project site 24 may only be affected by watershed number 6. Nevertheless, in case of high flood volumes and peaks, the entire project site will be subjected to risk, and it is difficult to specify which of the project sites could remain safe.

5.2 Morphological analysis

Morphological analysis is applied to determine the physical characteristics of the drainage basins, including: lengths, areas, and slopes. This is achieved through analyzing the DEM information using the WMS model, which identifies watersheds affecting the project area, and delineates the boundaries of the drainage basins, as described earlier. Figure (7) shows the drainage basins that affect the project area. Once the basin boundaries have been delineated, geometric attributes such as area, slope and runoff distances are computed automatically.

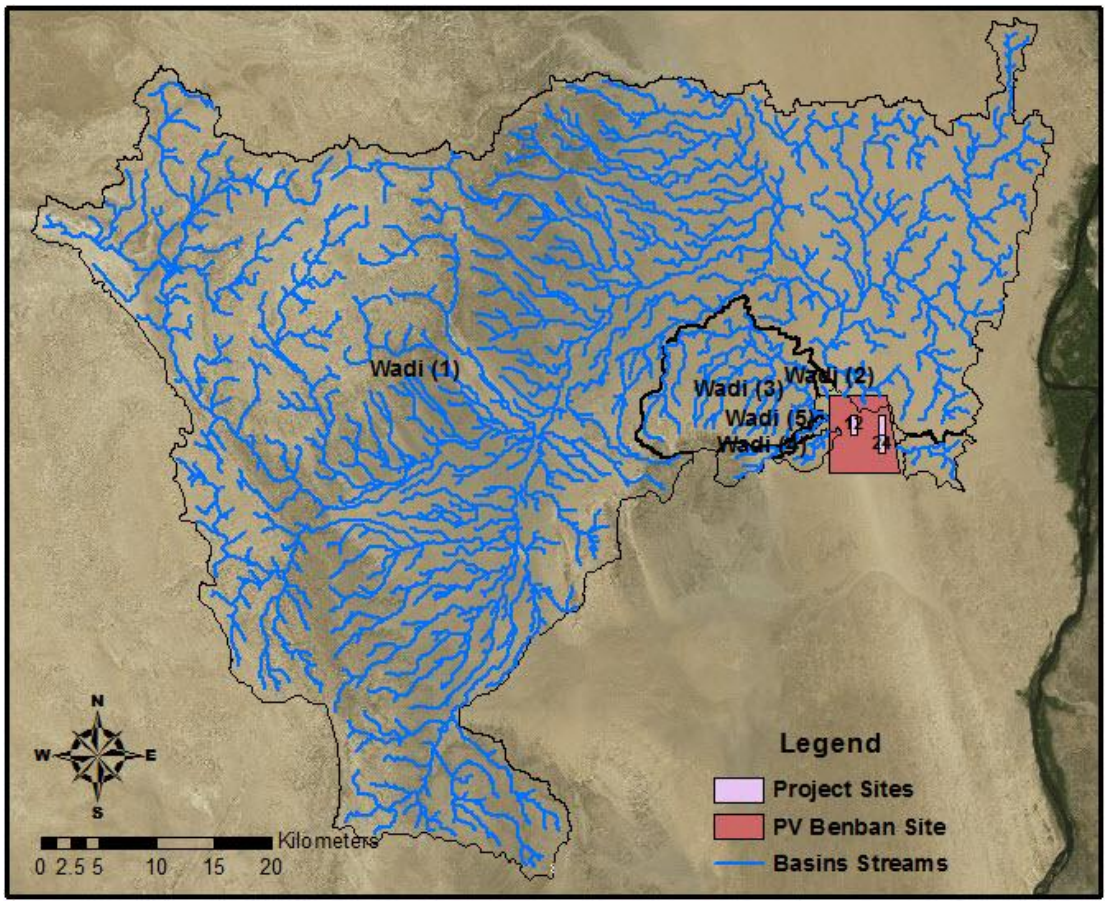


Figure (7): Drainage basins affecting the project area

Morphological analysis also determines unit hydrograph parameters, such as Lag Time (TLag) and Concentration Time (TC), which are crucial for the identification of the unit hydrograph of each drainage basin. TC is defined as the time needed by rainfall on the far point of a basin to reach its outlet as flood, while TLag is the time delay between the peak occurrences of unit rainfall and unit runoff. Around the project area, six drainage basins were identified, and their corresponding parameters are shown in Table (1).

Table (1): Morphological characteristics of the drainage basins

Drainage Basin	Area (km^2)	Length (Km)	Slope (%)	Lag Time (hr)	Concentration Time (hr)
Wadi (1)	3002.73	71.84	2.70	14.79	24.65
Wadi (2)	2.65	2.72	1.02	0.91	1.52
Wadi (3)	145.64	16.78	2.52	4.42	7.37
Wadi (4)	17.91	11.06	7.45	1.84	3.07
Wadi (5)	10.94	5.76	1.06	1.42	2.36
Wadi (6)	20.58	7.15	1.07	2.05	3.41

These parameters are important for calculating the hydrograph of the floods at different return periods (the volume of flood and its peak time). The areas of wadi (1) and wadi (3) are 3002.73 and 145.64 square kilometres, respectively. Wadi (4) is not

of a large area or extended length, however, it has a high slope of about 7%, which is clearly reflected in the hydrological analysis results. Except for wadi (4), the slopes of the basins are mild, which has direct bearing on the acceleration of water movement on land surface.

5.3 Geological analysis of the study area

Figure (8) shows the geological map features of the drainage basins that affect the project area. The analysis of the geological map around the region of Benban site shows that it is generally described by sand or lime stones with medium potential of cracks or faults. The rocks classification indicates that sedimentary soils (quaternary or wadi deposits) cover a large area of the drainage basins, in the direction towards the River Nile. Lime stone is spread out in the western side of the basins (tertiary), while the sand stone formation (Nubia formation or upper cretaceous calcite) is reserved in their middle. It is, therefore, concluded, that there is a high potential for rainfall losses to infiltration, which reduces the volume of floods runoff.

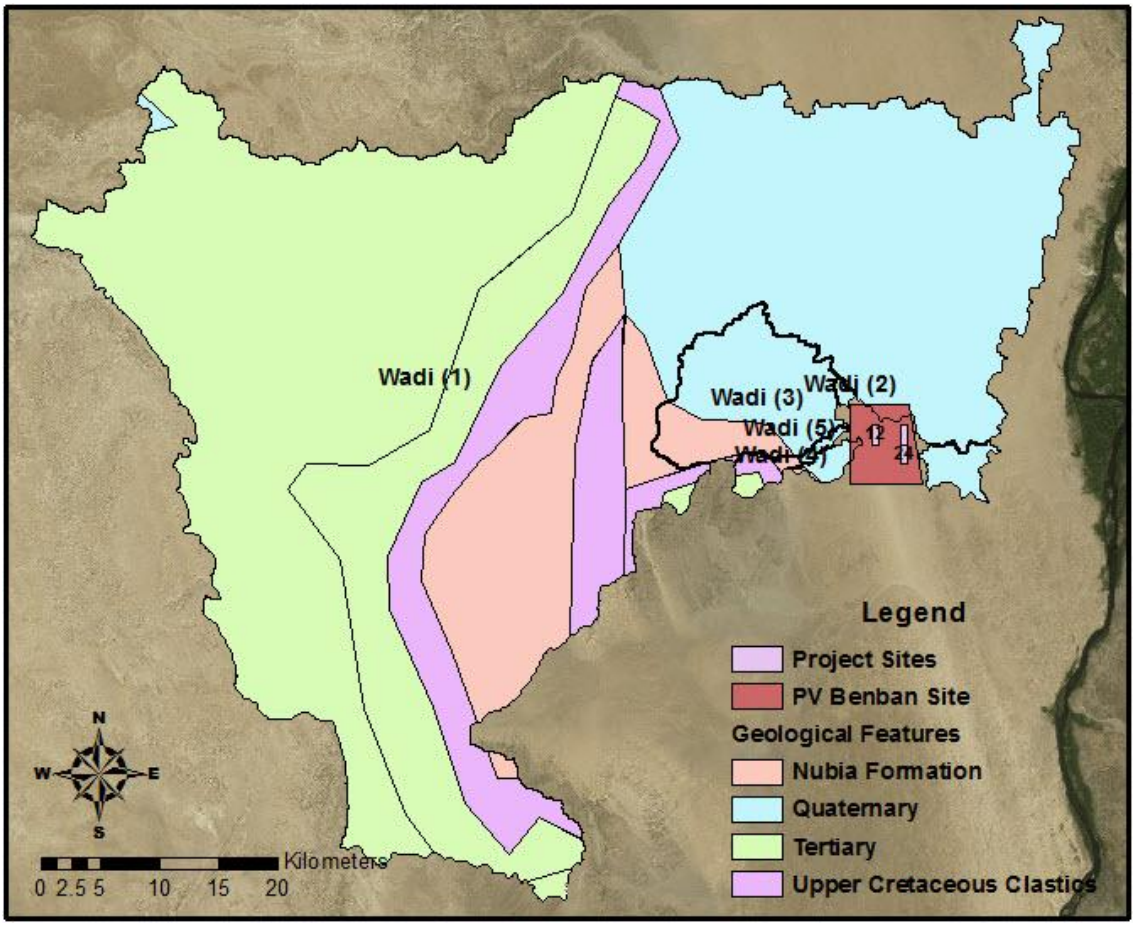


Figure (8): Geological map features for drainage basins around the project area

5.4 Meteorological analysis

Rainfall data is a required input for hydrological analysis, so as to determine the runoff volumes for each drainage basin affecting the project area. The closest rainfall station to the study area is Kom Ombo Station. Results of statistical analysis (obtained from Aswan Flood Atlas) were used to get the maximum daily rainfalls for 2, 5, 10, 25, 50 and 100 year return periods.

According to the Atlas, the frequency analysis of Kom Ombo Station using different statistical distributions has shown that the distribution that fits the rainfall data with the highest confidence of error is the General Extreme Values (GEV). This distribution is used to estimate the rainfall values for the required years. Table (2) indicates the results of this statistical analysis for the rainfall data for 2, 5, 10, 25, 50 and 100 year return periods. These rainfall values will be used as input to the hydrological model in order to estimate the flood hydrograph.

