Ras Shukeir Plot (South Plot)

1.1 GW Egypt Wind Project

Gulf of Suez area and Gabal El Zeit area

Red Sea Governorate - Egypt

Hydrological Study Report

Client

HAH-ACWA Power

1.1	24 April 2023	For Information	Eng. Aya Tarek	Dr. Hisham Hafez
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1. NTRODUCTION

1.1. General

This report has been prepared upon the request of Messrs. HAH-ACWA Power to carry out a hydrological study at the location of the proposed Ras Shukeir Plot, which the South Plot of the 1.1 GW Egypt Wind project, at Gulf of Suez area - Red Sea Governorate - Egypt. The South Plot of the 1.1 GW Egypt Wind project is located at Gabal El Zeit area and its hydrological study is presented in a separate report. Figure 1.1 shows the locations of the two plots.

Although Egypt relies on natural gas and oil to generate electricity, it pays great and increasing attention to diversifying energy sources and benefiting from the potential of renewable energy available in the country. Since Egypt has a great potential to generate renewable energy from wind, it is currently building a number of new wind projects as well as developing existing ones to increase electric power. It is worth noting that Egypt has succeeded in raising the percentage of renewable energy in the electricity generation capacity to 20%. In the context of this issue, HAH-ACWA Power is interested in developing a 1.1 GW Wind Energy project in Egypt.

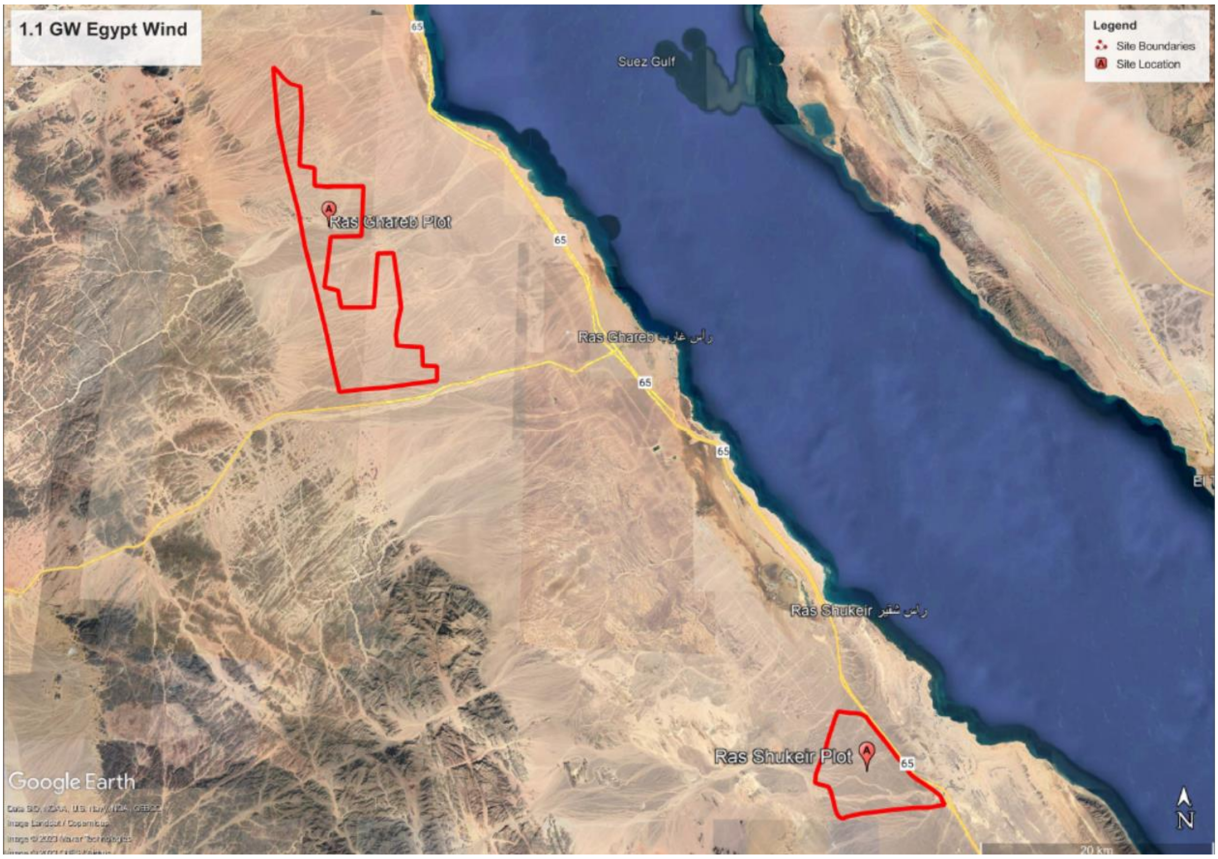


Figure 1.1: Proposed locations of 1.1 GW Egypt Wind project

Flash floods are natural phenomena occurring because of heavy rainfall over catchment areas (Wadis Basins) in open or desert areas. The heavy rainfall in these basins makes it hard for the surface soil to absorb these rains. As a result, surface water is collected in natural streams resulting in severe and high-speed floods. These floods wash away a lot of rock masses, sedimentary materials, and trees. In addition, they may attack infrastructures that were not protected from these flash floods due to either poor planning or the lack of hydrological studies conducted before their implementation.

The expansion of urban and industrial activities to desert areas outside the Nile Valley and Delta requires by return the extension of important vital infrastructure facilities to those areas. These infrastructures will often intersect with many small, medium, or large wadis in terms of basin area and surface water flows. These floods may expose these facilities to different levels of risk. In the present study, a complete hydrological study is conducted to determine the hydrological hazards that can affect Ras Shukeir Plot (South Plot) of the 1.1 GW Egypt Wind project.

1.2. Hydrological Study Objectives

This hydrological study aims to analyze the rain data of the meteorological stations close to the project plot (South Plot), identify the wadis affecting this plot, estimate their water flows, and to propose and design hydraulically the protection works to protect the project plot from flash floods hazards. The hydrological study area includes the region of the wadi basins affecting Ras Shukeir Plot.

1.3. Elements of Hydrological Study

The hydrological study necessary to protect the project area from the flash flood hazards includes conducting several specialized studies in the area under consideration as follows:

- **Data Collection and Site Visit**

During this study, all necessary data such as rainfall data; topographic, geological and digital elevation maps (DEM) are collected. In addition, a site visit and survey works are performed.

- **Wadi’s Delineation and Morphological Study**

This study aims to identify the Wadis affecting the study area and determine the most important morphological characteristics of these Wadis such as the basin area, main stream length and slope by using the computer package watershed modeling system (WMS) and the Digital Elevation Maps (DEM).

- **Geological Study**

This study aims to determine the geological characteristics of the top soil of the Wadis to estimate the rates of rain losses through the topsoil of the Wadi basins. In this study, the available geological maps and similar previous studies are used to estimate the top soil curve number (CN) to assist in determining the rainfall loss (mainly through infiltration).

- **Meteorological Study**

It is a study of the rainfall data of the nearest meteorological stations for a period of 25 years at least through using a suitable computer package to estimate rainfall storms corresponding to different return periods such as 25, 50, and 100.

- **Hydrological and Surface Flow Study**

In this stage of the study, all the results of the above-mentioned studies are incorporated into a suitable computer model such as HECHMS to estimate the expected water flows (rates and volumes) from wadis attacking Ras Shukeir Plot. These flows are used to propose the suitable works necessary to protect the study area from the flash flood hazards and then carrying out the hydraulic design of these works.

- **Proposing Alternatives**

In this part of the study, different solutions are assumed to protect the site such as open channel, dikes, culverts, etc.

- **Hydraulic Design**

In this stage, a detailed hydraulic design of the selected alternative is performed.

2. SITE VISIT

A field visit to the project area was conducted on March 4, 2023. The visit aimed to investigate the current situation of the project area, especially the existing drainage systems, and to verify some of the collected data. In addition, the topographic nature within the project boundary was checked. The paths of streams inside & surrounding the site, which could attack the site, were visually investigated. The existing hydraulic structures (mainly small dams and pipe culverts within and/or outside the project, which were previously implemented to protect the project area) were inspected. Photos 2.1 to 2.6 show the topographic nature, existing structures, and wadis within the site boundaries of Ras Shukeir Plot (South plot) - 1.1 GW Egypt Wind project.

Photo 2.1: Branch of Wadi Dara and road where plants appear within South Plot site

Photo 2.2: Branch of Wadi Dara within South Plot site

Photo 2.3: Wadi Dara barrier where plants appear within South Plot site

Photo 2.4: Wadi Dara where plants appear after all branches met within South Plot site

Photo 2.5: Multi-pipe culvert having a diameter of 0.5 m existing below Ras-Gharib - Hurghada road at Wadi Dara exit

Photo 2.6: One-vent box culvert below Ras-Gharib - Hurghada road at Wadi Dara exit

3. STUDY METHODOLOGY

3.1. Introduction

This section explains the study methodology necessary to protect the site, its vital facilities, and roads from the dangers of raging torrents. The hydrological studies aim to prevent flood hazards and storm events. They are based on a series of steps, which can be summarized in a simplified sketch as shown in Figure 3.1, illustrating the relationships between different study elements. Figure 3.2 shows the hydrology and hydraulic study methodology and work plan.

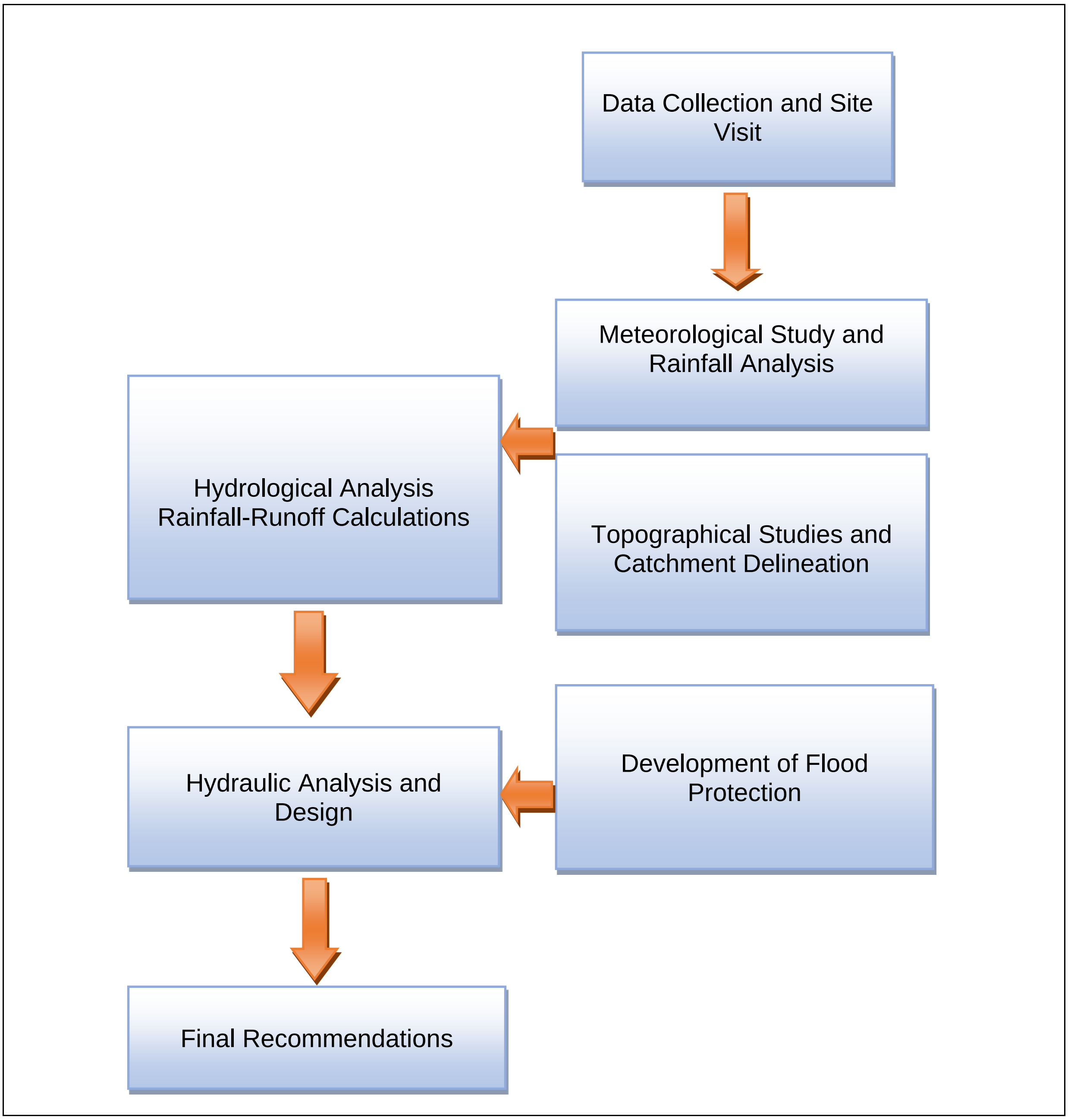


Figure 3.1: Work methodology

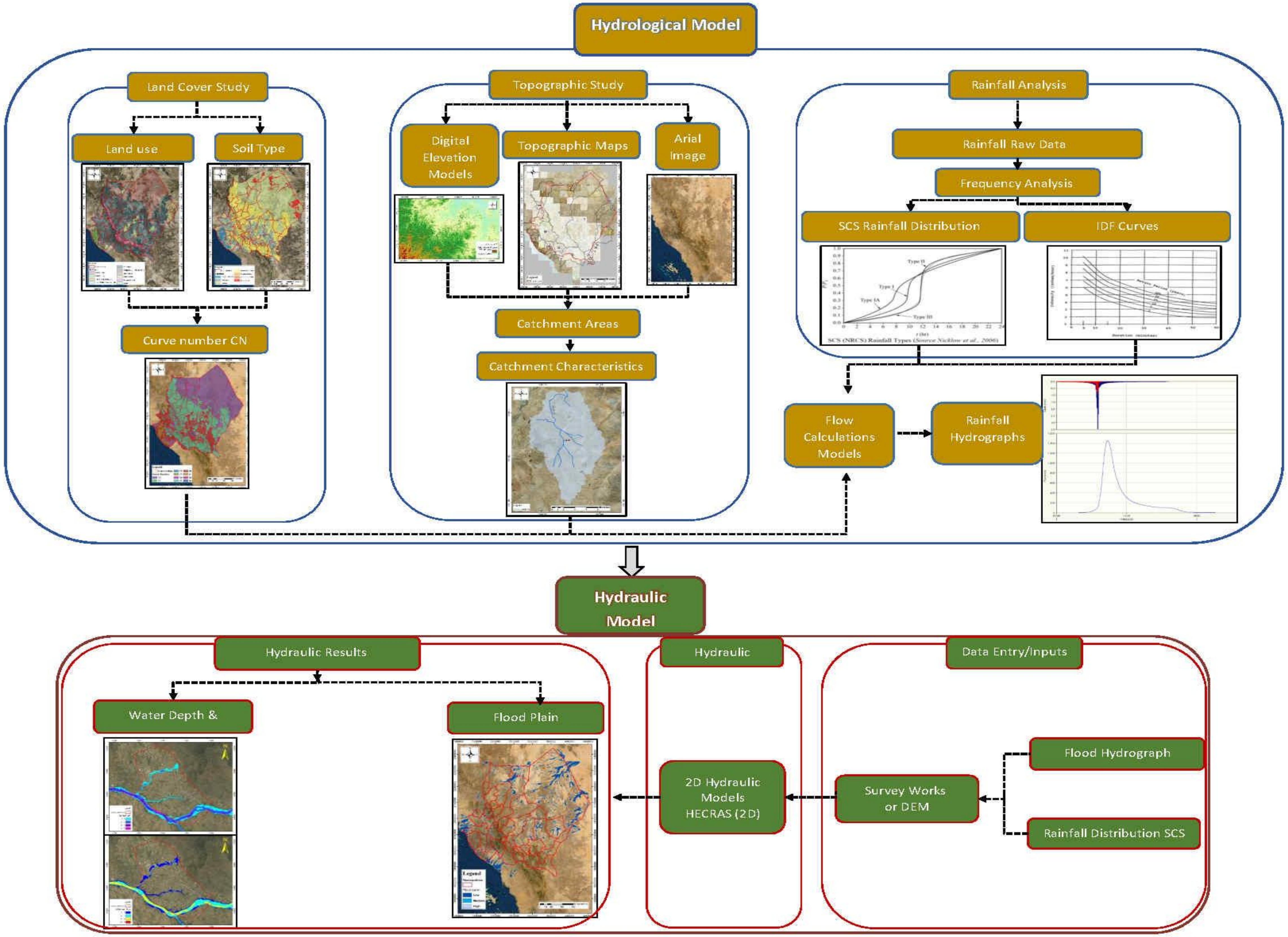


Figure 3.2: Hydrology and hydraulic study methodology and work plan

3.2. Morphological Study Methodology

The morphological study aims to determine the Wadis affecting the study area, and the most important characteristics of the drainage basins of these Wadis, which greatly affect the surface flow of water from these Wadis. These characteristics include the area of the drainage basin, the length of the main stream of the Wadi, the slope of the main stream, the slope of the drainage basin, etc.