Table (2): Results of the statistical analysis of the rainfall data at Kom Ombo station

Flood return period (Year)	**2**	**5**	**10**	**25**	**50**	**100**
Rainfall values using GEV distribution (mm)	4.82	7.22	10.9	19.4	29.1	43.7

5.4.1 Design Storm

Hydrological calculations depend on the rainfall design storm characteristics, which are estimated at different flood return periods from statistical analysis of rainfall measured at meteorological stations that affect the project area. Because of absence of the measured rainfall storm records (duration and distribution), the rainfall storm duration has been assumed depending on the time of concentration of the drainage basins. This would ensure that the rainfall storm duration will cover the whole drainage basin before flood occurs at the drainage outlet, hence this storm will be represented in the hydrograph. On the other hand, the storm distribution is assumed according to SCS-rainfall distributions standard types (Chow et al., 1988). By dividing the time into equal intervals, the corresponding rainfall intensity could be attained. This is used in calculations of the required hydrographs which is used in the hydrological analysis as will be mentioned later.

5.4.2 Rainfall Losses

The total amount of rainfall is divided into two parts which are the infiltrated amount to the top soil (losses) and the excess amount (runoff). Estimation of the rainfall losses is required to calculate the surface runoff in the drainage basin system. Despite the complexity of the actual loss process, there are many methods developed to estimate the rainfall losses. One of these methods is the Soil Conservation Service Curve Number (SCS-CN). This method is commonly used in research and analysis and it is one of the methods that WMS model uses. It will be used in the hydrological analysis and the following section describes how it works.

The method depends on the basin soil type and land-use characteristics. The rainfall-runoff relationship in this method is derived from the water balance equation and a proportionality relationship between retention and runoff. The SCS rainfall-runoff relationship is shown in Figure (9) and given by:

$$P_e = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \text{Equation (1)}$$

where:

P = Rainfall depth (mm).

Pe = Depth of excess rainfall (mm).

Ia = Initial abstractions (mm).

S = Volume of total storage (mm).

Storage includes both the initial abstractions and total infiltration. The initial abstraction is a function of land use, infiltration, detention storage, and antecedent soil moisture. The initial abstraction and the total storage are related in an empirical statistical equation which is given as:

$$I_a = 0.2S \qquad \text{Equation (2)}$$

Substituting Equation (2) into Equation (1) yields:

$$P_e = \frac{(P - 0.2S)^2}{(P - I_a) + S}$$

The storage S (in millimetres) is obtained using the formula:

$$S = \frac{25400}{CN_{IorIII}} - 254 \qquad \text{Equation (3)}$$

$$CN_I = \frac{4.2\,CN_{II}}{10 - 0.058\,CN_{II}} \qquad \text{Equation (4)}$$

$$CN_{III} = \frac{23\,CN_{II}}{10 + 0.13\,CN_{II}} \qquad \text{Equation (5)}$$

where:

CN_{II} is the curve number that can be obtained from standard tables for different combinations of land-use and land cover, hydrologic soil groups, and hydrologic condition.

CN_{IorIII} value is calculated according to the state of the initial soil condition (wet or dry).

Equation (4) is used in case of dry soil while Equation (5) is used for wet soil which is the critical case in estimating the flood volume. The conservative wet condition was assumed to estimate to the floods hydrographs. This means that the storm comes after a rainy day, not necessarily causing a flood, but saturating the soil and thus increasing run off of the subsequent storm.

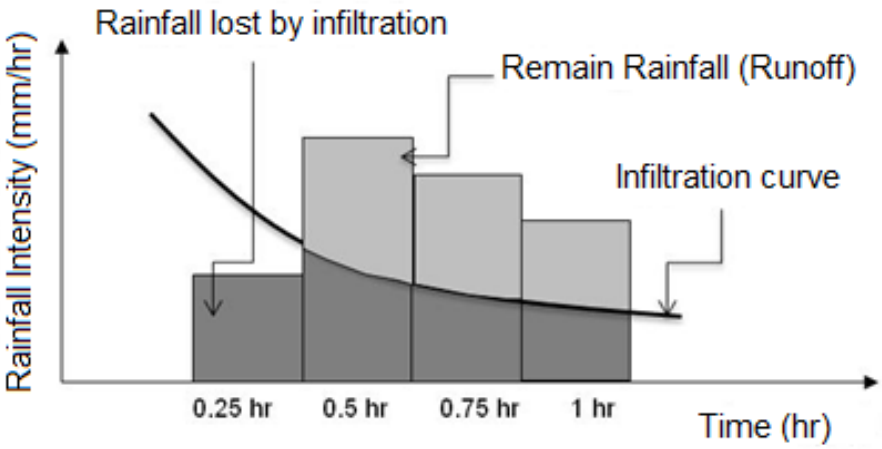


Figure (9): Schematic diagram for Loss Rate and Rainfall Excess Hyetograph

5.5 Hydrological analysis

As mentioned earlier, this analysis is concerned with the conclusion the hydrographs of the drainage basins. The hydrological analysis is based on the results of the meteorological, morphological and geological analyses to estimate the amount of flood water and the disposal and maximum time for the arrival of flood peak times.

5.5.1 Conclusion of the hydrographs

The hydrological analysis was done using the WMS model to calculate the properties of the hydrological drainage basins. WMS determines the drainage basins that have direct effect on the area of interest using the DEM of the region. It also helps in producing the required hydrographs according to complexity of the drainage basins, where natural methods are used in cases of availability of flood measurement data, while synthetic methods in cases of unavailability. In order to obtain the hydrograph for each catchment for the different return periods, the HEC-1 model (built in module in the WMS model) is used.

With the absence of the runoff measurements in the study area, synthetic unit hydrograph methods are used to calculate the characteristics of the surface runoff. The synthetic unit hydrograph of the Soil Conservation Service (SCS-UH) is one of the recommended methods used worldwide. It is based on a dimensionless unit hydrograph developed through the analysis of a large number of unit hydrographs for many regions. This method was used to estimate the required hydrographs for the drainage basins affecting the project area, in cases of lack of measured data that can be used for model calibration and validation.

Annex 1 includes the results of the hydrographs using the outcomes of the statistical rainfall analysis as per Table (2). These hydrographs are given for 25, 50 and 100 years flood return period.

Table (3): Summary of the hydrological analysis results for the drainage basins

Drainage Basin	Flood Volume (m3)			Peak Discharge (m3/s)			Time to peak (min)
	25-Year	50-Year	100-Year	25-Year	50-Year	100-Year	
Wadi (1)	-	879,361	7,298,644	-	9.80	80.89	1695
Wadi (2)	-	-	3,120	-	-	0.35	255
Wadi (3)	-	16,093	340,060	-	0.54	11.33	510
Wadi (4)	2,844	34,644	131,097	0.39	4.54	16.02	210
Wadi (5)	-	-	12,897	-	-	0.89	315
Wadi (6)	-	-	24,260	-	-	1.36	360

Table (3) summarizes the hydrological analysis results for the six drainage basins, showing the variance in runoff volumes and peak discharge values. According to these results, all the drainage basins give no water for 25-year return period except for wadi (4). The main explanation for this is that wadi (4) has a higher slope compared to others (except for wadi (1)), which, in addition to its soil classification, reduces the amount of infiltrated water. For the 50-year return period, some drainage basins do not give values for flood volumes, which is due to low rainfall volumes and high infiltration rates.

In general, the maximum values of flood volumes and discharge occur for 100 year flood return period for wadi (1) and wadi (3). The flood volumes for wadi (1) and wadi (6) are 7.29 and 0.34 million cubic metres, respectively, while the peak discharges for the same drainage basins are estimated, for this flood, as 80.89 and 11.33 m3/s respectively. The minimum values of flood runoff occur from wadi (2) and wadi (5) with volumes of 0.0031 and 0.012 million cubic meters, respectively.

Results show that in general, floods do not take long to reach their peak values except for wadi (1), with wadi (4) requiring least time (about 3.5 hours). Taking into account the volume of this flood and the basin length and area, the flood risk is considered low. The highest flood takes more than 24 hours to reach its peak value (wadi (1)). These results are derived from the available data of rainfall and rainfall storm distribution; however short duration rainfall storms could occur, which might lead to shorter time to peak discharge.

6. Floodplain Analysis

6.1 Cross section Extraction

Because of absence of surveying data in the region, ground elevations for the cross sections are extracted from the DEM for the six cross sections at intersection of watershed outlets with the project area. The locations of these cross sections are shown in Figure (10), and their ground elevations are obtained and summarized to be used for estimating flood water depths.

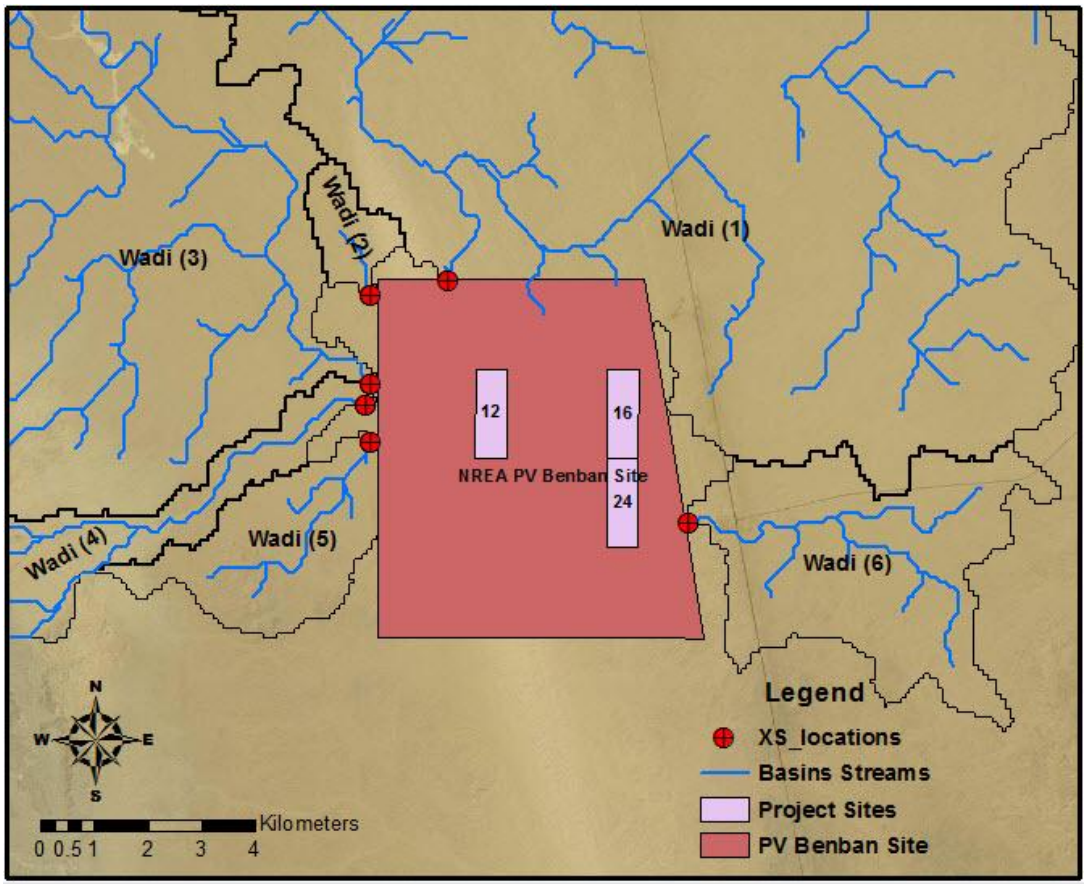


Figure (10): Locations of cross sections extracted from DEM

6.2 Hydraulic analysis of floods

The hydraulic analysis is used for checking whether the various cross sections are hydraulically safe, that is whether they can contain the floods volumes, and hence water depths in each cross section could be estimated. The Manning Formula is typically used to estimate the required water levels and depths. This equation uses the estimated runoff discharges from the hydrological analysis, as well as the extracted cross section areas to check whether their capacities are enough to contain floods volumes.

Manning Formula: $$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where:-

Q: floods discharge in m^3/s

n: Manning coefficient (based on roughness of the land)

A: Area of cross section in m^2

R: the Hydraulic radius of cross section and it equals A/P where P is wetted perimeter in m

S: slope of the stream in %

Water levels are calculated using this equation for each cross section for 25, 50 and 100 years flood return period. According to the hydrological analysis results, flood water levels for some of these return periods do not exist due to infiltration. The following figures (Figure (11) to Figure (16)) illustrate the results of floodplain analysis, showing the expected water levels in each cross section for different flood return periods.

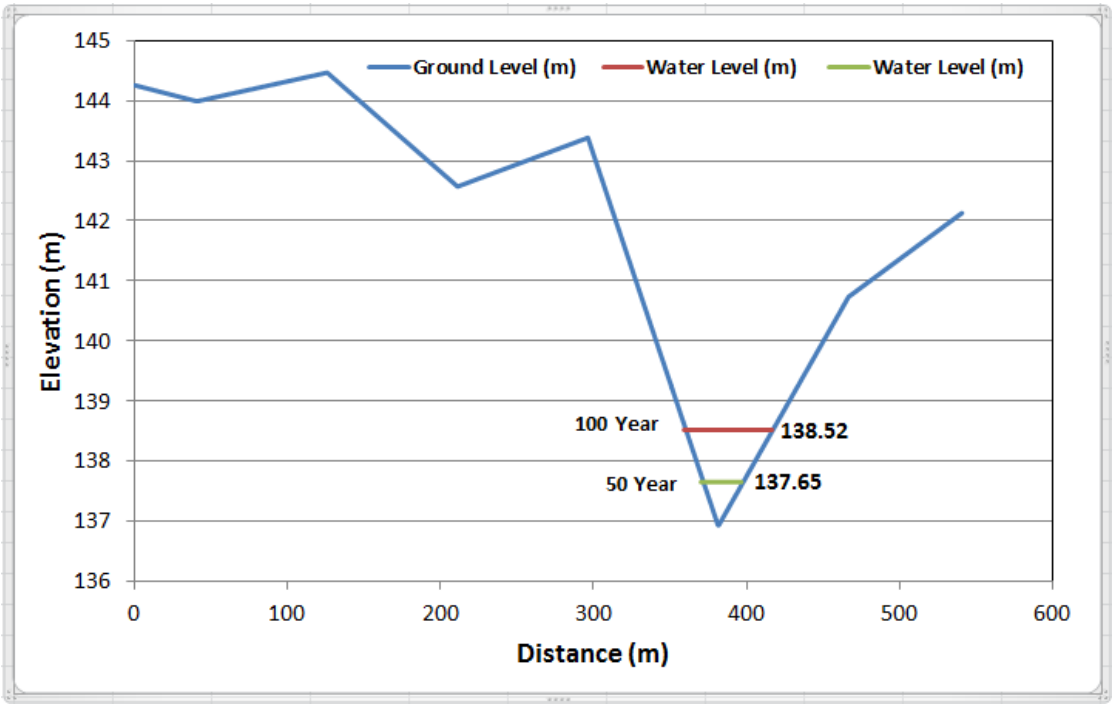


Figure (11): Floods Water Levels for Wadi (1)

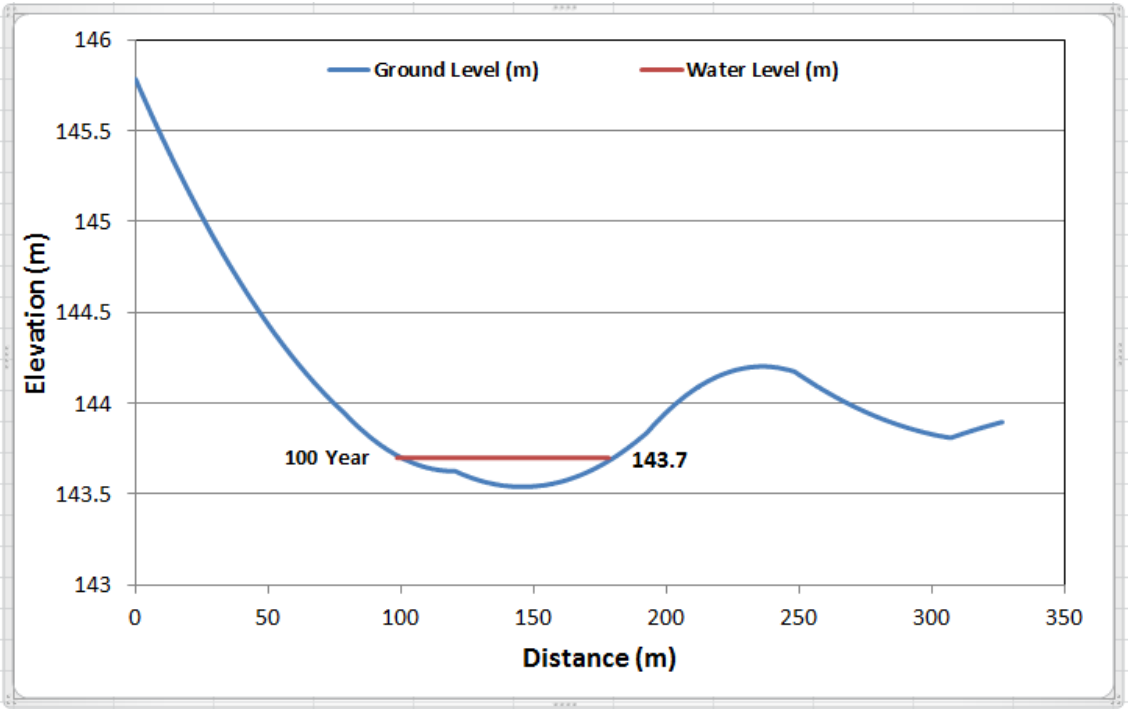


Figure (12): Floods Water Levels for Wadi (2)

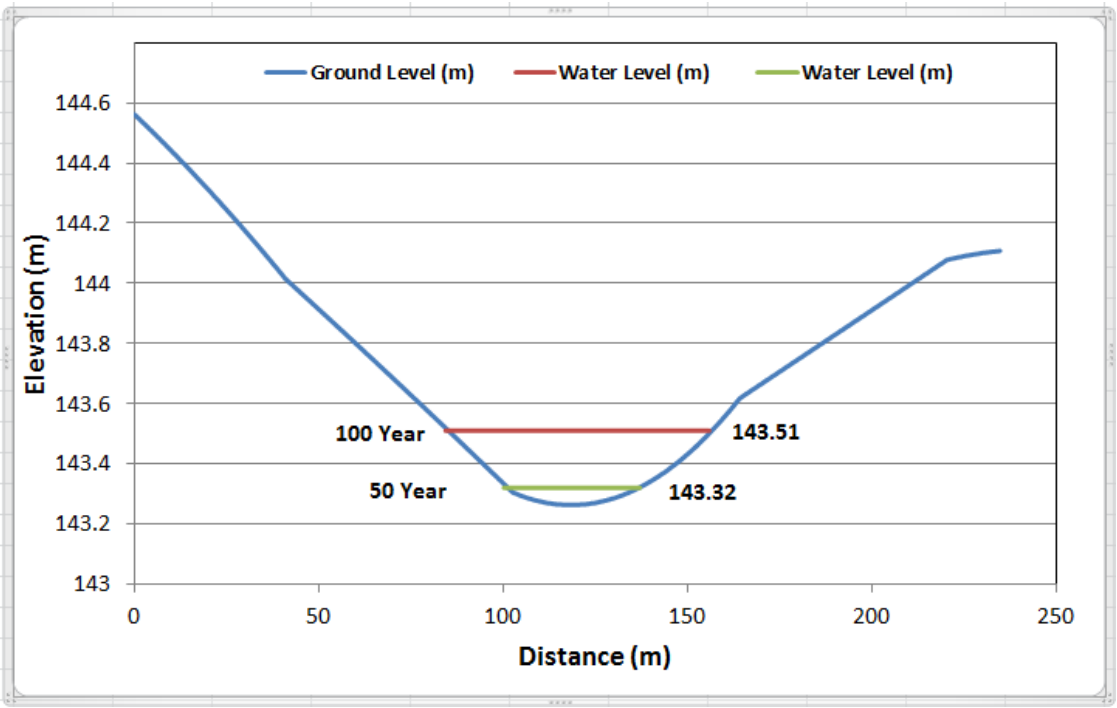


Figure (13): Floods Water Levels for Wadi (3)