To determine the Wadis, which affect the facilities and infrastructure of any study area and to obtain their morphological characteristics, the Watershed Modeling System (WMS) program is used. This program has been developed by Brigham Young University, USA in cooperation with U.S. Army Corps of Engineers. The WMS is fed with a digital elevation model (DEM), where the Wadis affecting the study area are identified. Then, the Wadis and their intersections with the various facilities and infrastructures are checked after matching them on Google Earth maps, as well as the available topographic maps of the area, which contain the influential Wadi basins. Table 3.1 shows the most important morphological characteristics of each Wadi, which were obtained from WMS.

Table 3.1: Most important morphological characteristics of Wadi basins

No.	Item	Symbol	Dimension
1	Drainage Basin Area	A	Km^2
2	Drainage Basin Slope	BS	m/m
3	Max Flow Distance	MFD	Km
4	Curve Number	CN	
5	Lag Time	T_{Lag}	hrs.

3.3. Geological Study Methodology

This study is concerned with determining the most important characteristics of the surface soil of the valleys, as well as the study of land uses, in order to estimate the losses of rain water on the Wadi basins. This study depends on the descriptive approach, which is the fieldwork. Then the analytical method is used; which depends on experience, information and maps related to the topic. Through this methodology, the geological characteristics of the surface soil of the wadis drainage basins are determined.

These characteristics are used in estimating the losses (infiltration through the soil of the valley) from the total rain falling on those basins. Therefore, the depth of excess rain is estimated, which is the cause of surface runoff (floodwater). In this study, the following are used:

1. Topographic maps, geomorphological maps and contour maps.
2. Geological maps with a scale of 1:250,000 to determine the geological units of the effective drainage basin or basins.
3. Maps showing faults and geological structures affecting water movement or surface runoff.
4. Geographic information systems are used to create a shape file for the influential basins.
5. Field work, if necessary, to measure the rate of underground leakage, especially in case of creating lakes or dams for the purpose of water retention.

Then a geological study is carried out. This study includes the accurate lithological description of the geological units in the drainage basin, the proposed location for the establishment of the facility, and the determination of the values of the curve number, which is referred to in this study as CN, as will be explained later.

3.4. Meteorological Study Methodology

This study aims at determining the locations of meteorological stations affecting the area of Ras Shukeir Plot. Therefore, the available observed rainfall data for the longest period are collected and analyzed. Furthermore, the most important statistical characteristics of these collected data are determined. To determine the best probability distribution, which describes this data and to determine the design rainstorms, a specialized statistical program, Hyfran Plus, is used.

The expected storms for each meteorological station affecting Ras Shukeir Plot for different recurring periods (2, 5, 10, 20, 50, 100, and 200 years) are estimated. Then Tieson Polygon method is used to estimate the average rainfall depth, which occurs over the wadi basins for each return period. Furthermore, the intensity-duration-frequency curves (IDF) are calculated for each design storm with a specific distribution such as SCS Type II for a duration time of 6, 12 or 24 hours.

3.5. Methodology of Estimating Surface Flow

The methodology of estimating surface flow aims at obtaining the water flow hydrographs for each influential wadi for each rainstorm for a specific recurring time. The estimation of surface flow can be considered as the basis for choosing the type of protection works against flash flood hazards, as well as the design of those works.

To estimate the surface flow of the influential wadis, the results of metrological study (design storms corresponding to different recurring times), morphological study (basin area, length of the main stream, and slope of the main stream), and the surface geological study (curve number CN) are fed to a specialized computer program called HECHMS.

The following is a method for estimating the surface flow from the influential valleys:

1. *Excess Rainfall Depth*:

   It is defined as the depth of the water causing the surface flow. It is equal to the total depth of rain falling on the valley basin minus the average losses during the precipitation period. This depth can be estimated using the soil conservation method (SCS Method), which can be written as follows:

$$I_{excess} = (P - 0.2\ S)^2 / (P + 0.8\ S) \quad (3\text{-}1)$$

$$S = 25.4\{(1000/CN) - 10\} \quad (3\text{-}2)$$

   in which

   I_{excess} = Excess rainfall depth (mm).

   S = Depth of water that soil can hold (mm).

   CN = Curve Number for the surface soil of the Wadi basin.

   P = Precipitation depth (mm)

   Woodward et al. (2003) found that the Initial Abstraction ratio value of 0.05 gives a better fit to the data and would be more appropriate for use in runoff calculations. Rainfall-runoff data from 307 watershed are used and a total of 28,301 events are available, which meet the rainfall depth (P and Q) criteria. In general, the results show that Ia (Ia is the initial loss) is not a constant from storm to storm or watershed to watershed, and that the assumption of Ia/S = 0.20 is unusually high.

From their results, it is obvious that a more appropriate “rounded" value of Ia would be in the vicinity of 0.05. Using this value, the runoff equation is adjusted, for which a new set of CNs based on Ia/S = 0.05 must be determined. Using Ia = 0.05, the runoff equation become:

$$I_{excess} = (P - 0.05\ S)^2 / (P + 0.95\ S) \qquad (3\text{-}3)$$

In arid regions when precipitation depths are small, the runoff is mainly affected by primary loss. As a result of rainwater falling with small amounts in low return intervals, the runoff will be almost vanished.

Based on the above-mentioned study about the initial loss (Ia), the data is fitted by least squares method to the CN equation for each case; i.e. for Ia/S = 0.05 and for the traditional value of Ia/S = 0.20. Accordingly, CN values are estimated and tabulated for the two cases. The results indicate that, for 252 of the 307 cases (about 83 %), the ratio of 0.05 fitting produces higher correlation factor (R2) and lower Root Mean Square Error (RMSE). The relationship between the values of S0.05 and S0.20 is found to be:

$$S0.05 = l.33 * S0.20 \qquad (3\text{-}4)$$

Preserving the basic definition of CN = 1000/(10+S), the above relationship permits the conversion from the 0.20-based CNs to 0.05-based CNs. Making the substitutions and simplifying gives:

$$\mathrm{CN}0.05 = \frac{100}{1.879\left(\frac{100}{\mathrm{CN}0.20} - 1\right)^{1.15} + 1} \qquad (3\text{-}5)$$

Considering Equation 3-5, Table 3.2 gives the $CN_{0.05}$ corresponding to current values of $CN_{0.20}$, or "Conjugate" Curve numbers. The results indicate that an (Ia/S) value of about 0.05 fits the observed rainfall-runoff data much better than does the handbook value of 0.20.

Altering (Ia/S) requires a change of handbook CNs; i.e. if (Ia/S) is changed, a different CN must be used. The most obvious differences in runoff modeling are at lower CNs and lower rainfalls, or in general, at low P/S situations. This would prevail for low CN watersheds, more frequently occurring rainstorm depths, and for climates where the more modest design return period rainfalls are found.

Table 3.2: $CN_{0.05}$ corresponding to $CN_{0.20}$

$CN_{0.20}$	$S_{0.20}$(in)	$CN_{0.05}$	$S_{0.05}$(in)	P_{crit} (in)
100.00	0.000	100.00	0.000	-----
95.00	0.526	94.02	0.636	2.44
90.00	1.111	86.95	1.501	1.72
85.00	1.765	79.64	2.556	1.95
80.00	2.500	72.39	3.815	2.27
75.00	3.333	65.31	5.311	2.63
70.00	4.286	58.51	7.091	3.05
65.00	5.385	52.03	9.219	4.51
60.00	6.667	45.90	11.785	4.04
55.00	8.182	40.14	14.915	4.64
50.00	10.000	34.74	18.787	5.35
45.00	12.222	29.71	23.663	6.15
40.00	15.000	25.03	29.947	7.13
35.00	18.571	20.71	38.285	8.35
30.00	23.333	16.73	49.777	9.92
25.00	30.000	13.08	66.457	12.02
20.00	40.000	9.75	92.517	15.04
15.00	56.667	6.75	138.095	19.81
10.00	90.000	4.08	235.088	-----
5.00	190.000	1.77	555.160	-----

2. *Concentration Time and Lag Time*:

The concentration time is defined as the time during which the excess water moves from the furthermost point in the wadi drainage basin until it reaches the exit point of the Wadi. On the other hand, the lag time is defined as the time from the middle of the rainstorm to the time of the maximum discharge of the wadi drainage basin.

The lag time can be calculated from the following SCS equation:

$$T_{lag} = L^{0.8} * (S+1)^{0.7} / (1900 * Y^{0.5}) \quad (3\text{-}6)$$

in which

T_{lag} = Lag time (hrs.)

L = Mainstream length of the Wadi basin (feet).

S = Maximum retention in watershed (in).

Y = Mainstream slope (%).

The maximum retention in watershed (S) is given as follows:

$$S = (1000/CN) - 10 \quad (3\text{-}7)$$

The Concentration Time (T_C) is given as follows:

$$T_C = T_{lag} / 0.6 \quad (3\text{-}8)$$

3. *Surface Runoff Hydrograph*:

The surface flow hydrograph can be estimated using the HEC-HMS mathematical model. This is carried out by estimating the unit hydrograph of the surface flow resulting from running an excess of 1 cm of rain over the surface of the wadi drainage basin. Afterwards, this hydrograph with the rain distribution curve (SCS Type II) is used to obtain the surface flow hydrograph of rainstorms with specific recurring times. Figure 3.3 illustrates the resulting rainfall distribution for the soil conservation service SCS Type II of a duration of 24 hours.

The maximum unit hydrograph flow can be deduced from the following equation:

$$q_{pUH} = \frac{2.08 * A}{Tp} \quad (3\text{-}9)$$

in which

q_{pUH} = Maximum unit hydrograph flow (m^3/sec).

A= Catchment area (km^2).

T_p = Time to peak flow (hours).

The time to peak flow can be estimated from the following equation:

$$T_p = 0.67\ T_c \quad (3\text{-}10)$$

3.6. Impact of Climate Change

An increase of 20% is considered for rainfall depths and rainfall intensities to account for the climate change effect.

Soil Conservation Service Type II Storm Distribution

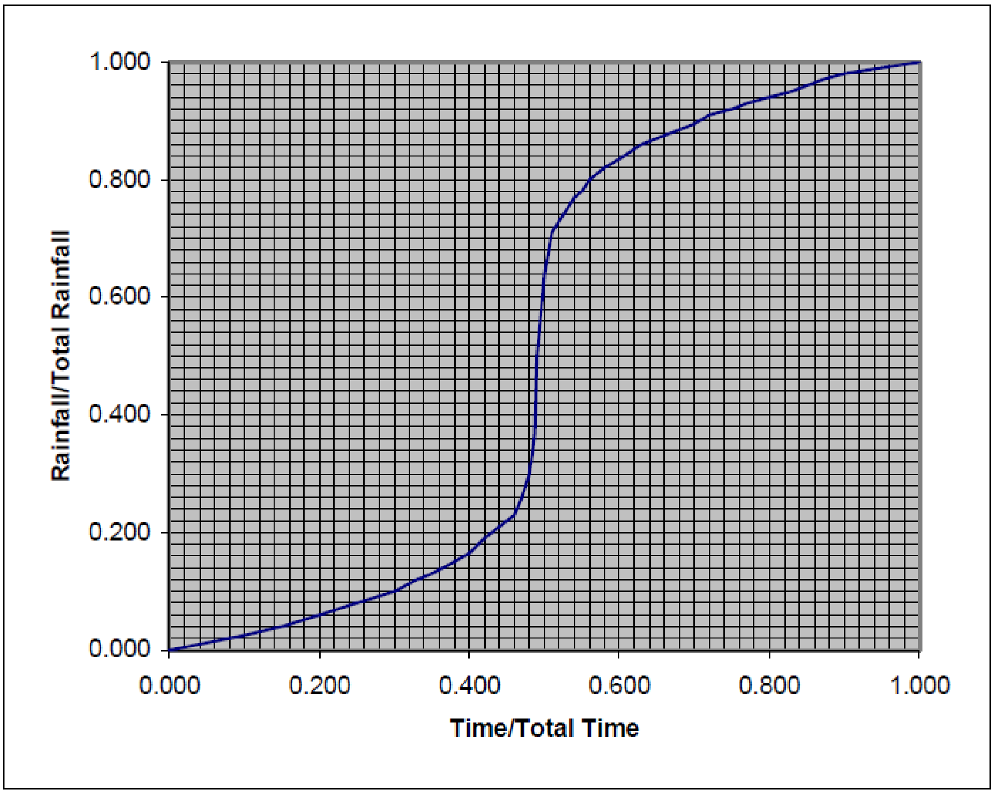


Figure 3.3: Soil conservation service Type II storm duration curve

4. GEOLOGICAL STUDY

4.1. Introduction

Ras Shukeir Plot is located at the Northern part of the Egyptian Eastern Desert West of Ras Shukeir along the Gulf of Suez as shown in Figure 1.1. The hydrologic basin originating from the highly mountainous areas in the West and draining into the flood plain along the Gulf of Suez coast and then into the Gulf is shown in Figure 4.1 for Ras Shukeir Plot (South Plot).

The geological map of Egypt (scale 1:2 million), issued by the Egyptian Geologic Survey (1982) and that of Conoco Corral Petroleum Company (1987) are used to give highlight on the geology of the area (Figure 4.2). The surface geology of the basin includes sedimentary rocks, as well as basement and metamorphic rocks. The sedimentary rocks include Recent and Quaternary deposits, and Miocene and Cretaceous rocks (Section 4.2). The basement and metamorphic rocks include Younger Granitites rocks, Dokhan Volcanic rocks, Meta-Gabbro-Diorite Complex, and Geosynclinals Meta-Volcanic rocks Section 4.3. Finally, the geologic structures are outlined in Section 4.4.