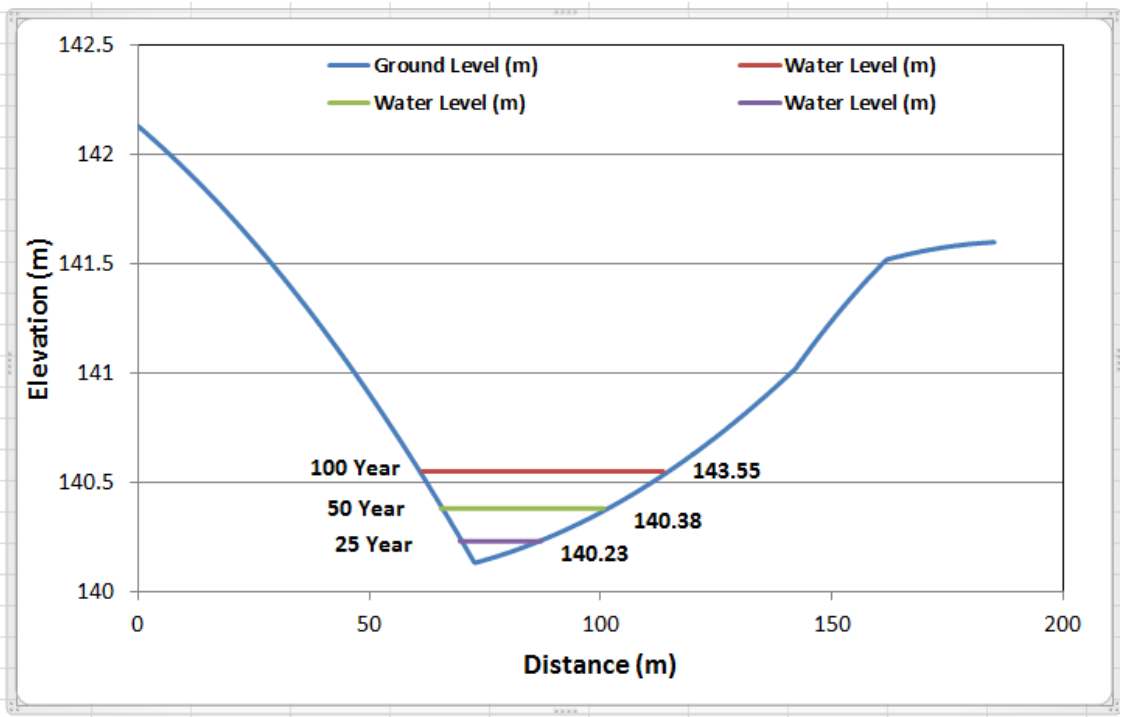


Figure (14): Floods Water Levels for Wadi (4)

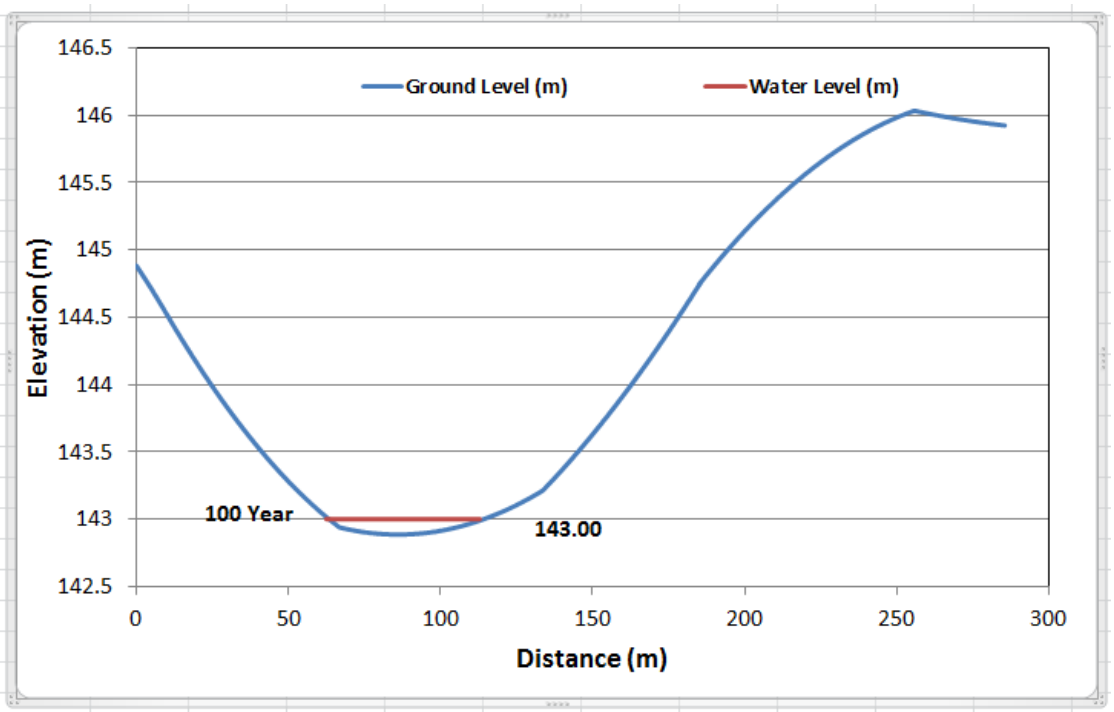


Figure (15): Floods Water Levels for Wadi (5)

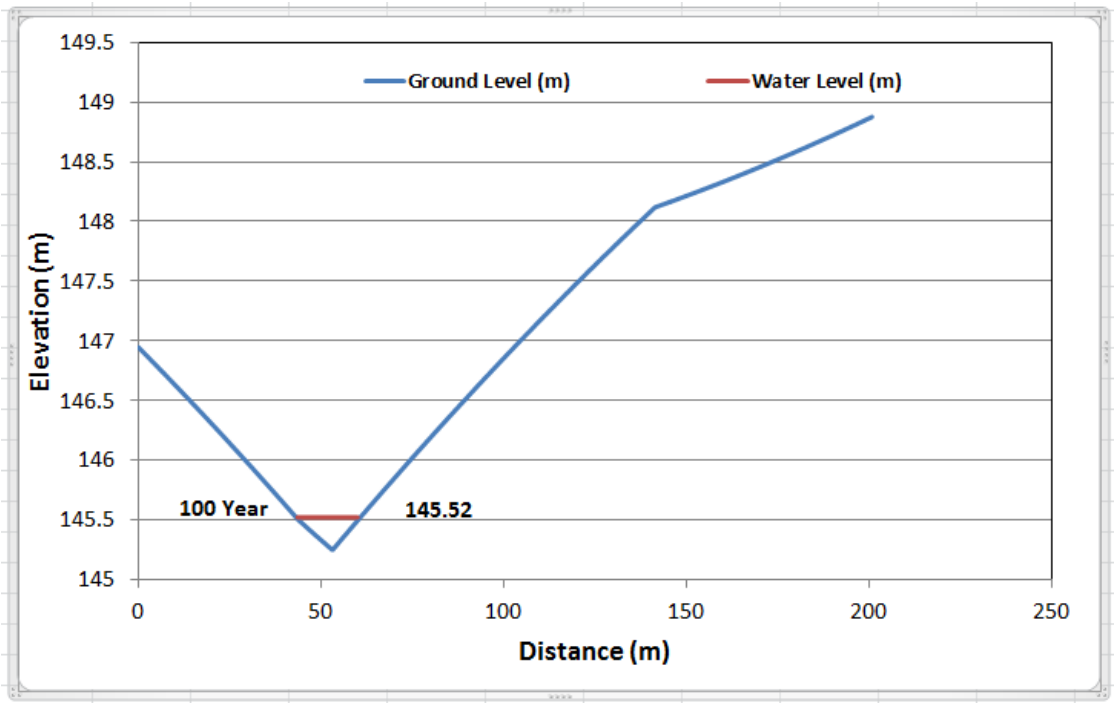


Figure (16): Floods Water Levels for Wadi (6)

Figure (17) to Figure (19) present a group of maps that reflect the expected water depths over ground level at each cross section for different flood return period. These values can be used to identify suitable flood protection methods. For example, Figure (17) shows that all the drainage basins have no water for 25-year return period, except for wadi (4), where the water depth over ground reaches 10 cm. Figures 18 and 19 show that the highest water depths over ground come from wadi (1), being 0.72 and 1.59 meters for 50-year and 100-year return period, respectively. Table (4) summarizes the values of the water depths at each cross section for all the given return periods.

Table (4): Floods water Depths and Velocities at each cross for different return period

Locations of Cross Section	Water Depth (m)			Velocity (m/s)		
	100-Year	50-Year	25-Year	100-Year	50-Year	25-Year
Wadi (1)	1.59	0.72	0.00	1.8220	1.0810	0.0000
Wadi (2)	0.16	0.00	0.00	0.2990	0.0000	0.0000
Wadi (3)	0.25	0.06	0.00	0.8240	0.3100	0.0000
Wadi (4)	0.42	0.25	0.10	1.1390	0.7990	0.4250
Wadi (5)	0.16	0.00	0.00	0.3680	0.0000	0.0000
Wadi (6)	0.27	0.00	0.00	0.5290	0.0000	0.0000