Figure 4.1: Hydrologic basin originating from highly mountainous areas in the West

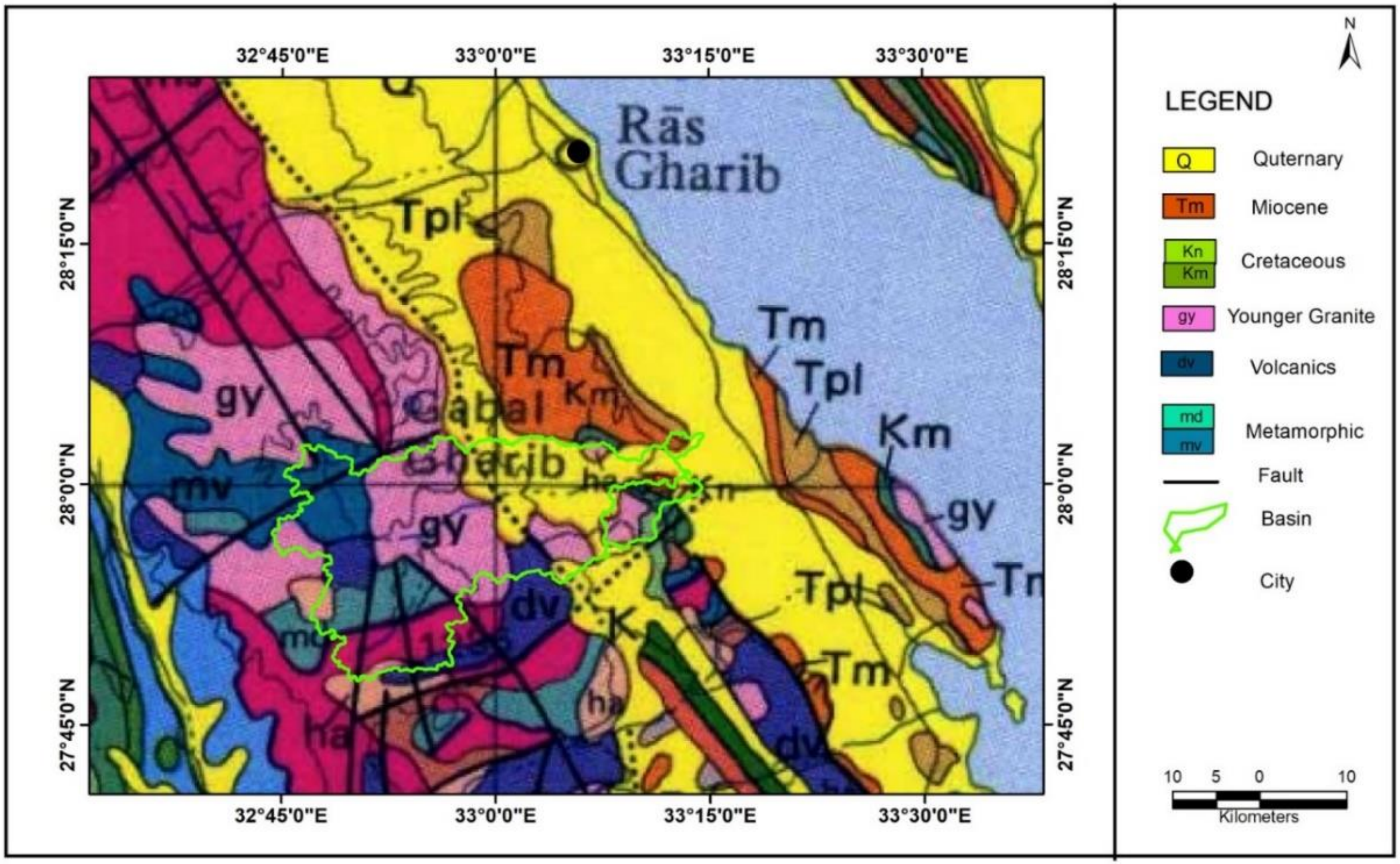


Figure 4.2: Geology of area under consideration

4.2. Sedimentary Rocks

In general, the sedimentary rocks occupy about 30% of the total basin area and could be classified as follows.

4.2.1 Recent and Quaternary Deposits (Q)

The recent and Quaternary deposits (Q) consist of wadi deposits (gravels, sand, and silt) as a results of erosion of the basement rocks covering most of the hydrologic basins. These sediments cover the floor of small streams and the area near the outlet.

4.2.2 Miocene Rocks (Tm)

The Miocene rocks (Tm) are well distributed in very small and local areas near the outlet. These sediments consist of evaporates and shales. They are characterized by the presence of salt domes. In the subsurface, they are considered the cap rock of petroleum entrapments in the Gulf of Suez.

4.2.3 Cetaceous Rocks (Kn & Km)

The Cetaceous Rocks (Kn & Km) consist of sandstone, shale, limestone, chalk and phosphate of the upper Cretaceous age. These rocks are well represented at the outlet of the basin area at a very small scale.

4.3. Basement and Metamorphic Rocks

In general, the basement and metamorphic rocks occupy about 70% of the total basin area and could be classified as follows.

4.3.1 Younger Granitites Rocks (gy)

The Younger Granitites Rocks (gy) consist of post-tectonic granite, granodiorite and adamellite. These rocks are well distributed at a large scale at the center of the basin area in the study area.

4.3.2 Dokhan Volcanic Rocks (dv)

The Dokhan Volcanic Rocks (dv) consist of slightly metamorphosed andesite, porphyrite, pyroclastic, and the purple-colored Imperial porphyry.

4.3.3 Meta-Gabbro-Diorite Complex (md)

The Gabbro and Dolerite masses are tetanized and affected by older Granitoids.

4.3.4 Geosynclinals Meta-Volcanic Rocks (mv)

The Meta-Volcanic Rocks (mv) consist of metamorphosed rhyolite, dacite, andesite, basalt and pyroclastic rocks.

4.4. Geologic Structures

The study area is part of the Egyptian Eastern desert. Therefore, its tectonic condition is directly related to the Red Sea Graben and the Gulf of Suez origin in the Oligocene Era. Different types of structures are present such as faults, joints, and deformation shapes like Mélanges. These structures take different directions, most important is the NW/SE parallel to the Red Sea and Gulf of Suez grabens.

Consequently, the Curve Number (CN) ranges between 85 and 90.

5. MORPHOLOGICAL STUDY

5.1. Introduction

This study aims to identify the Wadis affecting the study area (Ras Shukeir Plot) and determine the most important morphological characteristics of these wadis by using a suitable computer package such as Watershed Modeling System (WMS). These characteristics include the drainage basin area, the main stream length, the slope of the main stream, the slope of the drainage basin, and others. These characteristics are obtained by feeding WMS with the data of the digital elevation model (DEM).

The first step in the morphological study is to identify the intersection points of the affecting Wadis with the area and facilities required to be protected from the flash flood hazards. Then these points are checked and confirmed using the available ground survey, Google Earth maps and topographic maps for the wadi basins. Then the above-mentioned characteristics are obtained.

5.2. Morphological Characteristics of Wadis Affecting Ras Shukeir Plot

Following the methodology outlined in Section 3, it is necessary to undertake a delineation process to determine the wadis and the boundaries of the catchments contributing to flood risk within the study area and affecting Ras Shukeir Plot. These Wadis affecting the Plot are determined using the WMS model and the digital elevation model (DEM) for the drainage basins of the affecting Wadis. In addition, this process enables the derivation of the catchments and sub-catchments required to develop HEC-HMS models.

The collected topographic maps, drawn to a scale of 1:50,000, and recent satellite images are used to verify the results of the WMS software, delineated catchment boundaries and drainage lines. After checking the points of intersections, the drainage basins of these Wadis are obtained. Then the streams and watercourses are identified and the different morphological characteristics of all catchments such as (area, longest flow path, slope, etc.) are determined. These characteristics are considered in the hydrological study to estimate water flows of these Wadis affecting Ras Shukeir Plot to be protected from the flash flood hazards.

Table 5.1 indicates the most important morphological characteristics of the Wadis affecting Ras Shukeir Plot while Figures 5.1 and 5.2 show the Wadis, streams, and catchments affecting the project area.

Table 5.1: Most important morphological characteristics of Wadis affecting Ras Shukeir Plot

Basin Name	Basin Area (km^2)	$CN_{0.2}$	$CN_{0.05}$	Basin Slope m/m	Basin Slope %	MFD (m)	T_{Lag} (Hrs.)
1B	1.22	76	67	0.035859	3.586	3334.0	99.5
2B	1.76	76	67	0.036652	3.665	3662.8	106.1
3B	9.87	76	67	0.053693	5.369	7738.0	159.4
4B	12.14	79	71	0.082204	8.220	7231.5	110.0
5B	36.48	84	79	0.27678	27.678	20716.6	110.1
6B	1.51	76	67	0.034568	3.457	3658.4	109.1
7B	7.81	76	67	0.082995	8.300	6970.4	117.9
8B	14.61	84	78	0.202988	20.299	12161.3	85.3
9B	10.67	84	79	0.257909	25.791	11343.7	71.0
10B	7.77	85	80	0.26976	26.976	7659.7	49.0
11B	25.03	85	80	0.212632	21.263	11910.4	78.5
12B	17.06	85	80	0.188181	18.818	7916.2	60.2
13B	11.99	85	80	0.160205	16.021	9477.7	75.3
14B	10.34	85	80	0.230274	23.027	7347.1	51.3
15B	39.33	85	80	0.280406	28.041	18401.5	96.8
16B	26.27	85	80	0.263325	26.333	15254.3	86.0
17B	9.14	85	80	0.238852	23.885	6311.8	44.6
18B	27.40	85	80	0.277741	27.774	14483.3	80.3
19B	15.36	85	80	0.220282	22.028	8171.1	57.1
20B	2.02	85	80	0.210827	21.083	3853.6	32.0
21B	0.13	85	80	0.060709	6.071	830.6	17.5
22B	0.14	85	80	0.080493	8.049	848.0	15.4
23B	30.24	85	80	0.233802	23.380	14397.7	87.1

Basin Name	Basin Area (km^2)	$CN_{0.2}$	$CN_{0.05}$	Basin Slope m/m	Basin Slope %	MFD (m)	T_{Lag} (Hrs.)
24B	7.59	85	80	0.211864	21.186	6541.8	48.7
25B	1.45	85	80	0.119731	11.973	2950.3	34.3
26B	42.05	85	80	0.212773	21.277	18721.1	112.7
27B	0.46	85	80	0.162541	16.254	1319.5	15.4
28B	32.21	85	80	0.195499	19.550	13565.1	90.9
29B	19.96	85	80	0.209446	20.945	11390.1	76.3
30B	38.39	85	80	0.247851	24.785	12983.8	77.9
31B	33.54	85	80	0.224204	22.420	12798.7	81.0
32B	6.17	76	67	0.056681	5.668	7681.8	154.3
33B	11.44	76	67	0.060559	6.056	10899.1	197.4
34B	10.71	76	67	0.079699	7.970	9420.9	153.2
35B	13.18	76	67	0.054981	5.498	11498.0	216.3
36B	42.22	76	67	0.061453	6.145	16886.9	278.2
37B	6.10	76	67	0.042776	4.278	8060.0	184.5
38B	22.36	76	67	0.083517	8.352	14451.7	206.9
39B	22.75	76	67	0.069541	6.954	15530.5	244.5
40B	11.58	76	67	0.04742	4.742	11681.3	234.7
41B	20.88	81	74	0.098824	9.882	17882.3	189.8
42B	18.55	83	76	0.153511	15.351	13787.6	115.8
43B	27.26	83	76	0.213181	21.318	15320.2	106.1
44B	5.31	76	67	0.037784	3.778	7824.8	191.7
45B	10.87	76	67	0.052848	5.285	7709.0	160.2
46B	12.91	76	67	0.071315	7.132	11287.6	187.1
47B	15.23	76	67	0.065507	6.551	9669.8	172.5
48B	9.54	76	67	0.035776	3.578	8399.5	208.5
49B	11.55	76	67	0.031758	3.176	8886.4	231.6
50B	4.95	76	67	0.032935	3.294	6246.9	171.5
51B	8.37	76	67	0.032196	3.220	8761.1	227.4
52B	8.87	76	67	0.033349	3.335	11053.7	269.1
53B	2.13	76	67	0.035493	3.549	4889.6	135.8
54B	15.13	76	67	0.045758	4.576	11267.0	233.2
55B	19.00	76	67	0.074265	7.427	11911.1	191.4
56B	28.91	76	67	0.062592	6.259	15130.0	252.5
57B	14.19	76	67	0.065363	6.536	10399.8	183.0
58B	13.65	76	67	0.056402	5.640	12946.3	232.9
59B	39.31	82	75	0.192147	19.215	18822.5	137.6
60B	28.32	83	77	0.211022	21.102	9462.2	70.5
61B	24.86	85	80	0.265694	26.569	9201.7	57.1

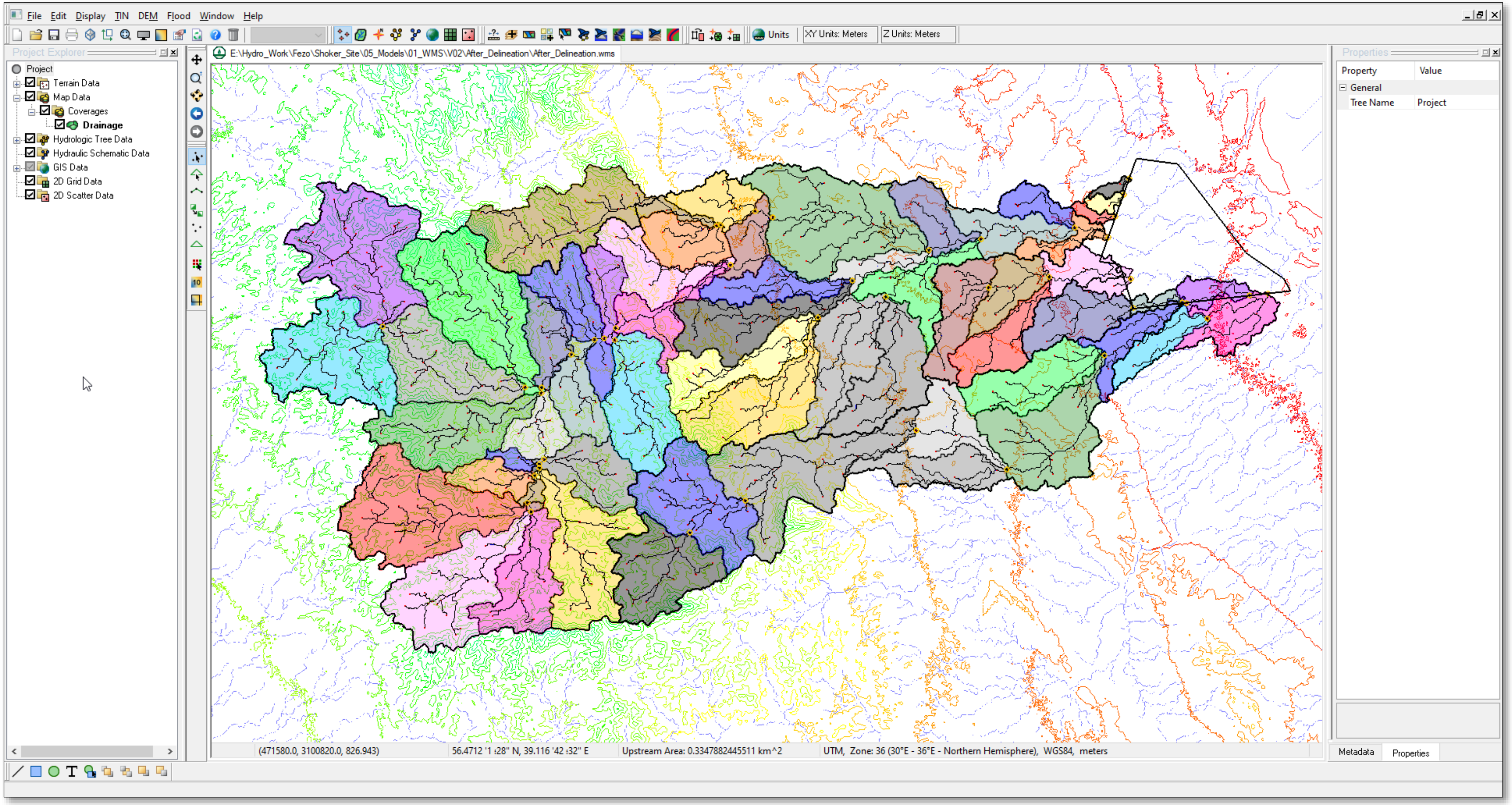


Figure 5.1: WMS Wadis affecting Ras Shukeir Plot

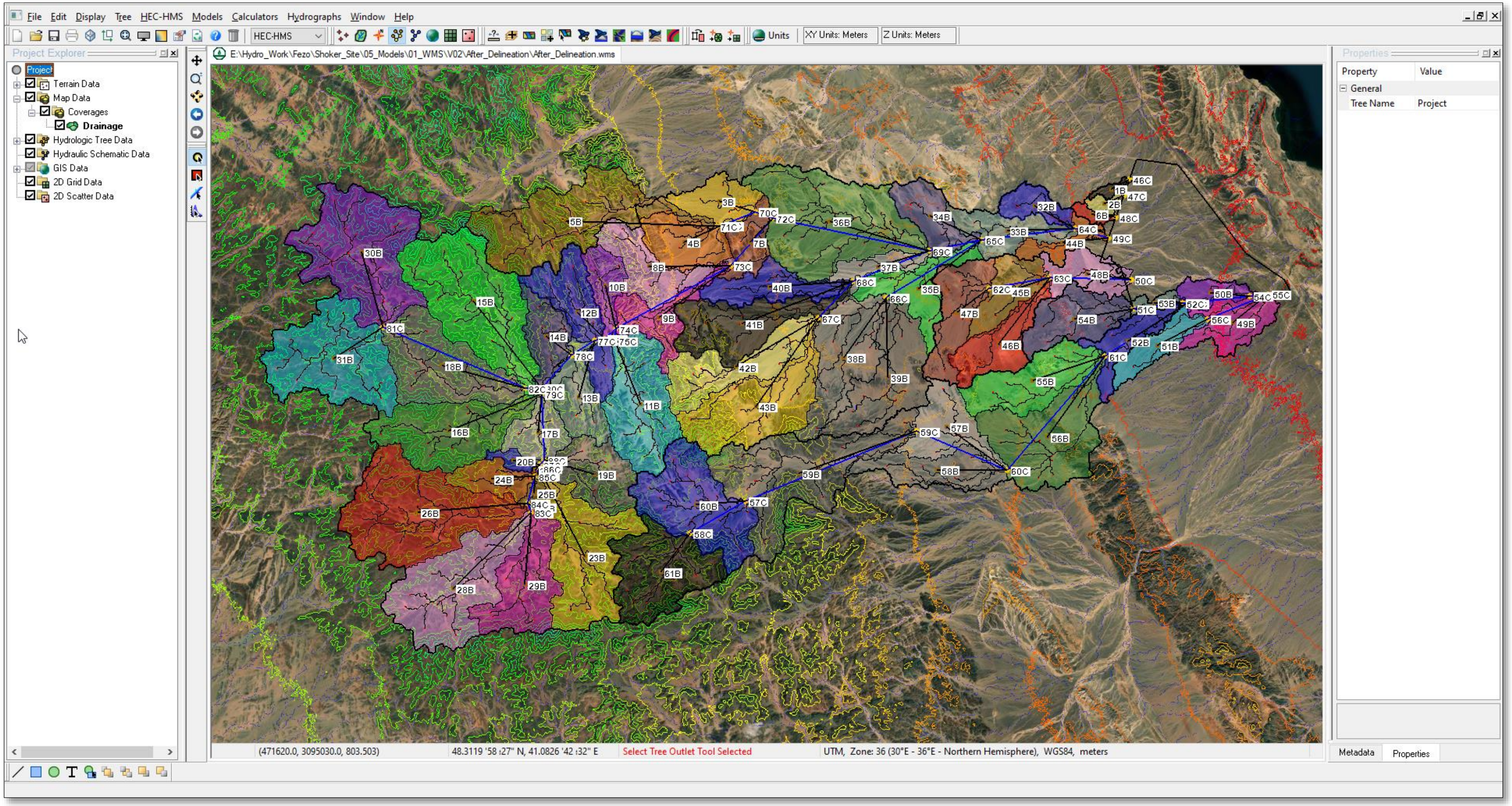


Figure 5.2: Main streams and catchments affecting Ras Shukeir Plot (Satellite Image)

5.3. Design Return Period

The design return period is the frequency of storms within a specified period. The frequency of the storm reflects the degree of flood risks. The selection of design return period depends on the importance and location of the proposed protection structure. Based on the importance of the site, the flood mitigation and analysis will be based on a 100-year storm, while taking the effect of climate change into consideration, to avoid any flood hazards.

6. METEOROLOGICAL STUDY AND FLOW ESTIMATION

6.1. Introduction

The meteorological study and flow estimation aims to determine the locations of meteorological stations affecting the study area, analyze the collected rainfall data, and determine the most important statistical characteristics of this data. The statistical analysis of rainfall data is one of the most important studies to be carried out in any flood protection and storm drainage project, where rainfall is the main element causing the flow in streams. Therefore, this study is given maximum priority.

The analysis typically involves compilation of data, analysis and statistical tests to deduce the design storm depth, for which design flows is calculated. To determine the best probability distribution, which describes this data, and to determine the design rainstorms; a specialized statistical program (Hyfran Plus) is used. Using this program, the expected storms for different return periods (2, 5, 10, 20, 50, 100, and 200 years) are estimated. In addition, the intensity-duration-frequency curves (IDF) are calculated for each design storm with a specific distribution such as SCS Type II for a duration time of 6, 12 or 24 hours.

6.2. Estimation of Design Storms

All nearby available rainfall stations are considered in this study. Data of five meteorological stations are used (Hurghada, Suez, Ras Sidr, Abu Rudeis, and Al-Tur meteorological stations). Figure 6.1 shows the locations of these stations while Table 6.1 gives the coordinates of these meteorological stations and their heights above sea level. Figures 6.2 to 6.6 show the maximum rainfalls, which occur in a day in a year, used in the present study; while Table 6.2 provides the most important statistical parameters of these data.

To determine the proportions of influence of each of the five stations on the study area, a Thiessen polygon is used to determine the meteorological station affecting the study area as shown in Figure 6.7. It is clear from the polygon that Al-Tur station is the one that affects the study area (Ras Shukeir Plot).

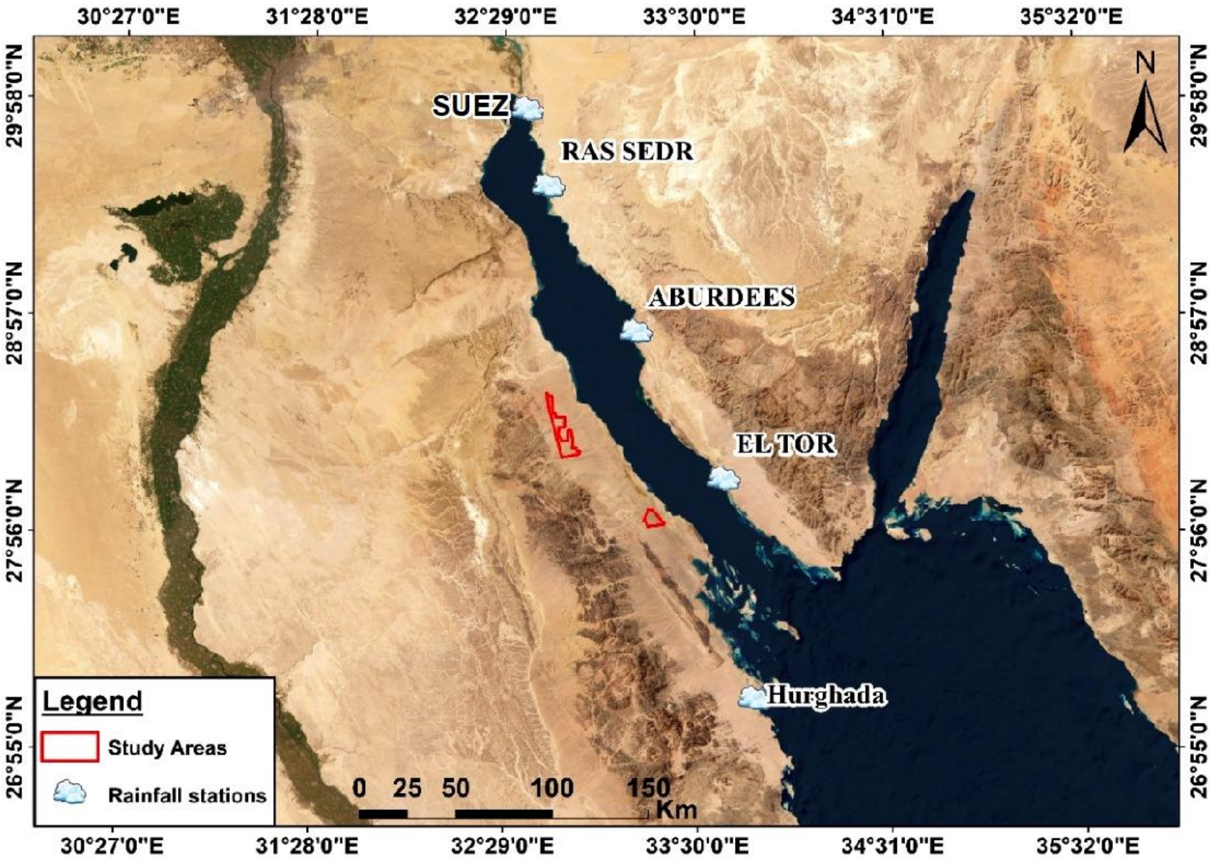


Figure 6.1: Locations of meteorological stations

Table 6.1: Coordinates of five meteorological stations & their heights above sea level

Station	LONGITUDE	LATITUDE	ELEVATION (m)
Hurghada	33.799436	27.178317	15.84
Al-Tur	33.645517	28.209028	35.05
Abu Rudeis	33.1833333	28.9	8
Ras Sidr	32.7166666	29.5833333	16
Suez	32.543333	29.983623	5

6.3. Rainfall Analysis

Al-Tur data is analyzed statistically using Hyfran Plus statistical analysis software, in order to determine the best probability distribution to represent the data. More than one probability distribution are tested. Comparing the results of these distributions indicates that the lognormal probability distribution is the best to represent the data of the Al-Tur station as shown in Figure 6.8. This figure indicates that the measured rainfall data and those calculated from the lognormal probability distribution, which is selected to represent the data, are almost identical with a confidence level of 95%.

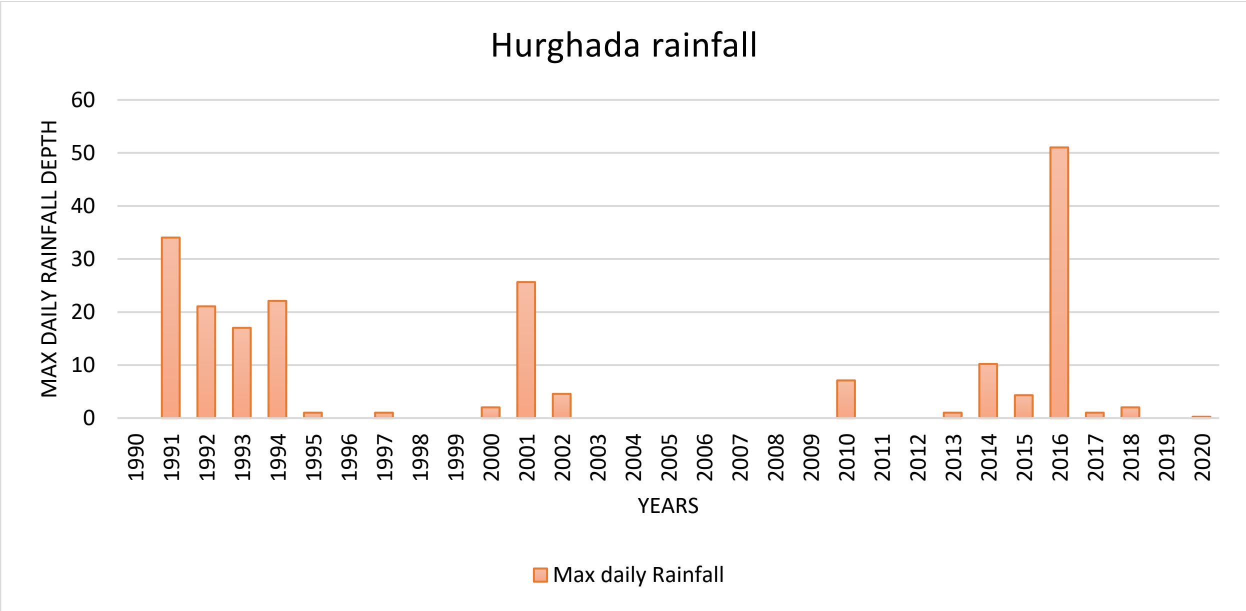


Figure 6.2: Maximum rainfall depth (mm/day) for Hurghada meteorological station

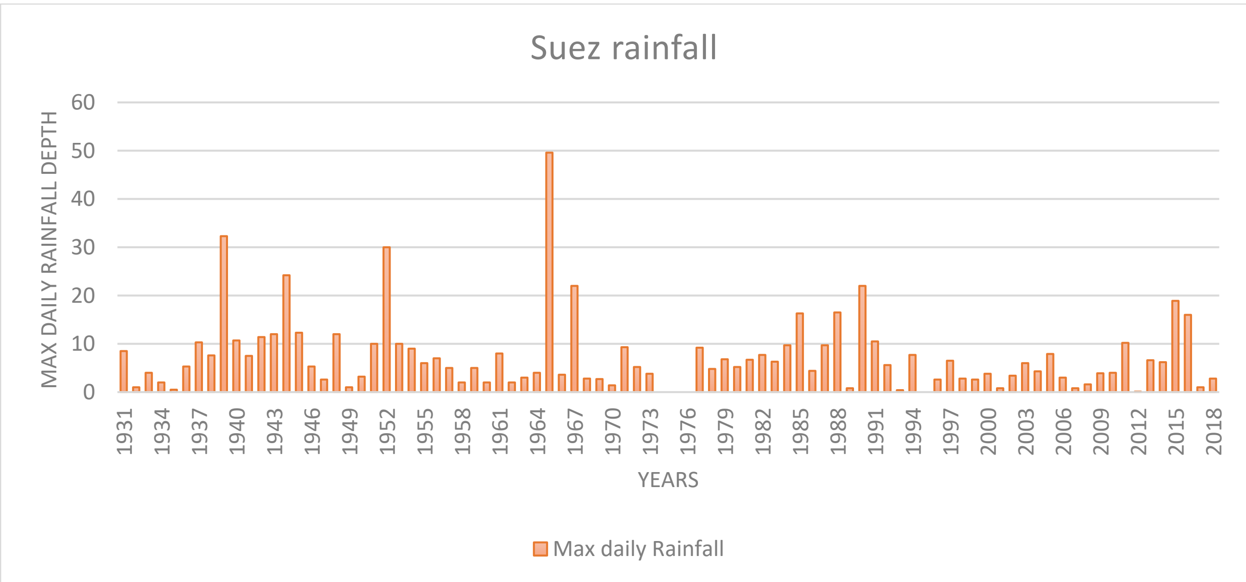


Figure 6.3: Maximum rainfall depth (mm/day) for Suez meteorological station

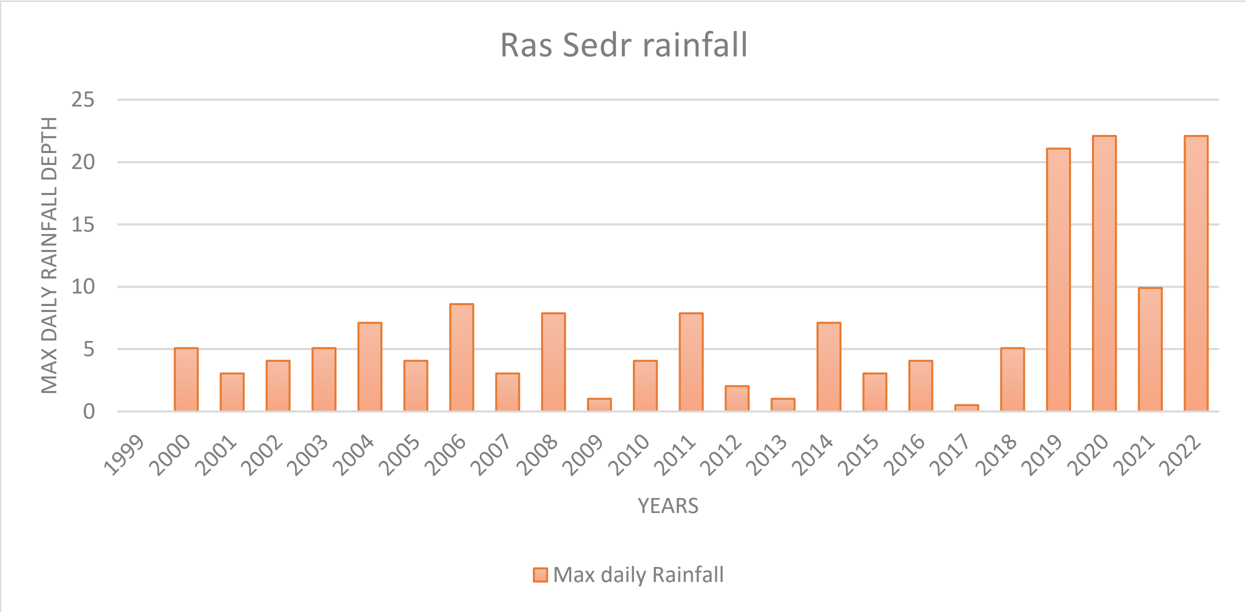


Figure 6.4: Maximum rainfall depth (mm/day) for Ras Sedr meteorological station

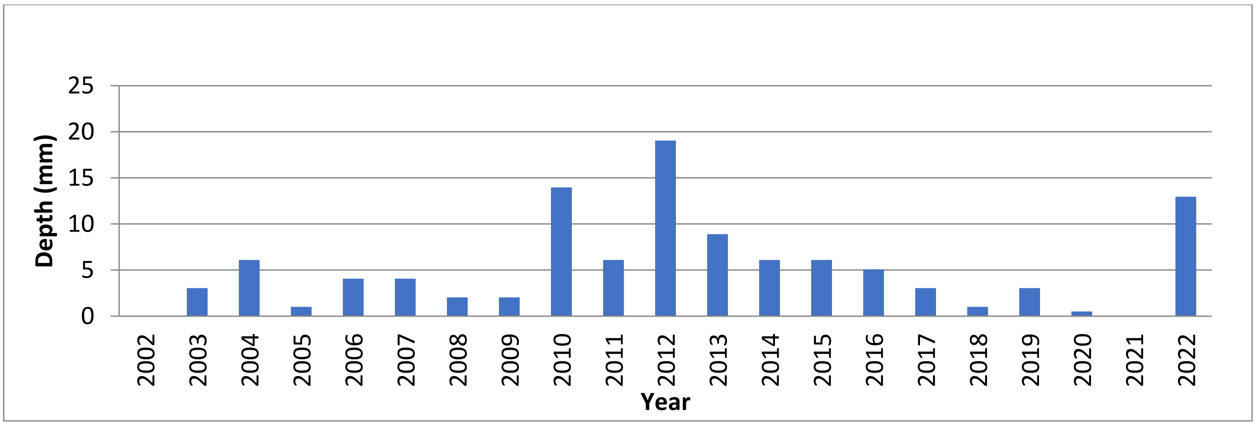


Figure 6.5: Maximum rainfall depth (mm/day) for Abu Rudeis meteorological station