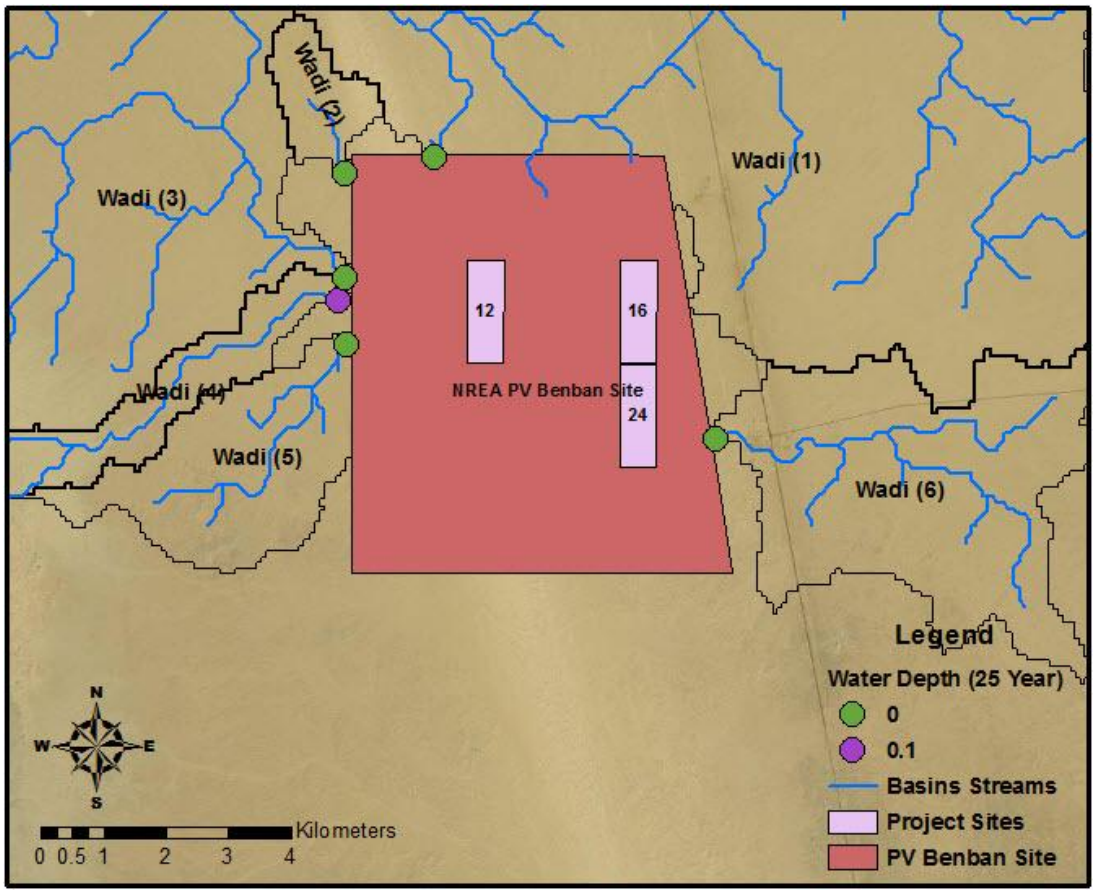


Figure (17): Floods Water depth map for 25-flood return period

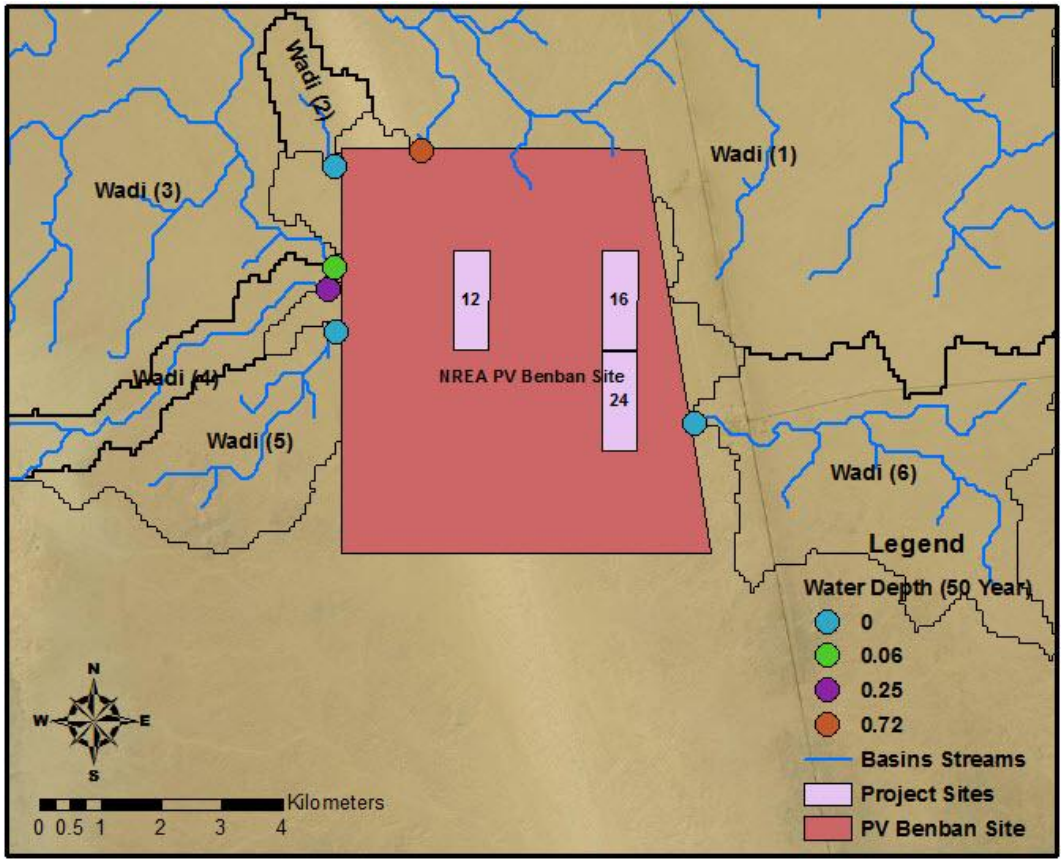


Figure (18): Floods Water depth map for 50-flood return period

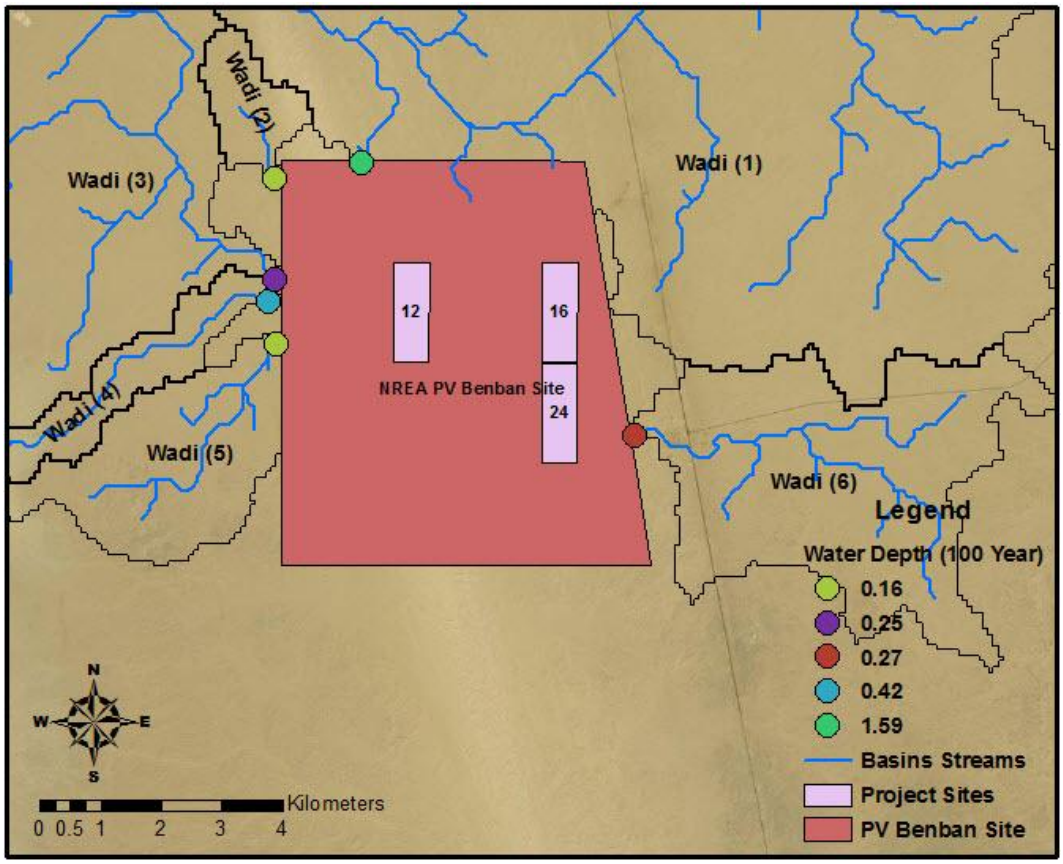


Figure (19): Floods Water depth map for 100-flood return period

Figure (20) presents a map that illustrates the velocities of flood water at each cross section for different flood return period. In general, all the expected water velocities are within the slow range, where most the values fall between 0.25 and 0.85 m/s. Velocities exceeding 1.0 m/s are limited to one and two in the 50 year and 100 year return period respectively, as indicated in Figure (20) and in Table (4). The maximum flood velocity occurs at the outlet of wadi (1) with a value of 1.82 m/s. However, this velocity is considered slow for destructive flash floods events which velocity exceeds 2-3 m/s. It can be concluded that these velocities are not destructive; however, they can still have an effect on the project area.

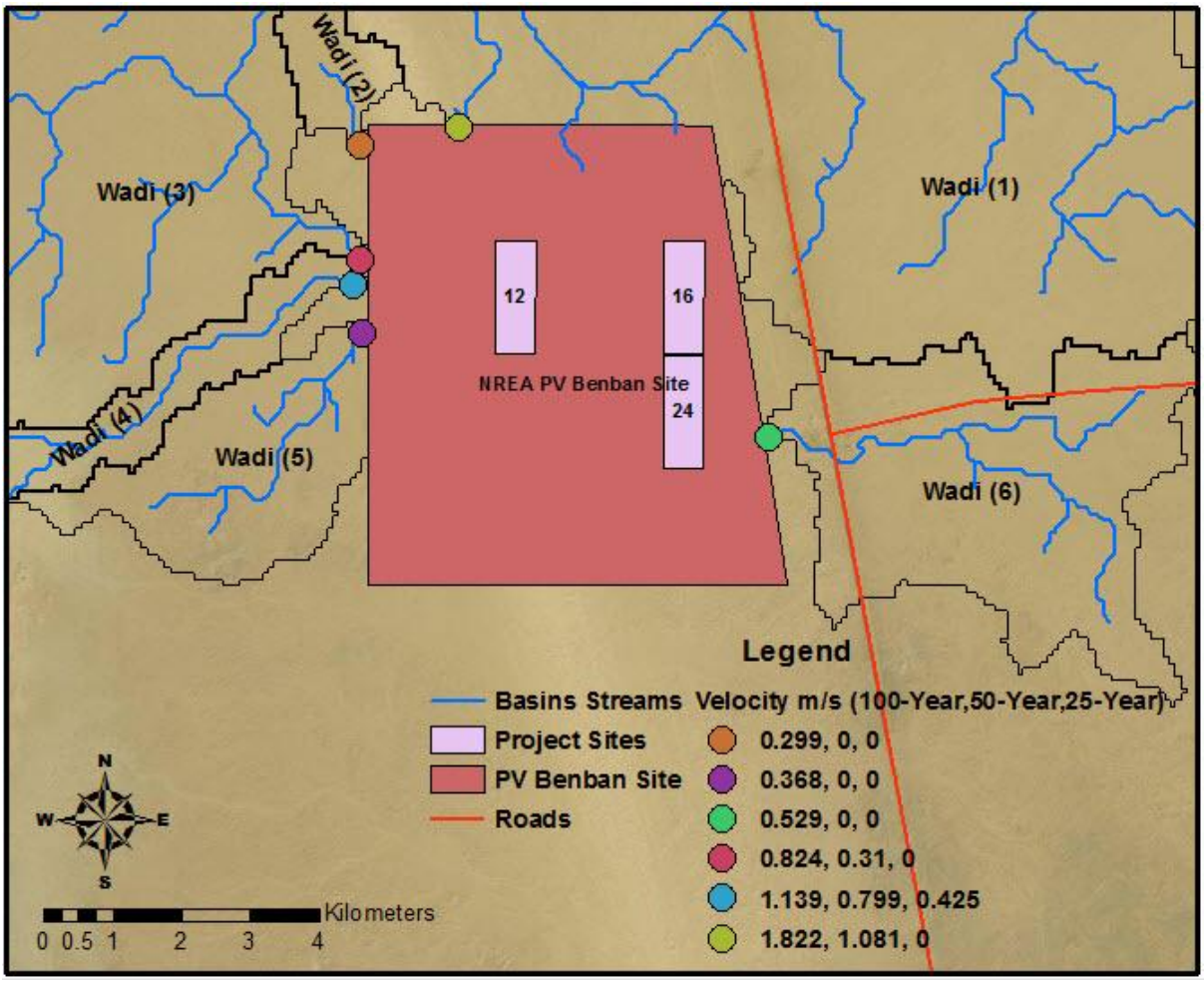


Figure (20): Velocities of floods water at cross sections locations for different return period

Figure (21) shows the roads around the project area. Road (1) intersects two drainage basins (wadi (1) and wadi (6)), while Road (2) is parallel to the streams inside wadi (6). With respect to flood caused by 100 year return period, Road (2) is not affected, since it is located on relatively high land, which makes it accessible during floods events. During floods from wadi (6), taking into account low flood velocity and the elevation of Road (1) (Figure (22)), water would be ponded before the road. If the flood water exceeds the road elevation level, it would cross the road as a low sheet flow. Hence, Road (1) in this section would be accessible too. Furthermore, the small branch of wadi (1) intersecting Road (1) will not affect it because of the small volume of flood water and the high infiltration rate of the soil. Therefore, all the project sites would be accessible in case of flooding, due to slow flood velocity and roads elevation, which reduce potential hazards.

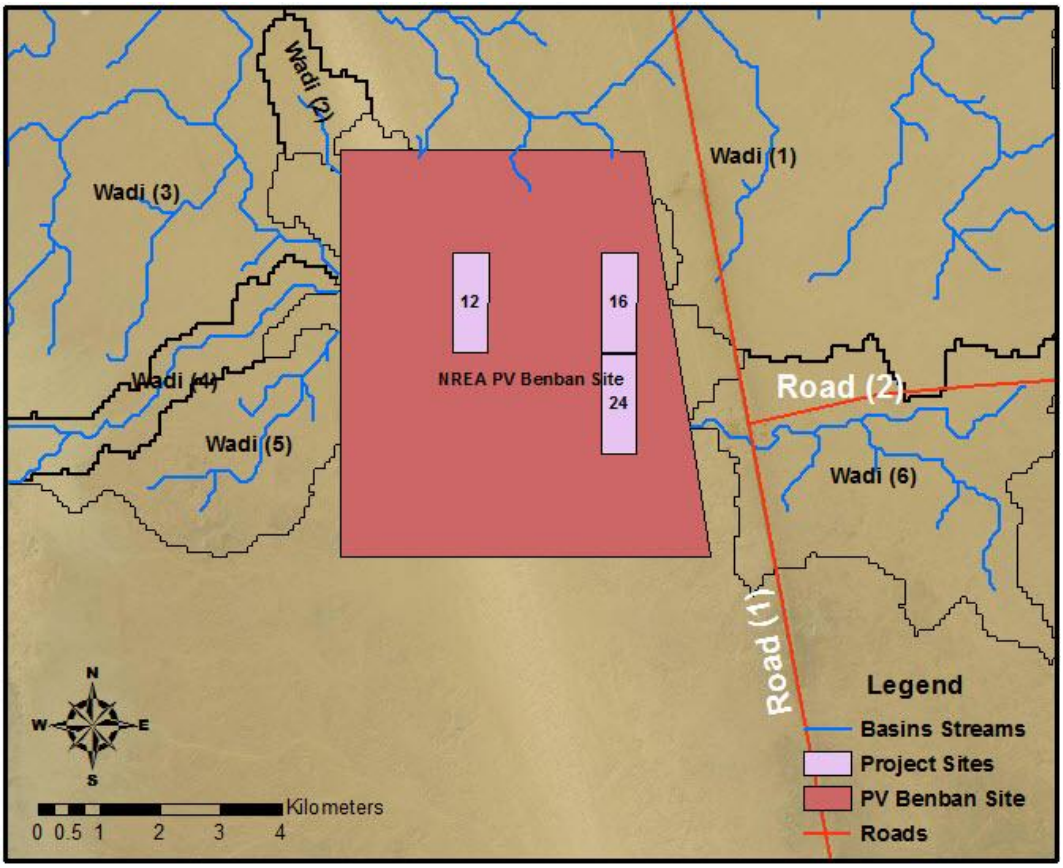


Figure (21): Roads around the project area

Figure (22): Photo of intersection of Road (1) and Road (2)

Figure (23) illustrates the proposed protection works for the project area with respect to floods with 100 year return period. Because of lack the details of works planned for each plot within the park, it is difficult to specify a separate protection construction for each. Moreover, the protection of each plot, even if technically feasible is expected to be more expensive than a collective protection of the park.

Accordingly, the most suitable solution is to protect the whole project area (PV Benban Site) as one unit, which would reduce construction cost and achieve better safety. This overall protection can be done by constructing two short dikes (maximum height 2 or 1m , if protection is from floods of 100 or 50 year recurrence respectively) at the western and northern directions of the project area, as shown in Figure (23). The main function of these dikes would be to collect water and reduce its velocity then divert flood water away from the project area. Dike (1) is to be constructed with a tilted angle to ensure diverting flood water to the western side, while Dike (2) is to be constructed in parallel to the area, and with the same height, to guarantee that the diverted water would not overflow. These dikes will protect the park from the impacts of floods from all drainage basins, except Wadi (6). In order to avoid potential hazards from this Wadi, and given the relatively small quantity of expected water, a small pond to be excavated on its path as it approaches Road (1) will be sufficient to collect flood water.

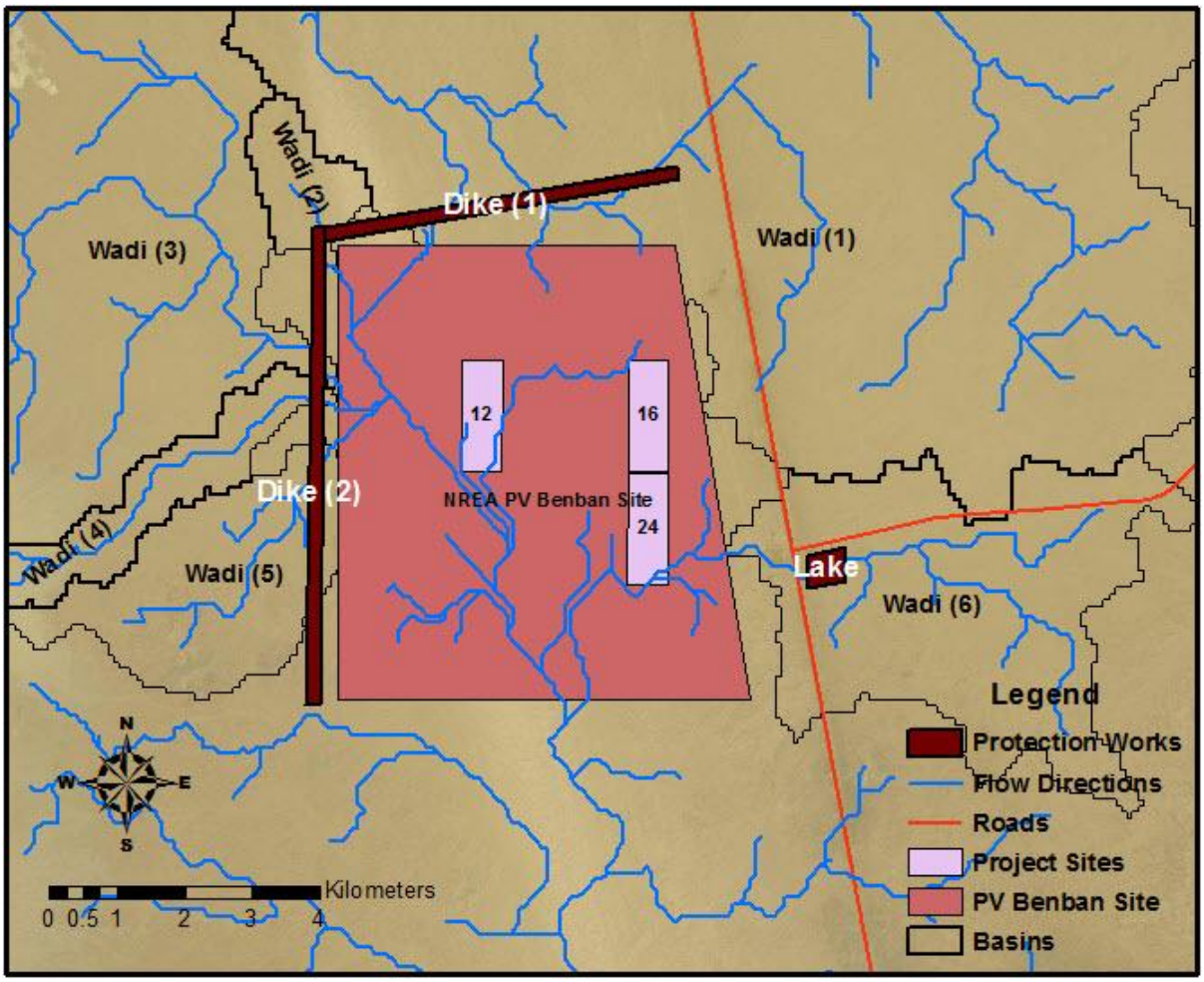


Figure (23): Proposed protection works for the project area (Diagrammatic)

7. Conclusion

Topographical analysis of the project area has shown that the drainage basins start at far distances and relatively high elevations. The land-use map has not demonstrated any activities inside these basins. Geological analysis of the region indicates that expected water losses to infiltration are high.