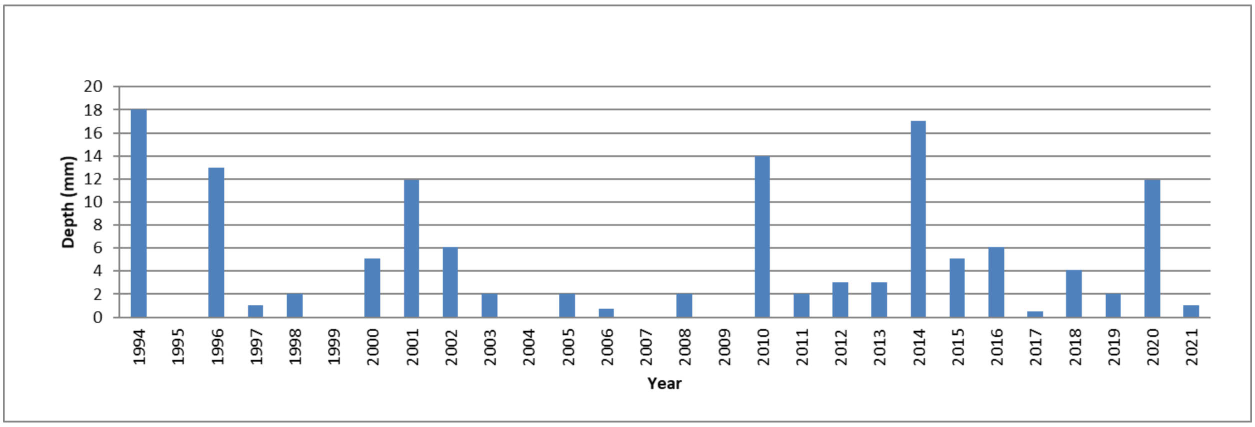


Figure 6.6: Maximum rainfall depth (mm/day) for Al-Tur meteorological station

Table 6.2: Main characteristics of data of five meteorological stations

Station	Minimum (mm)	Maximum (mm)	Average (mm)	Standard Deviation	Variation Coefficient	Skewness Coefficient
Hurghada	0.25	51	12.1	14.5	1.20	1.48
Al-Tur	0.5	18	5.82	5.53	0.95	1.09
Abu Rudeis	0.51	19.1	5.69	4.91	0.863	1.50
Ras Sidr	0.5	22.1	6.91	6.39	0.924	1.68
Suez	0.1	49.6	7.66	7.85	1.02	2.76

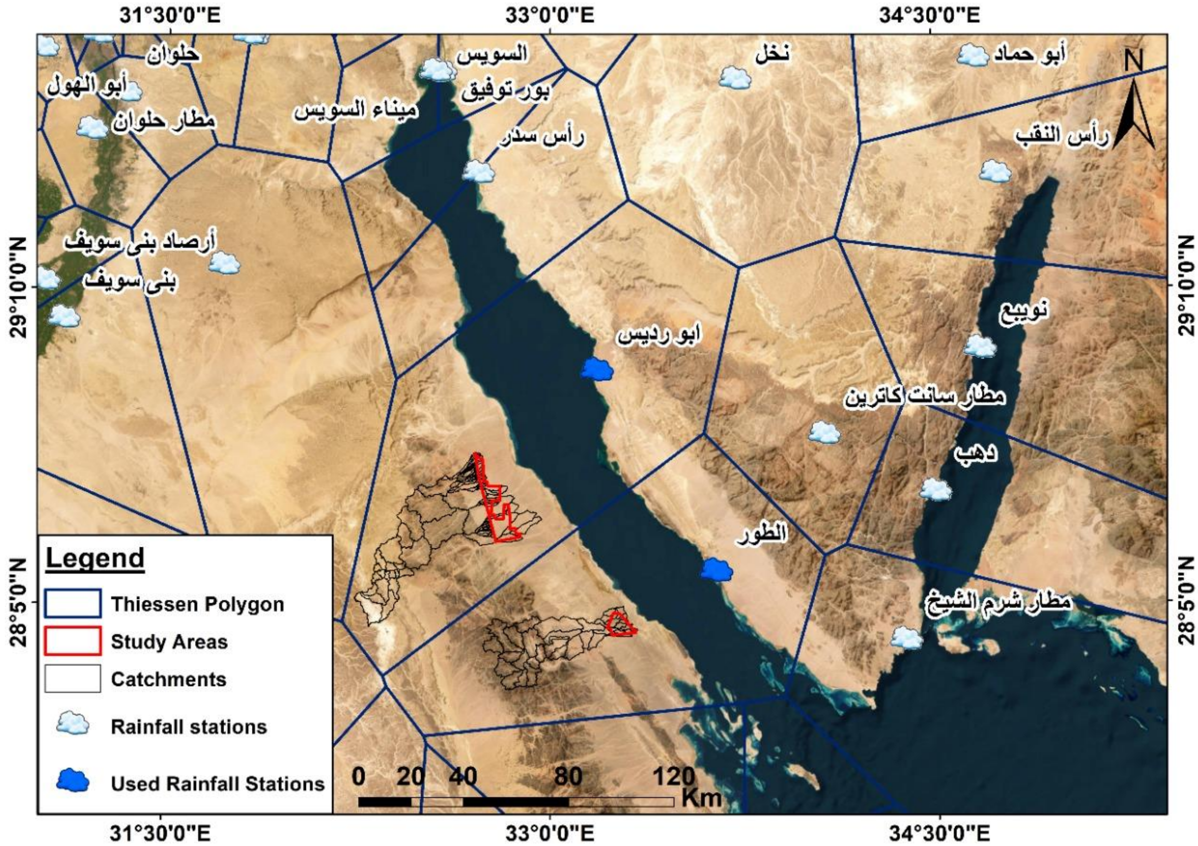


Figure 6.7: Thiessen Polygon for the meteorological stations

The Lognormal probability distribution of the rainfall data of Al-Tur Meteorological Station is used to estimate the rain storms corresponding to the frequency times from 2 to 2000 years, as shown in Figure 6.9. Due to the importance of the project as one of the most important sources of non-conventional energy in Egypt, the rainstorm corresponding to an iterative period of 100 years is selected to be the design rainstorm for all protection works from the flash flood hazards. The value of this storm is about 40.6 mm for Al-Tur Meteorological Station.

The intensity-duration-frequency (IDF) curves for the Abu Rudeis Meteorological Station are derived using the results of the lognormal distribution obtained from the Hyfran-Plus model with the SCS Type II distribution for rainfall as shown in Figure 6.10. These curves have several useful uses, including estimating the surface flow (floodwater) of small Wadis within 1 km^2 area using simple mathematical models such as the Rational Method, as well as designing rainwater drainage networks.

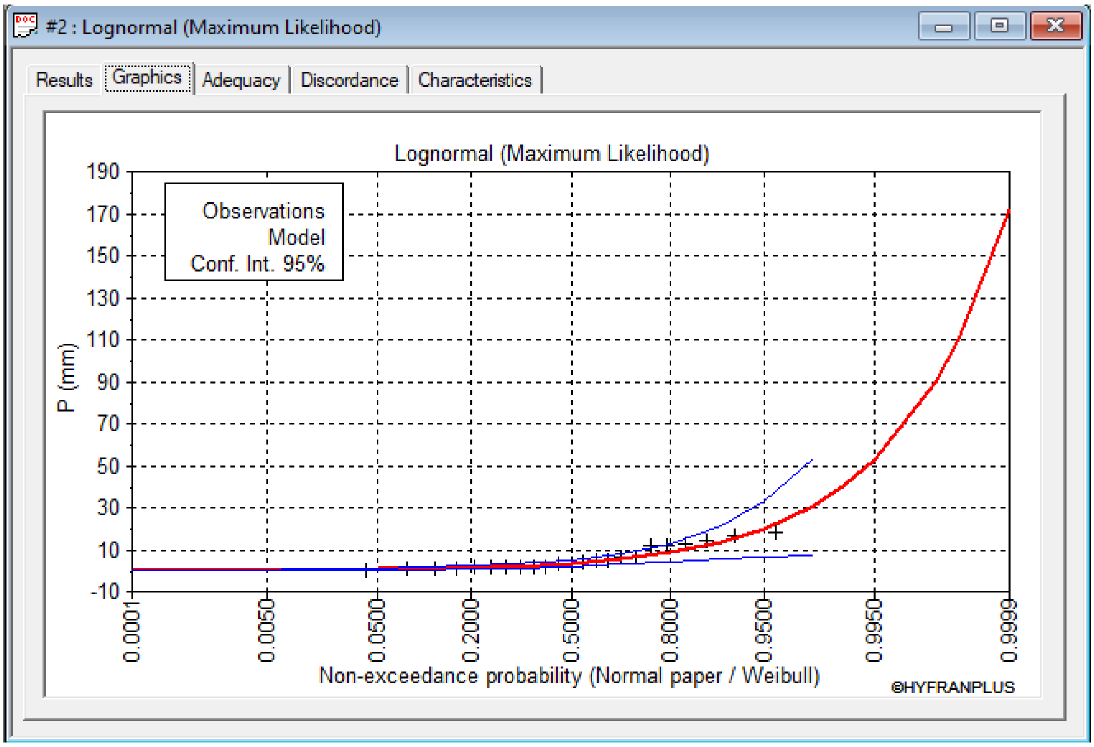
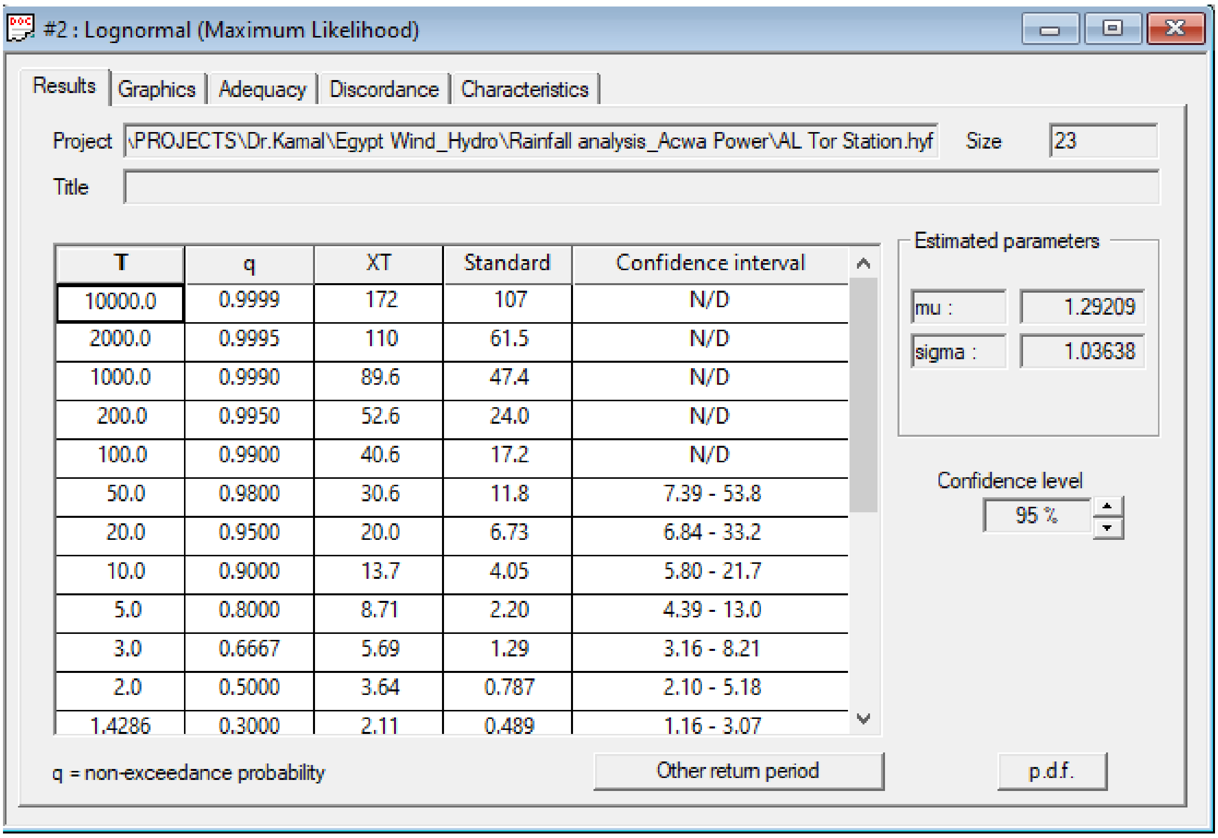


Figure 6.8: Rainfall measured at Al-Tur station compared to calculated lognormal probability distribution (95% confidence)

6.4. Peak Flows and Runoff Hydrographs

HEC-HMS software is used to estimate the peak flows from the contributing watersheds using the SCS Unit Hydrograph method for catchment areas above 100 ha, while the rational method was used for watershed areas below 100 ha (Figure 6.11). Peak flow is usually used to estimate the hydraulic characteristics of the existing streams. The peak flows of all catchments are estimated for 2-, 10-, 20-, 50-, 100- and 200-year design storm. The 100-year design storm is adopted and increased by 20% to account for climate change. Table 6.3 gives the morphological parameters and the model results of wadis discharges affecting the project boundary for different return periods.



#2 : Lognormal (Maximum Likelihood)

Results | Graphics | Adequacy | Discordance | Characteristics

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Title

T	q	XT	Standard	Confidence interval
10000.0	0.9999	172	107	N/D
2000.0	0.9995	110	61.5	N/D
1000.0	0.9990	89.6	47.4	N/D
200.0	0.9950	52.6	24.0	N/D
100.0	0.9900	40.6	17.2	N/D
50.0	0.9800	30.6	11.8	7.39 - 53.8
20.0	0.9500	20.0	6.73	6.84 - 33.2
10.0	0.9000	13.7	4.05	5.80 - 21.7
5.0	0.8000	8.71	2.20	4.39 - 13.0
3.0	0.6667	5.69	1.29	3.16 - 8.21
2.0	0.5000	3.64	0.787	2.10 - 5.18
1.4286	0.3000	2.11	0.489	1.16 - 3.07

Estimated parameters

mu : 1.29209

sigma : 1.03638

Confidence level 95 %

q = non-exceedance probability

Other return period

p.d.f.