According to the morphological analysis, six watersheds affect the project area, two of which would potentially produce the maximum volumes of flood water because of their relatively large areas. However, the type of soil and low rainfall volume directly affect percentages of water loss. The results of rainfall statistical analysis were used in the hydrological model to produce the required hydrographs. The hydrological analysis estimated the flood volumes, their peak discharges and the time needed to reach these peaks. The potential flood would initiate from wadi (1) with a volume of 7.29 million cubic meters. The shortest potential flooding time is about 3.5 hours, from wadi (4).

The cross sections needed for floodplain were extracted from DEM, due to the absence of surveying data. Results were presented in terms of flood water depths and velocities at each cross section for the intersection locations with the project area. The results showed that most water velocities are within safe range and that water depths are below one meter except for wadi (1).

The project area is subject to flashflood hazards from several drainage basins. The potential total volume of the flood water necessitates establishing protection works. Project sites (12) and (16) are subject to potential impact from western and northern sides, while project site (24) is subject to potential impact from the eastern side. During potential floods, all roads leading to these sites will be accessible. It is recommended to protect the whole Benban Solar Park area, instead of constructing separate protection works for each site. Protection is especially required at the northern and western sides, where it is suggested to construct two short dikes to collect and divert flood water. A small pond is required at the eastern direction right before Road (1). These protective measures would ensure controlling the highest peak discharges, thus reducing the potential flooding risks from the drainage basins at the site.

References

Aswan Flood Atlas (2012). Ministry of Water Resources and Irrigation master plan (MWRI), National Water Research Center (NWRC), Water Resources Research Institute (WRRI)

US Army Topographic Maps (1953). - Egypt Scale 1:250000

Geological Map of Egypt, (1981). Ministry of Industry and Mineral resources, The Egyptian Geological Survey and Mining Authority - Scale 1:2 000 000

Chow, V. T., Maidment, D. R., & Mays, L. W. (1988). Applied hydrology. New York: McGraw-Hill.

Website for Climate: http://en.tutiempo.net/climate/

Annex (1)

Hydrographs of the Drainage basins

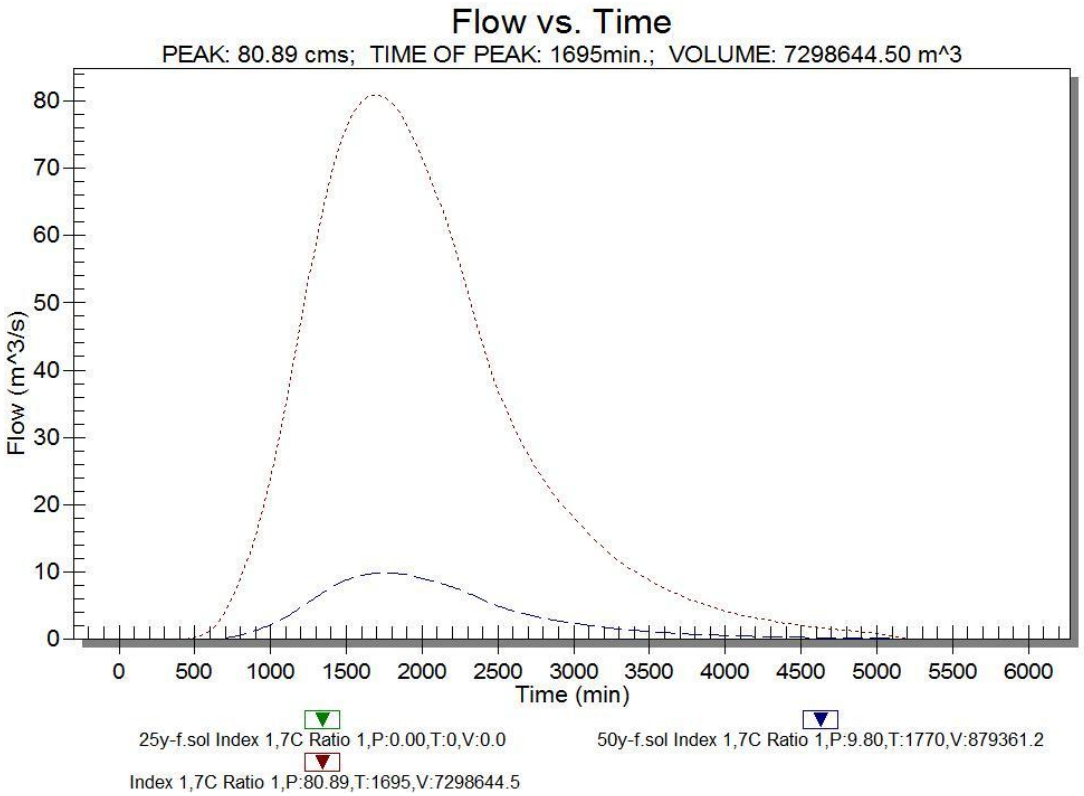


Figure (A-1): Hydrograph for Wadi (1)

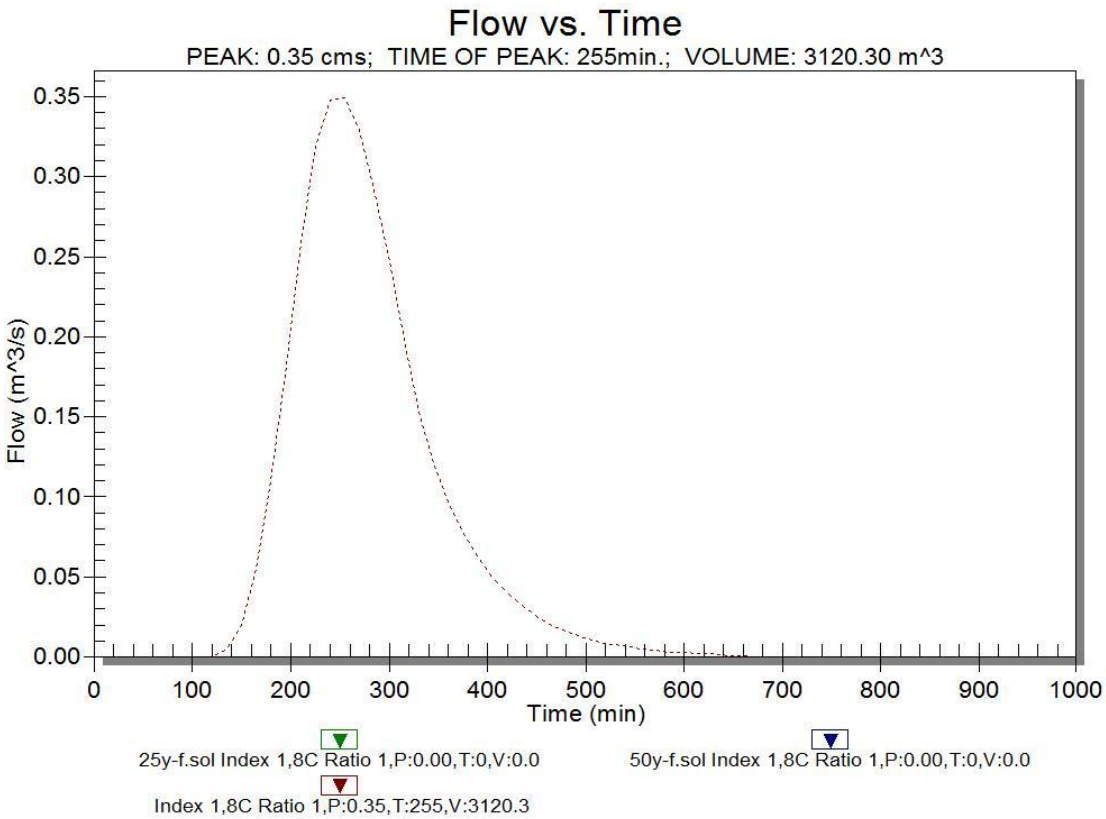


Figure (A-2): Hydrograph for Wadi (2)

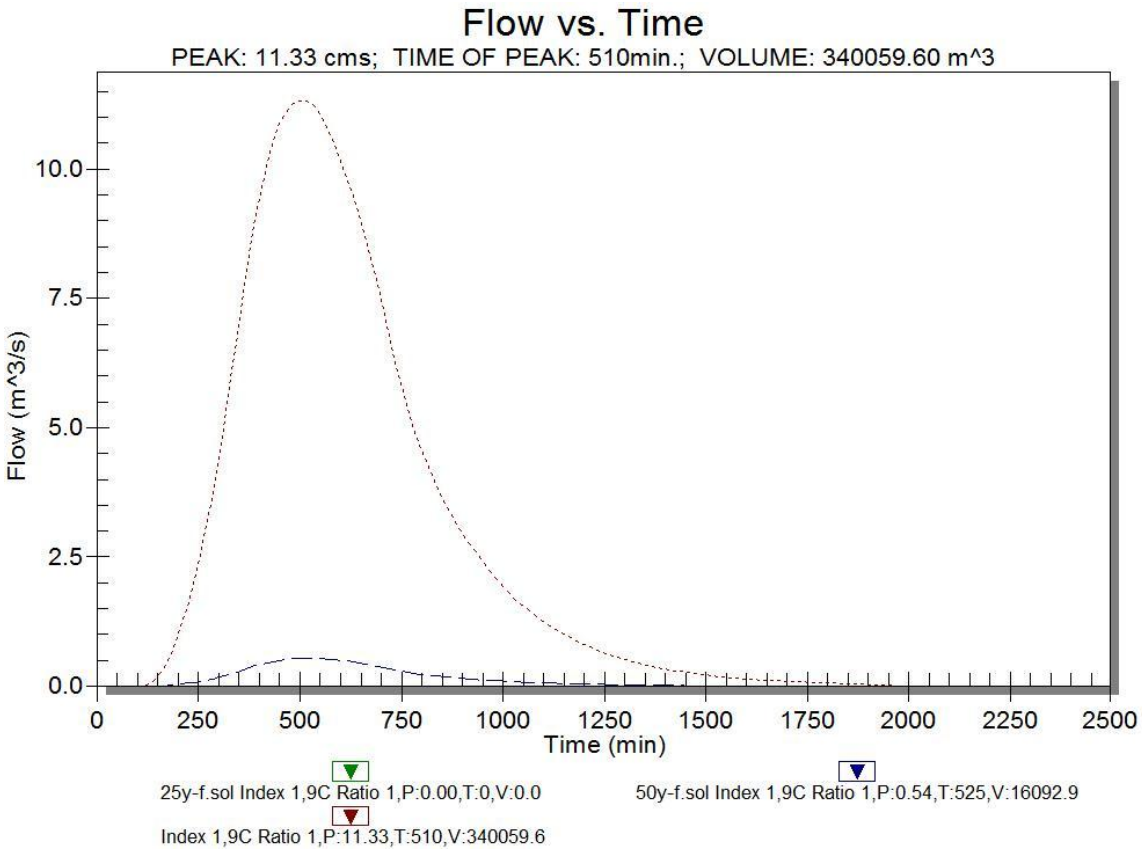


Figure (A-3): Hydrograph for Wadi (3)