Figure 6.9: Rainstorms for different frequency periods from 2 to 2000 years for Al-Tur meteorological station

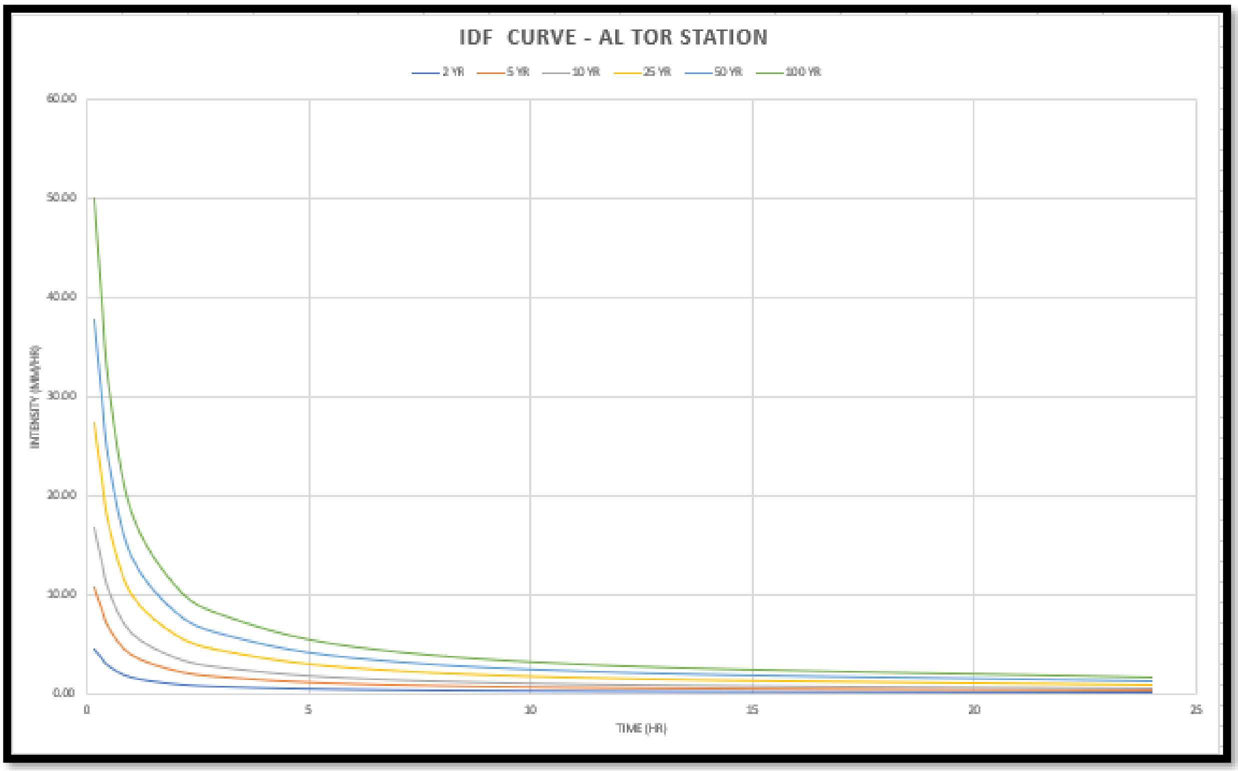

Figure 6.10: Intensity-Duration-Frequency (IDF) curves for Al-Tur meteorological station

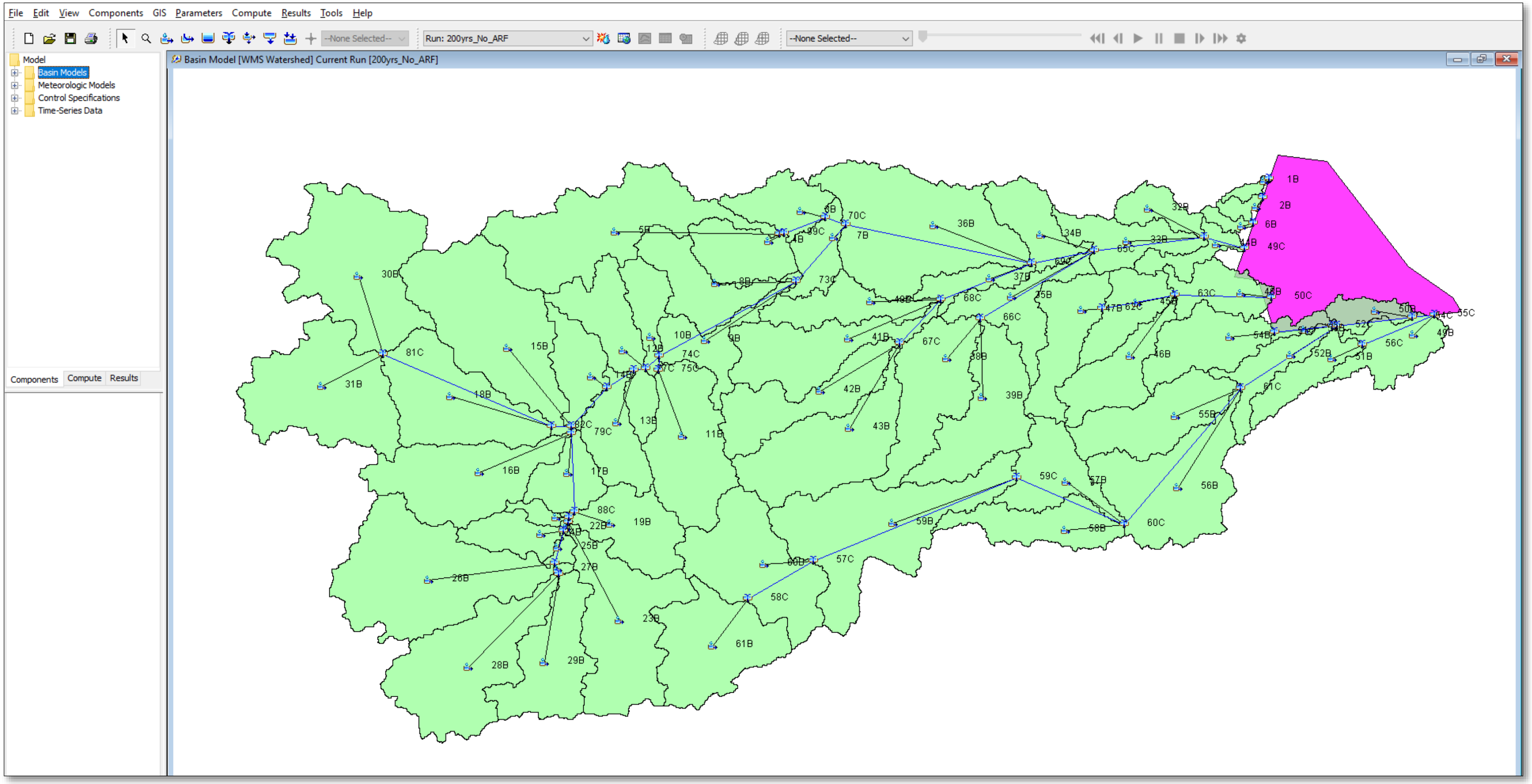

Figure 6.11: Flow calculations from HEC-HMS software

Table 6.3 : Morphological characteristics for catchment areas and model results

Basin Name	Basin Area (km^2)	$CN_{0.2}$	$CN_{0.05}$	Q 2 yrs. (m^3/s)	Q 5 yrs. (m^3/s)	Q 10 yrs. (m^3/s)	Q 20 yrs. (m^3/s)	Q 50 yrs. (m3/s)	Q 100 yrs. (m^3/s)	Q 100 yrs. + CC (m^3/s)	Q 200 yrs. (m^3/s)
1B	1.22	76	67	0.0	0.0	0.1	0.2	0.5	0.8	1.1	1.3
2B	1.76	76	67	0.0	0.1	0.1	0.3	0.7	1.1	1.5	1.8
3B	9.87	76	67	0.0	0.3	0.6	1.2	2.7	4.6	6.3	7.2
4B	12.14	79	71	0.1	0.5	1.2	2.4	5.2	8.6	11.8	13.4
5B	36.48	84	79	0.4	2.2	5.1	10.2	21.7	35.1	47.4	53.6
6B	1.51	76	67	0.0	0.1	0.1	0.3	0.6	0.9	1.3	1.5
7B	7.81	76	67	0.0	0.2	0.6	1.2	2.7	4.6	6.3	7.2
8B	14.61	84	78	0.2	1.0	2.4	4.8	10.3	16.7	22.6	25.5
9B	10.67	84	79	0.2	0.9	2.0	4.1	8.7	14.1	19.1	21.6
10B	7.77	85	80	0.2	0.9	2.1	4.1	8.8	14.2	19.1	21.6
11B	25.03	85	80	0.4	2.0	4.7	9.4	20.0	32.2	43.3	49.0
12B	17.06	85	80	0.3	1.7	3.9	7.8	16.6	26.7	36.0	40.7
13B	11.99	85	80	0.2	1.0	2.3	4.7	9.9	15.9	21.4	24.2
14B	10.34	85	80	0.2	1.1	2.7	5.3	11.3	18.2	24.6	27.8
15B	39.33	85	80	0.5	2.7	6.3	12.7	26.8	43.2	58.2	65.7
16B	26.27	85	80	0.4	2.0	4.6	9.3	19.6	31.5	42.5	48.0
17B	9.14	85	80	0.2	1.1	2.6	5.2	11.1	17.9	24.1	27.2
18B	27.40	85	80	0.4	2.2	5.1	10.1	21.5	34.6	46.6	52.7
19B	15.36	85	80	0.3	1.6	3.7	7.3	15.5	25.0	33.7	38.1
20B	2.02	85	80	0.1	0.3	0.7	1.5	3.1	5.0	6.7	7.6
21B	0.13	85	80	0.0	0.0	0.1	0.1	0.3	0.5	0.7	0.8
22B	0.14	85	80	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.8
23B	30.24	85	80	0.4	2.2	5.3	10.5	22.3	35.9	48.4	54.7
24B	7.59	85	80	0.2	0.9	2.0	4.1	8.6	13.9	18.7	21.2
25B	1.45	85	80	0.0	0.2	0.5	1.0	2.1	3.4	4.6	5.2
26B	42.05	85	80	0.5	2.6	6.1	12.1	25.6	41.2	55.4	62.7
27B	0.46	85	80	0.0	0.1	0.3	0.5	1.1	1.8	2.5	2.8
28B	32.21	85	80	0.4	2.3	5.4	10.9	23.0	37.1	50.0	56.5
29B	19.96	85	80	0.3	1.6	3.8	7.7	16.3	26.2	35.3	39.9
30B	38.39	85	80	0.6	3.1	7.3	14.5	30.8	49.6	66.9	75.6

Basin Name	Basin Area (km²)	$CN_{0.2}$	$CN_{0.05}$	Q 2 yrs. (m³/s)	Q 5 yrs. (m³/s)	Q 10 yrs. (m³/s)	Q 20 yrs. (m³/s)	Q 50 yrs. (m3/s)	Q 100 yrs. (m³/s)	Q 100 yrs. + CC (m³/s)	Q 200 yrs. (m³/s)
31B	33.54	85	80	0.5	2.6	6.2	12.3	26.1	42.1	56.7	64.1
32B	6.17	76	67	0.0	0.2	0.4	0.8	1.8	2.9	4.1	4.6
33B	11.44	76	67	0.0	0.2	0.6	1.2	2.7	4.5	6.2	7.1
34B	10.71	76	67	0.0	0.3	0.7	1.4	3.1	5.1	7.1	8.1
35B	13.18	76	67	0.0	0.3	0.6	1.3	2.9	4.9	6.7	7.7
36B	42.22	76	67	0.1	0.7	1.7	3.5	7.7	12.9	17.8	20.3
37B	6.10	76	67	0.0	0.1	0.3	0.7	1.5	2.5	3.5	4.0
38B	22.36	76	67	0.1	0.5	1.2	2.4	5.3	8.7	12.1	13.8
39B	22.75	76	67	0.1	0.4	1.0	2.1	4.6	7.7	10.6	12.1
40B	11.58	76	67	0.0	0.2	0.5	1.1	2.4	4.0	5.6	6.4
41B	20.88	81	74	0.1	0.6	1.5	3.1	6.7	11.0	15.0	17.0
42B	18.55	83	76	0.2	0.9	2.2	4.4	9.5	15.4	21.0	23.8
43B	27.26	83	76	0.3	1.5	3.5	7.0	15.0	24.5	33.2	37.7
44B	5.31	76	67	0.0	0.1	0.3	0.6	1.3	2.1	3.0	3.4
45B	10.87	76	67	0.0	0.3	0.7	1.4	3.0	5.0	6.9	7.9
46B	12.91	76	67	0.1	0.3	0.7	1.4	3.2	5.3	7.3	8.4
47B	15.23	76	67	0.1	0.4	0.9	1.8	4.0	6.7	9.2	10.5
48B	9.54	76	67	0.0	0.2	0.5	1.0	2.2	3.6	5.0	5.7
49B	11.55	76	67	0.0	0.2	0.5	1.1	2.4	4.0	5.6	6.4
50B	4.95	76	67	0.0	0.1	0.3	0.6	1.3	2.2	3.0	3.4
51B	8.37	76	67	0.0	0.2	0.4	0.8	1.8	3.0	4.1	4.7
52B	8.87	76	67	0.0	0.2	0.4	0.8	1.7	2.8	3.8	4.4
53B	2.13	76	67	0.0	0.1	0.1	0.3	0.7	1.1	1.5	1.8
54B	15.13	76	67	0.1	0.3	0.7	1.4	3.2	5.3	7.3	8.3
55B	19.00	76	67	0.1	0.4	1.0	2.1	4.6	7.7	10.6	12.1
56B	28.91	76	67	0.1	0.5	1.3	2.6	5.7	9.5	13.1	15.0
57B	14.19	76	67	0.1	0.3	0.8	1.6	3.6	5.9	8.2	9.4
58B	13.65	76	67	0.0	0.3	0.6	1.3	2.9	4.8	6.6	7.6
59B	39.31	82	75	0.3	1.6	3.8	7.8	16.8	27.4	37.4	42.4
60B	28.32	83	77	0.4	2.2	5.1	10.3	22.0	35.9	48.6	55.1
61B	24.86	85	80	0.5	2.5	5.9	11.9	25.1	40.5	54.6	61.7

7. HYDRAULIC MODELING

Hydraulic modeling is used to calculate flood depth and velocity, as well as flood extent. Two-dimensional (2D) models are more accurate in determining stream limits, flow depths and velocities compared to the 1D modeling. Therefore, two-dimensional modeling is generally required in flat urban areas. In addition, the use of 2D model is recommended if the wadi is frequently flooding towards populated areas, causing damage to properties and endangering lives.

Some 2D HEC-RAS models are carried out for the study area in order to study the extent of the flood and estimate the flood hazards, which could affect the site boundaries. Several model scenarios are carried out in order to study the flood risk and propose the best solution to ensure the safety of the site. The following sections summarize the most important scenarios results.

7.1. Hydraulic Model Development

The following data have been used to develop the hydraulic models for the study area (Ras Shukeir Plot):

- Boundary Conditions/Catchments Hydrographs.
- Topographic Survey.

Figure 7.1 shows the site boundaries and the hydraulic model boundary conditions (BC). On the other hand, Figures 7.2 to 7.9 show the flow hydrographs, which are used as boundary conditions in the hydraulic model for the different scenarios for 2, 5, 10, 20, 50, 100, 100 +CC and 200 years.

7.2. Existing Condition Scenarios

To fully identify the flood hazards, the pre-development scenarios are carried out taking into consideration the undeveloped condition of the land use prior to the project being considered. These models show the behavior of the main wadis where the flood plain extends along the site boundary for different return periods.

This is to assess the effect of the flood plain extent, depth of water and velocity on all existing roads and structures. For each return period, a separate run is conducted to simulate the effect of wadis on the study area for different scenarios.

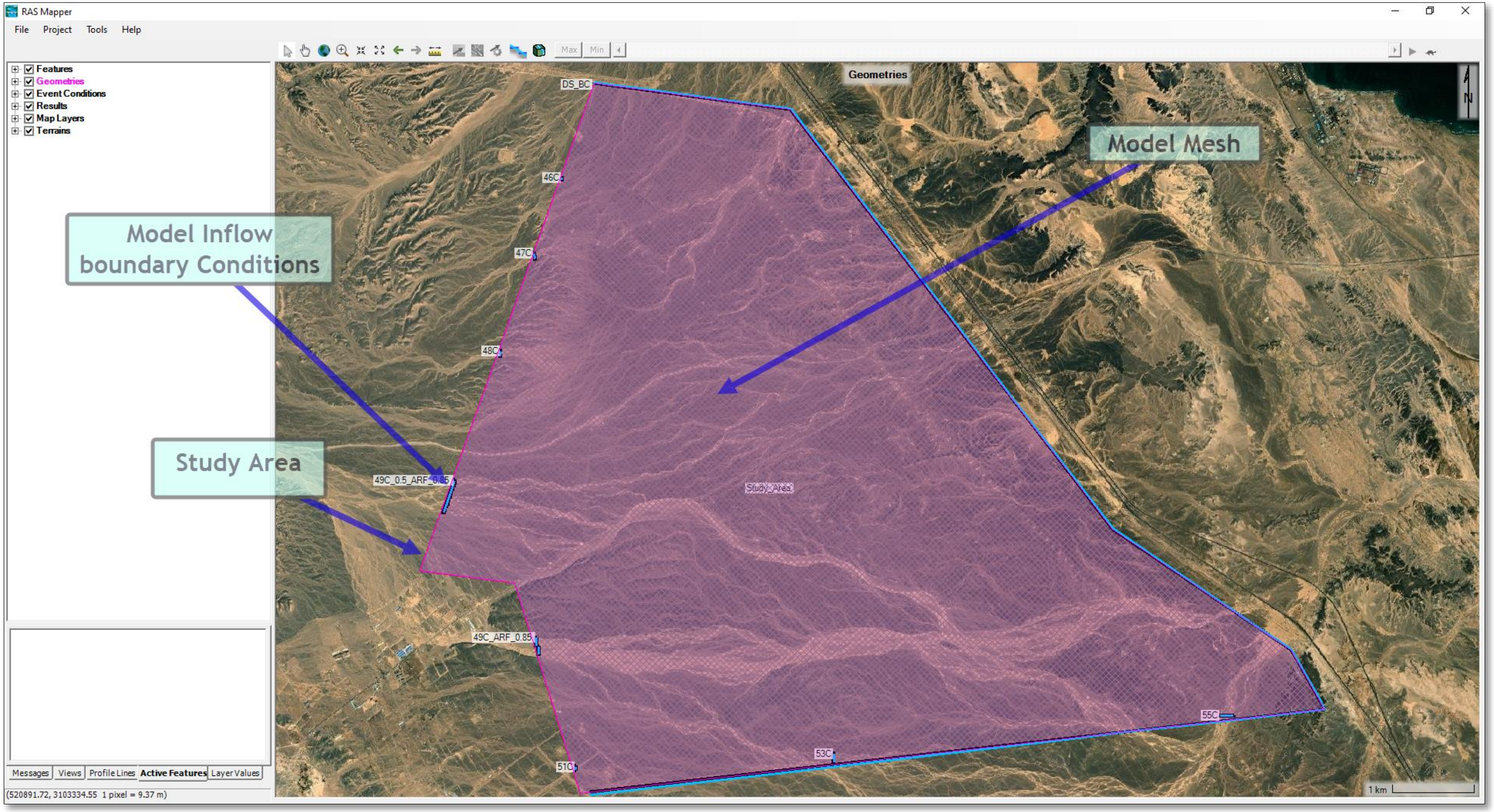

Figure 7.1: Site boundary and hydraulic model boundary conditions (BC)

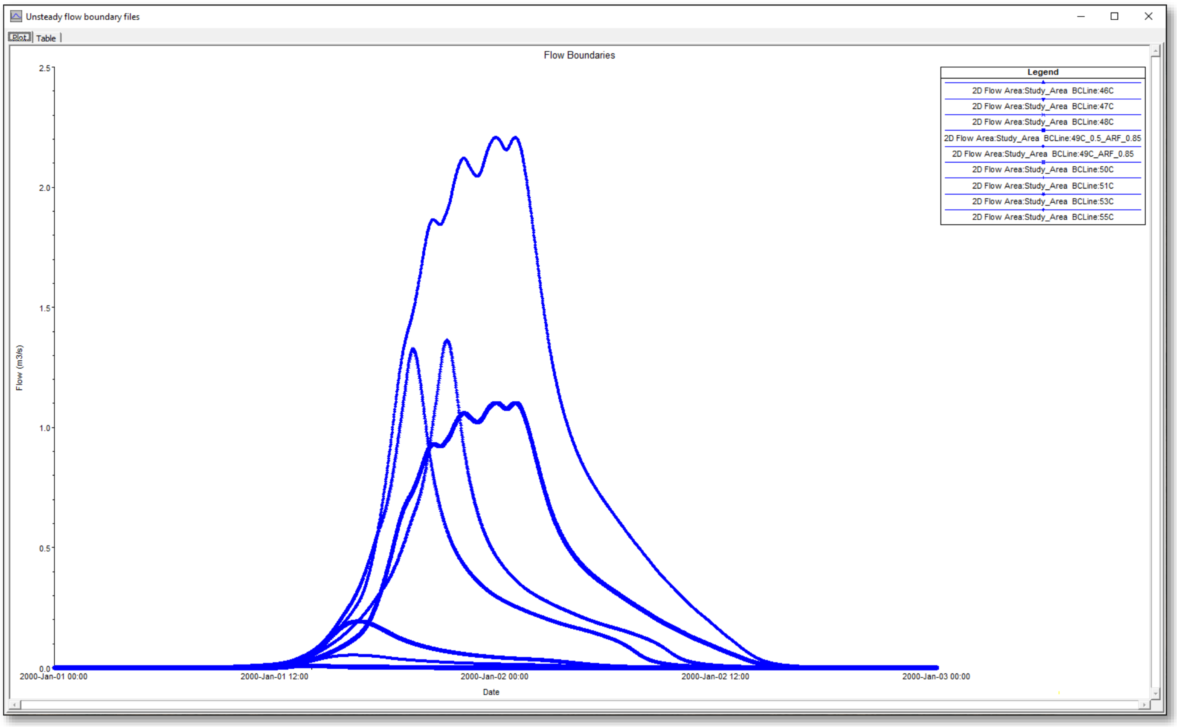

Figure 7.2: Boundary conditions (BC) for return period of 2 years (Hydrographs)

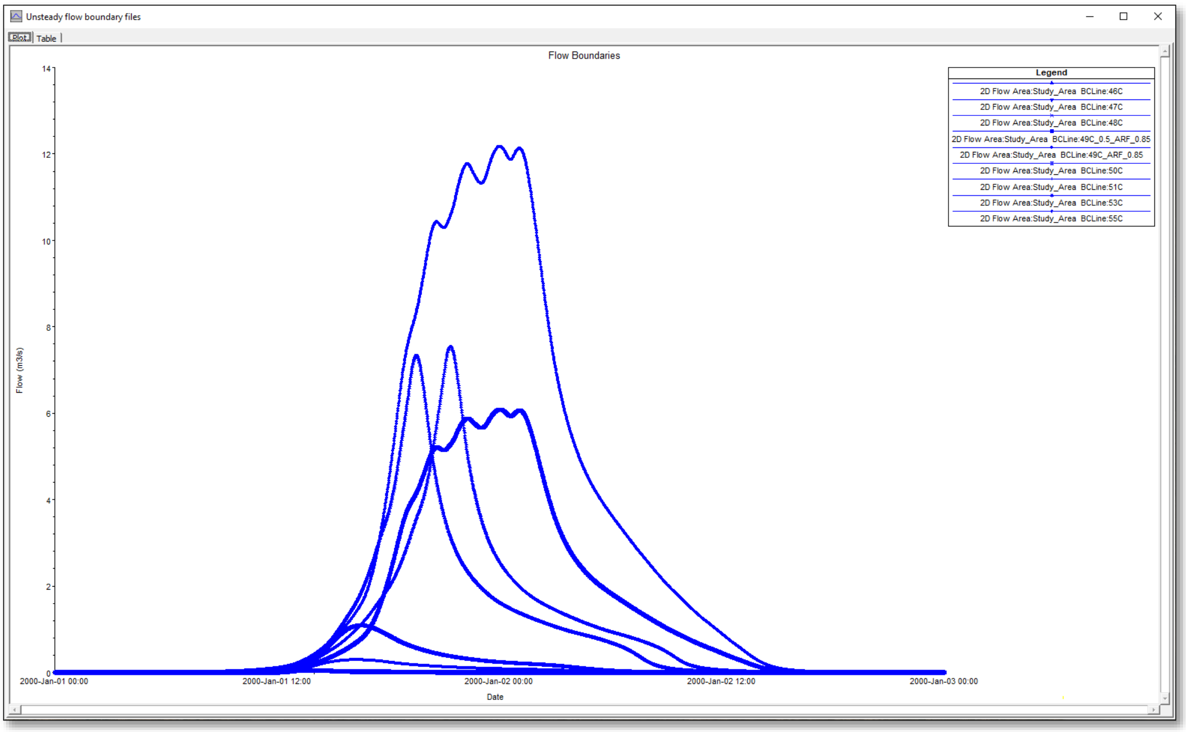

Figure 7.3: Boundary conditions (BC) for return period of 5 years (Hydrographs)

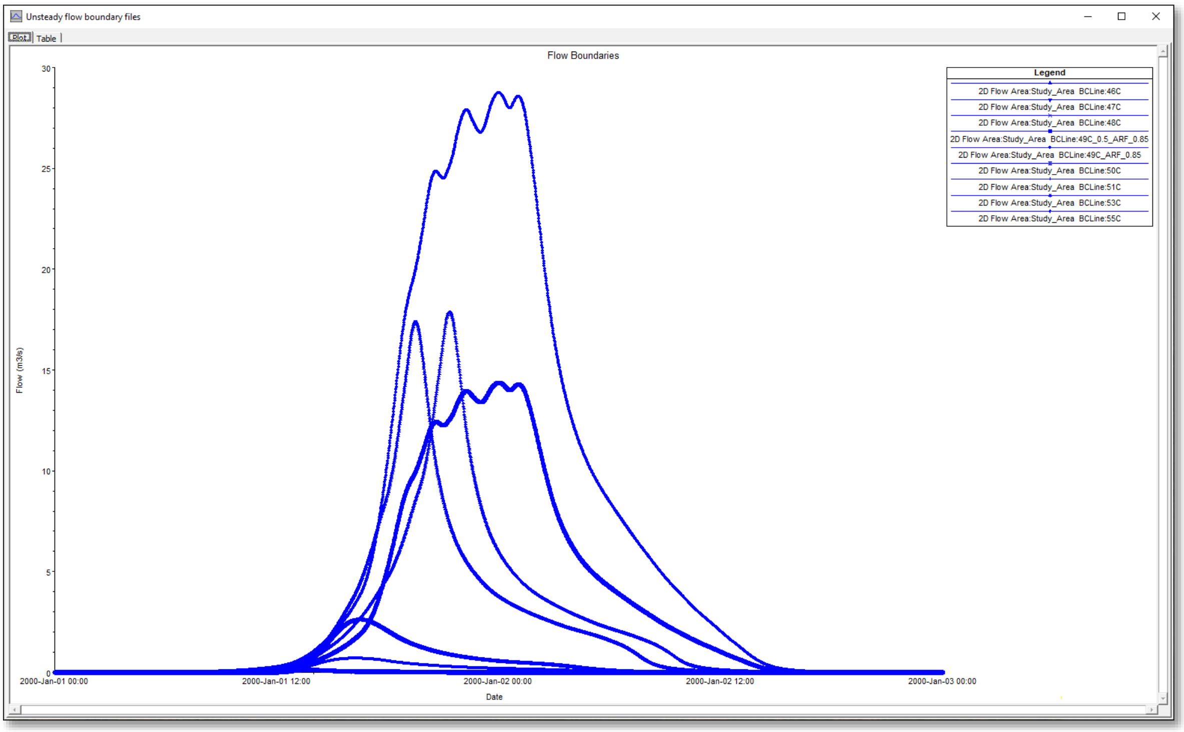

Figure 7.4: Boundary conditions (BC) for return period of 10 years (Hydrographs)

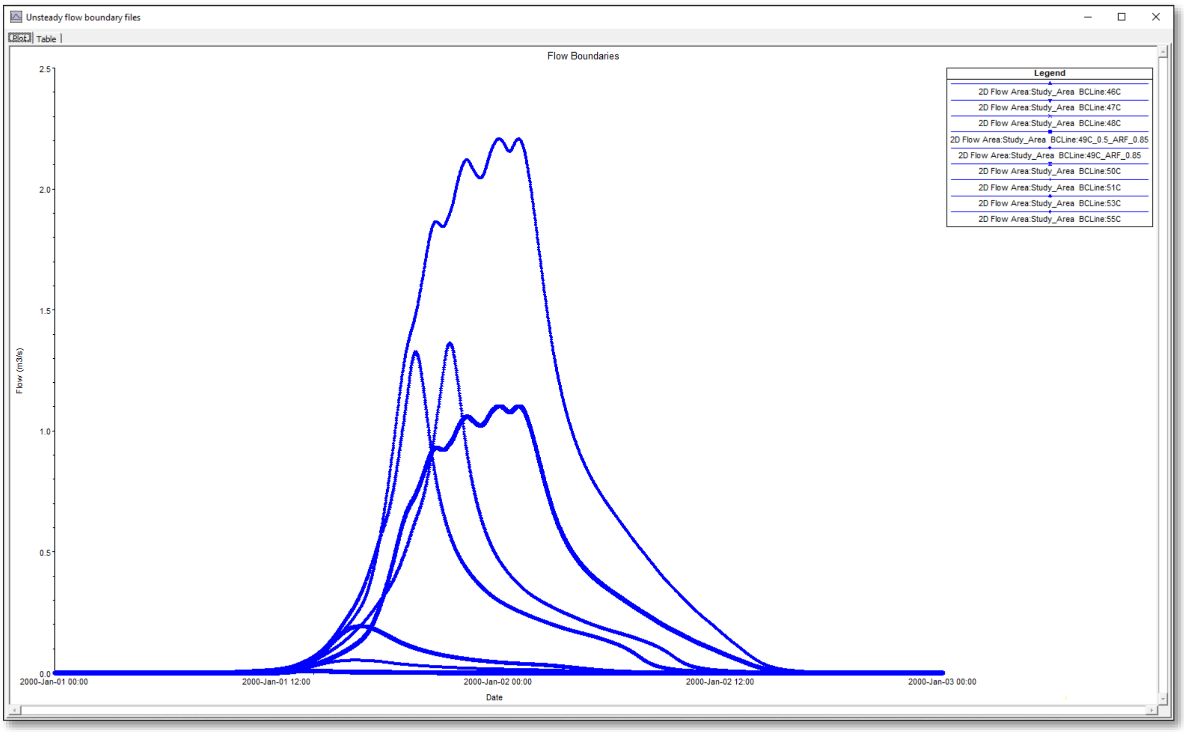

Figure 7.5: Boundary conditions (BC) for return period of 20 years (Hydrographs)