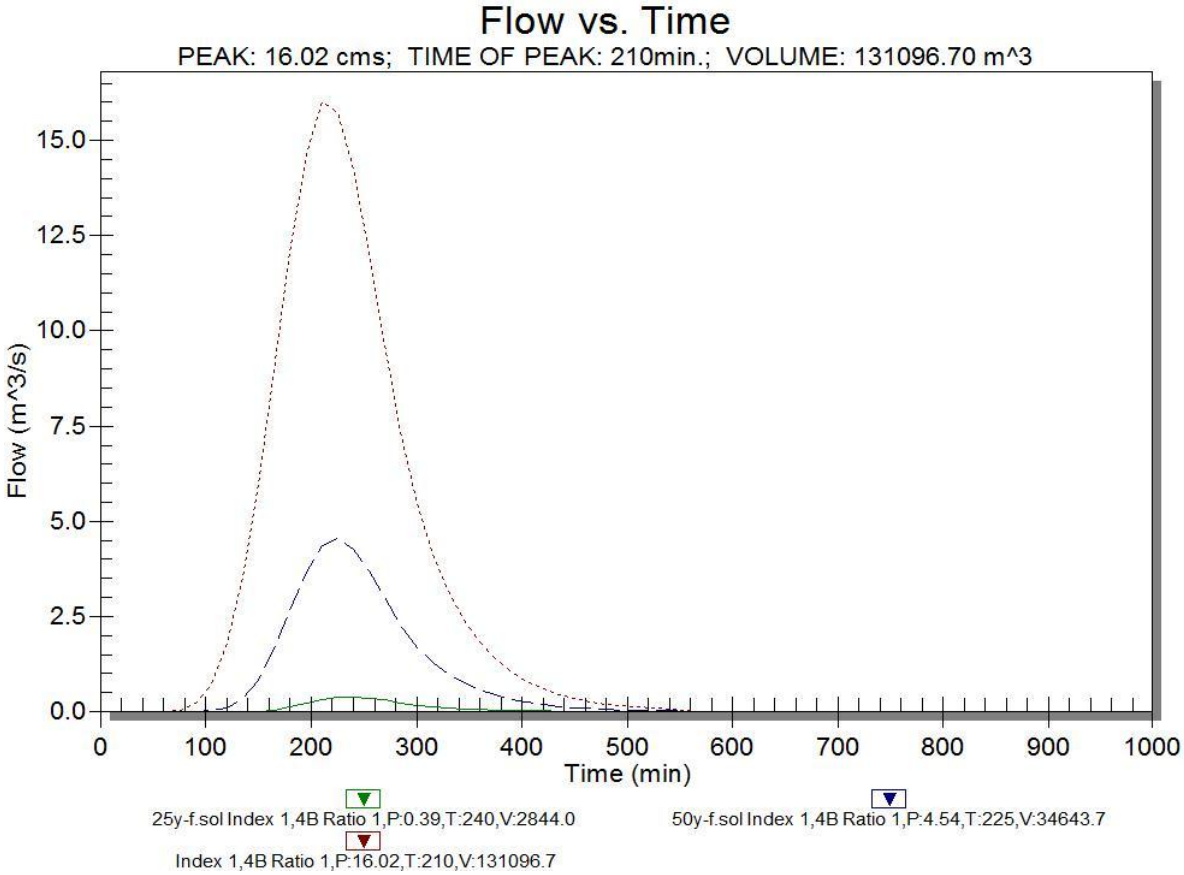


Figure (A-4): Hydrograph for Wadi (4)

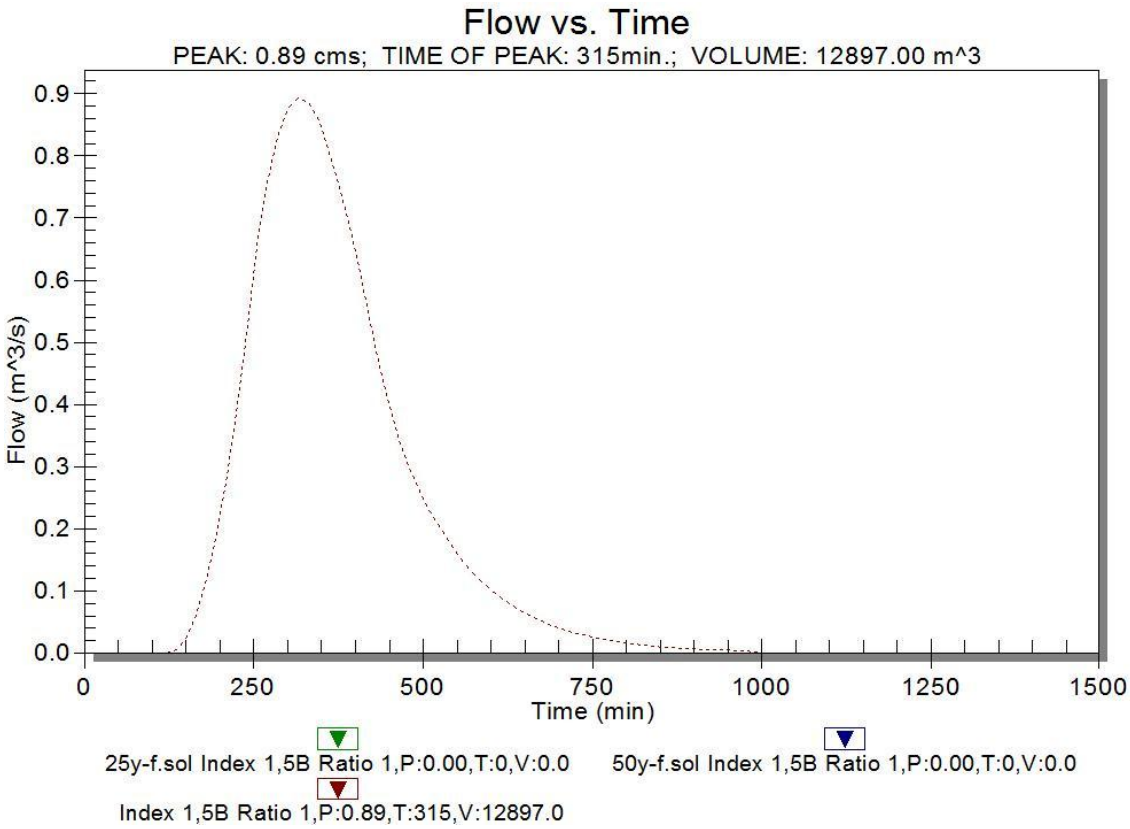


Figure (A-5): Hydrograph for Wadi (5)

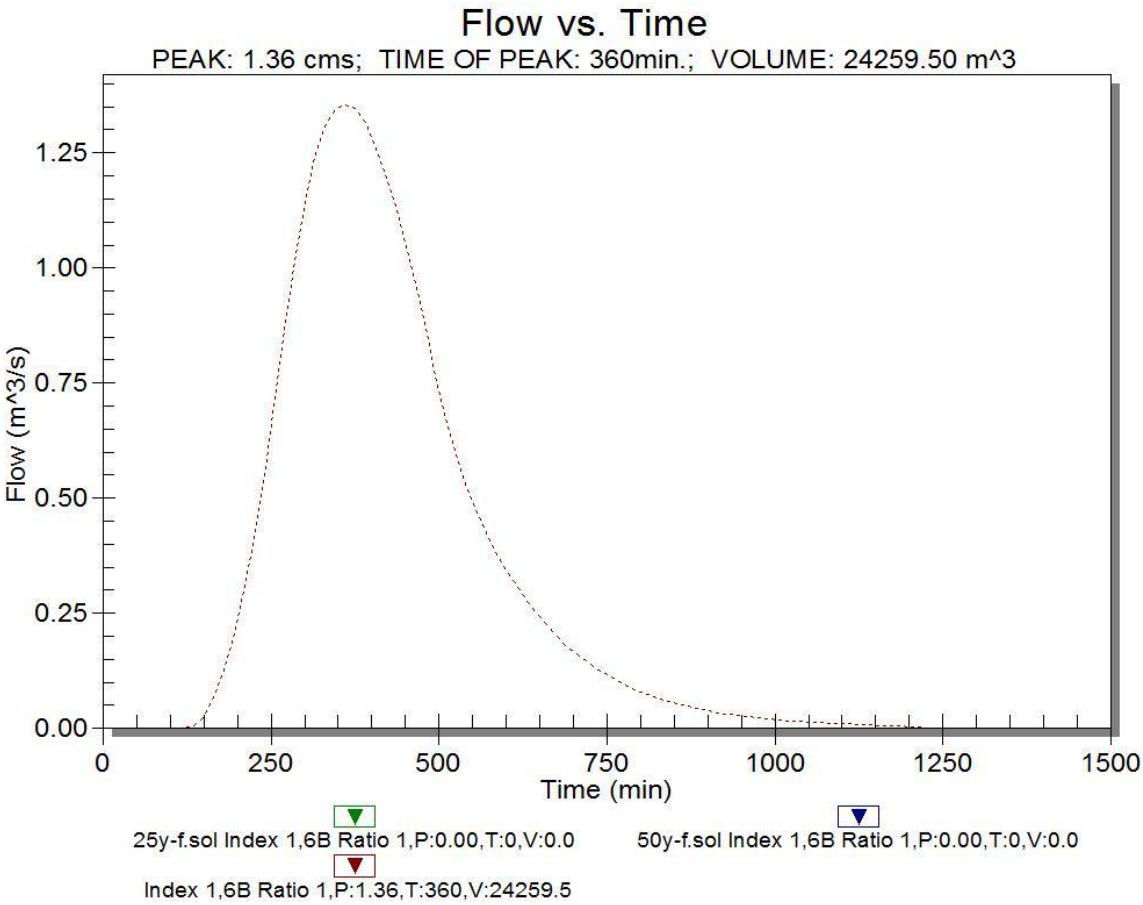


Figure (A-6): Hydrograph for Wadi (6)