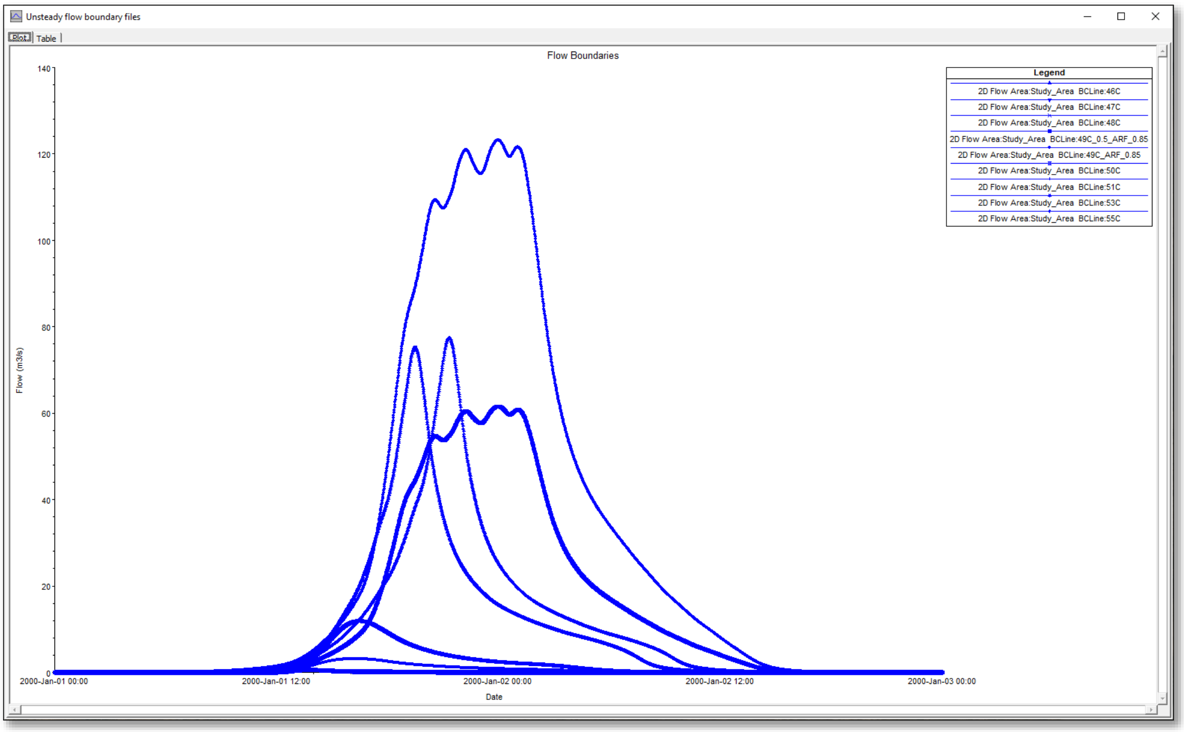

Figure 7.6: Boundary conditions (BC) for return period of 50 years (Hydrographs)

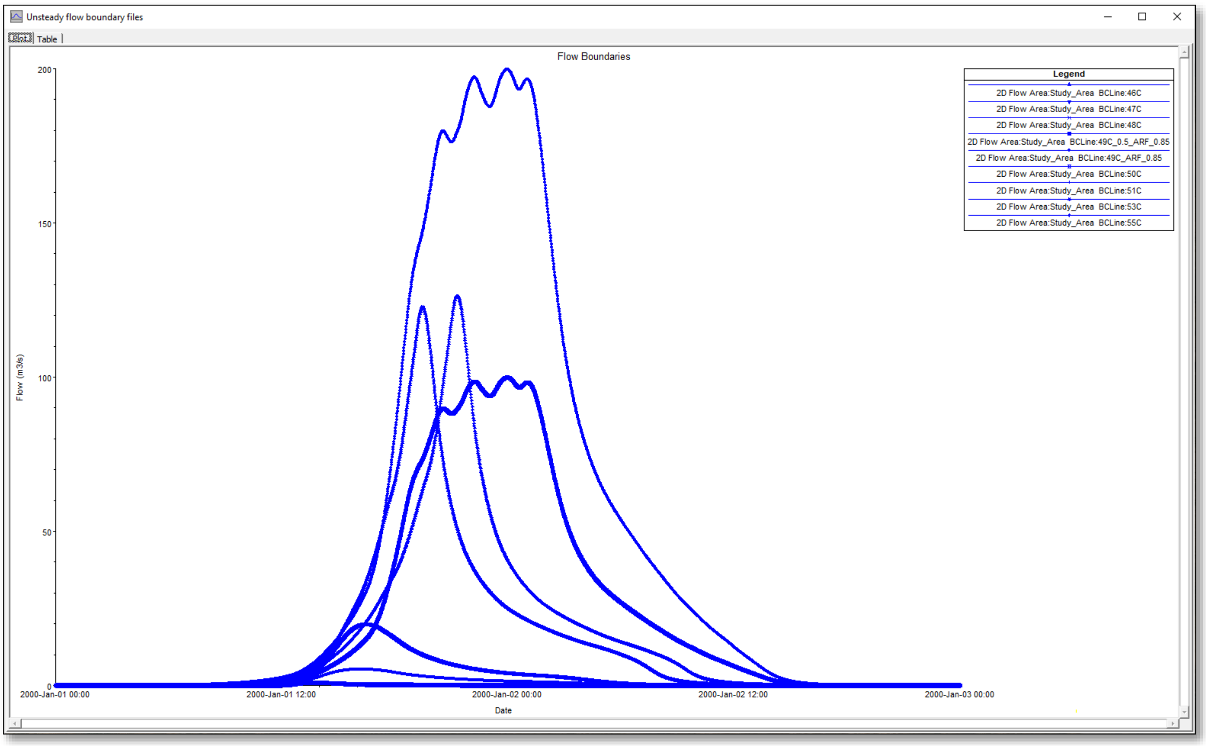

Figure 7.7: Boundary conditions (BC) for return period of 100 years (Hydrographs)

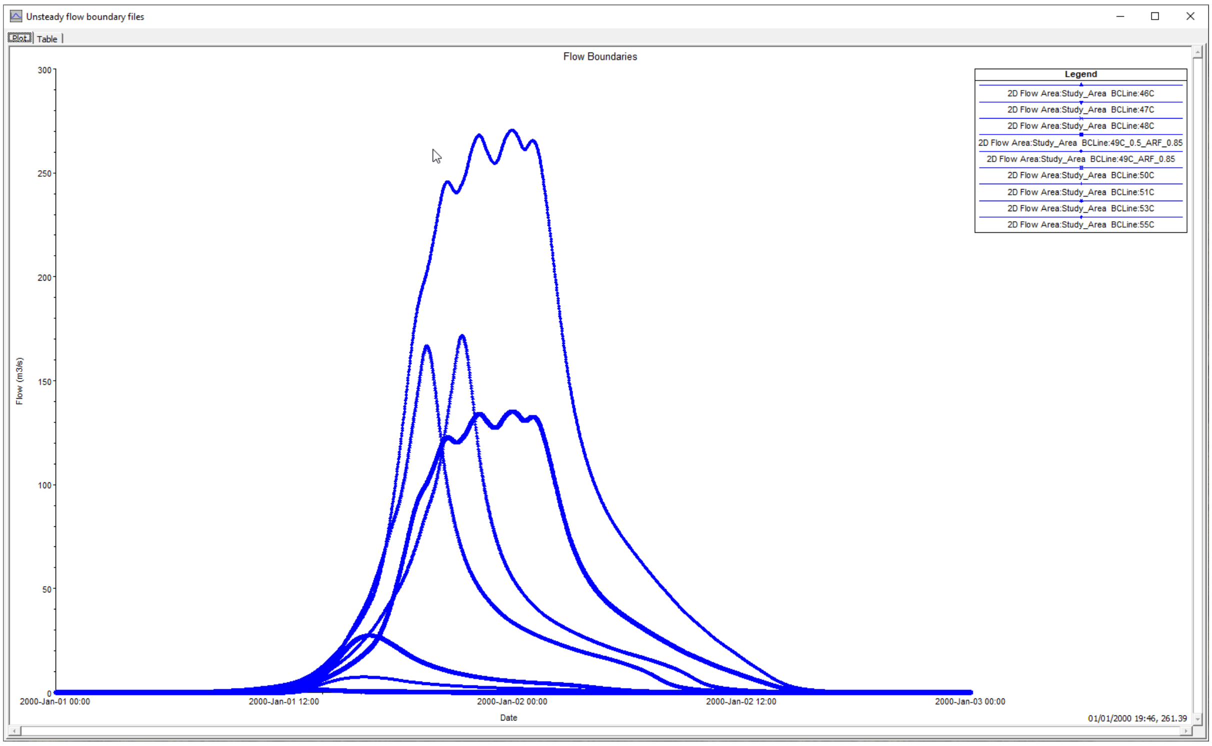

Figure 7.8: Boundary conditions (BC) for return period of 100 years Climate Change (Hydrographs)

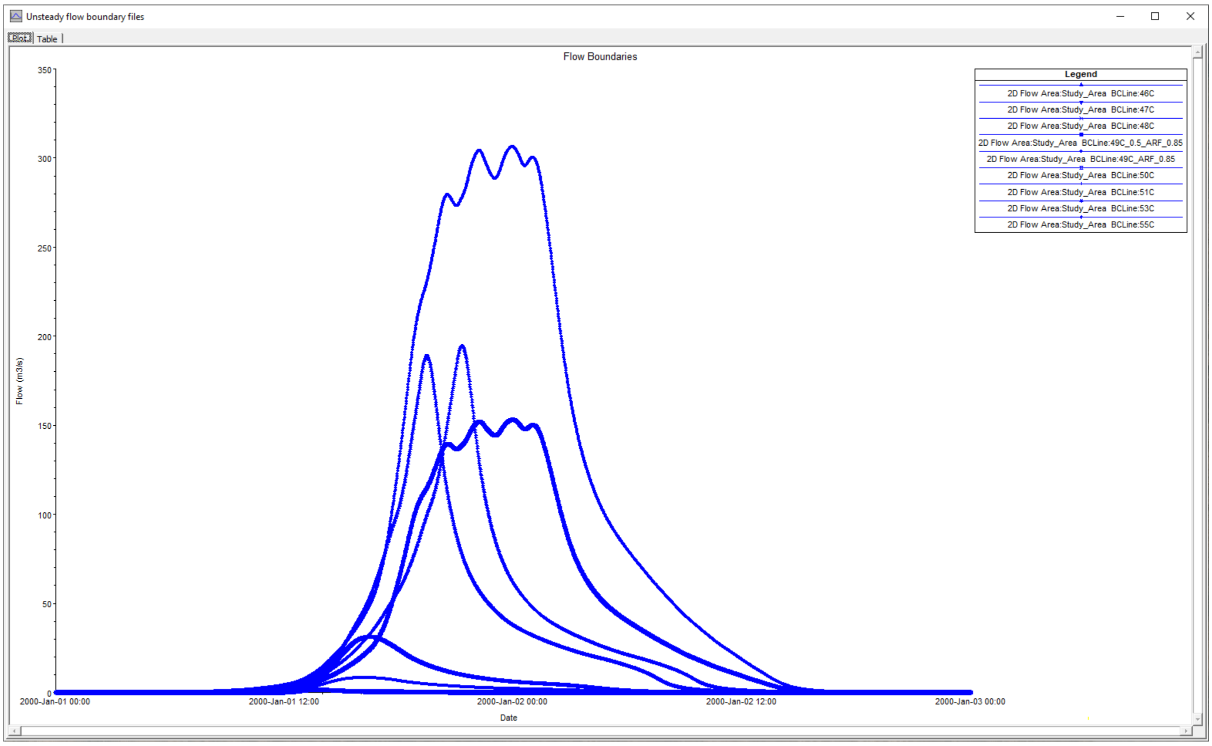

Figure 7.9: Boundary conditions (BC) for return period of 200 years (Hydrographs)

7.3. 2D Hydraulic Models Outputs

The results of the existing condition simulation are analyzed to examine the effect of the floodplain on structures and the internal roads inside the site, assess the risk to them, and propose the necessary protection.

Figures 7.10 to 7.17 show the depth maps for return periods of 2, 5, 10, 20, 50, 100, 100 + CC, 200 years; respectively. On the other hand, Figures 7.18 to 7.25 show the velocity maps for the same return periods of 2, 5, 10, 20, 50, 100, 100 + CC, 200 years.

The depth maps (Figures 7.10 to 7.17) indicate that the flood depth for each return period is as follows:

- For the 2-year return period, flood depth ranges from 0 to 0.2 m.
- For the 5-year return period, flood depth ranges from 0 to 0.25 m.
- For the 10-year return period, flood depth ranges from 0 to 0.35 m.
- For the 20-year return period, flood depth ranges from 0 to 0.45 m.
- For the 50-year return period, flood depth ranges from 0 to 0.70 m.
- For the 100-year return period, flood depth ranges from 0 to 0.90 m.
- For the return period of 100 year + CC, flood depth ranges from 0 to 1.15 m
- For the 200-year return period, flood depth ranges from 0 to 1.10 m.

7.4. Flood Risk Assessment

The flood risk maps are derived according to a methodology from numerical analysis resulting from 2-D hydraulic modeling. Figure 7.30 illustrates the methodology used to derive flood hazard maps. These maps are used to show the spatial distribution of the intensity of flooding taking into consideration the depth and velocity of floods resulting from the 2-D hydraulic modeling.

At the beginning, the geographical distribution of the flood depth and velocity values over the study area is derived from the results of the two-dimensional hydraulic modeling. The values of depth and velocity of each point in the study area are then reclassified and the range of values for each classification is determined according to different statistical distributions such as:

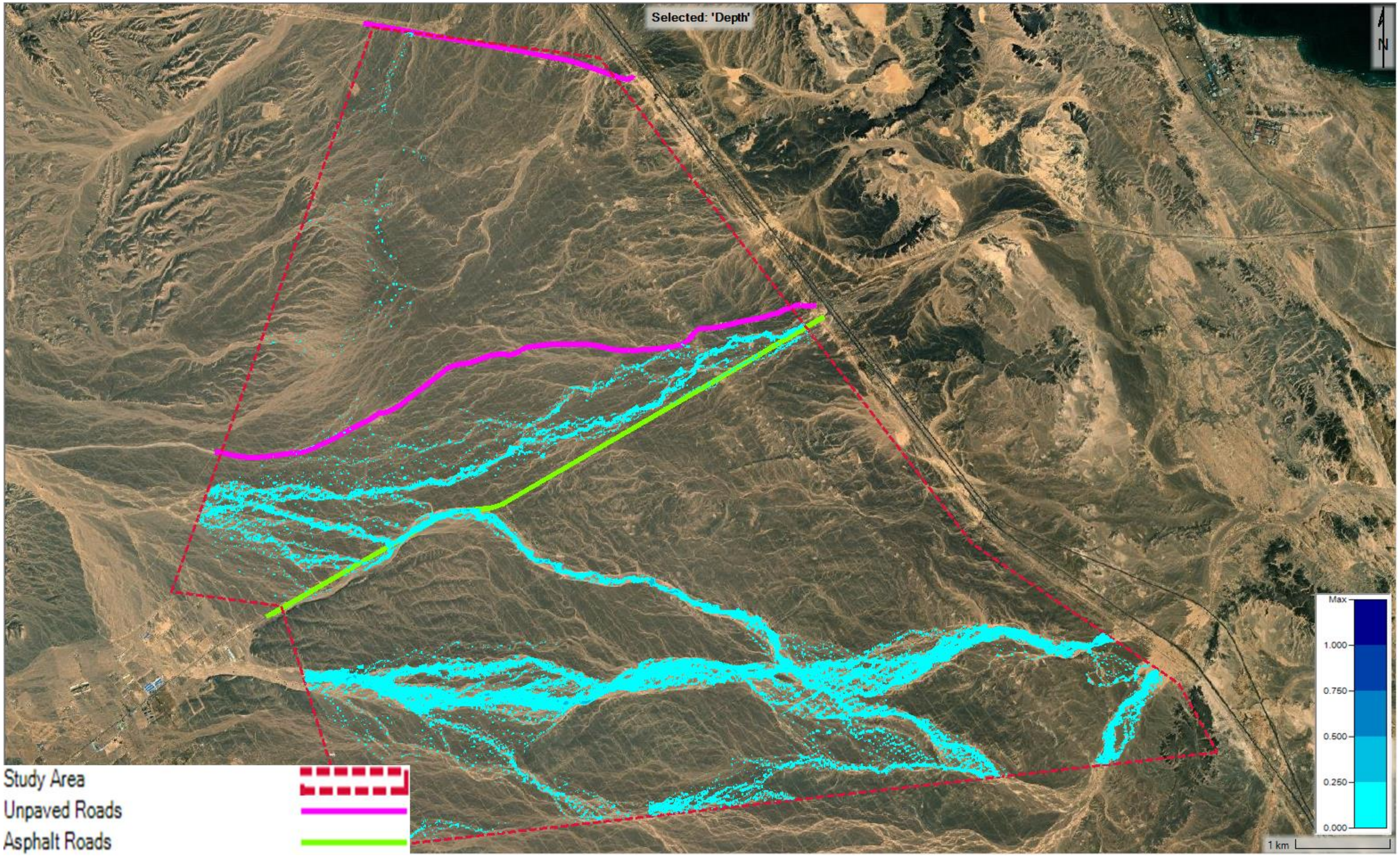

Figure 7.10: Depth map for return period of 2 years

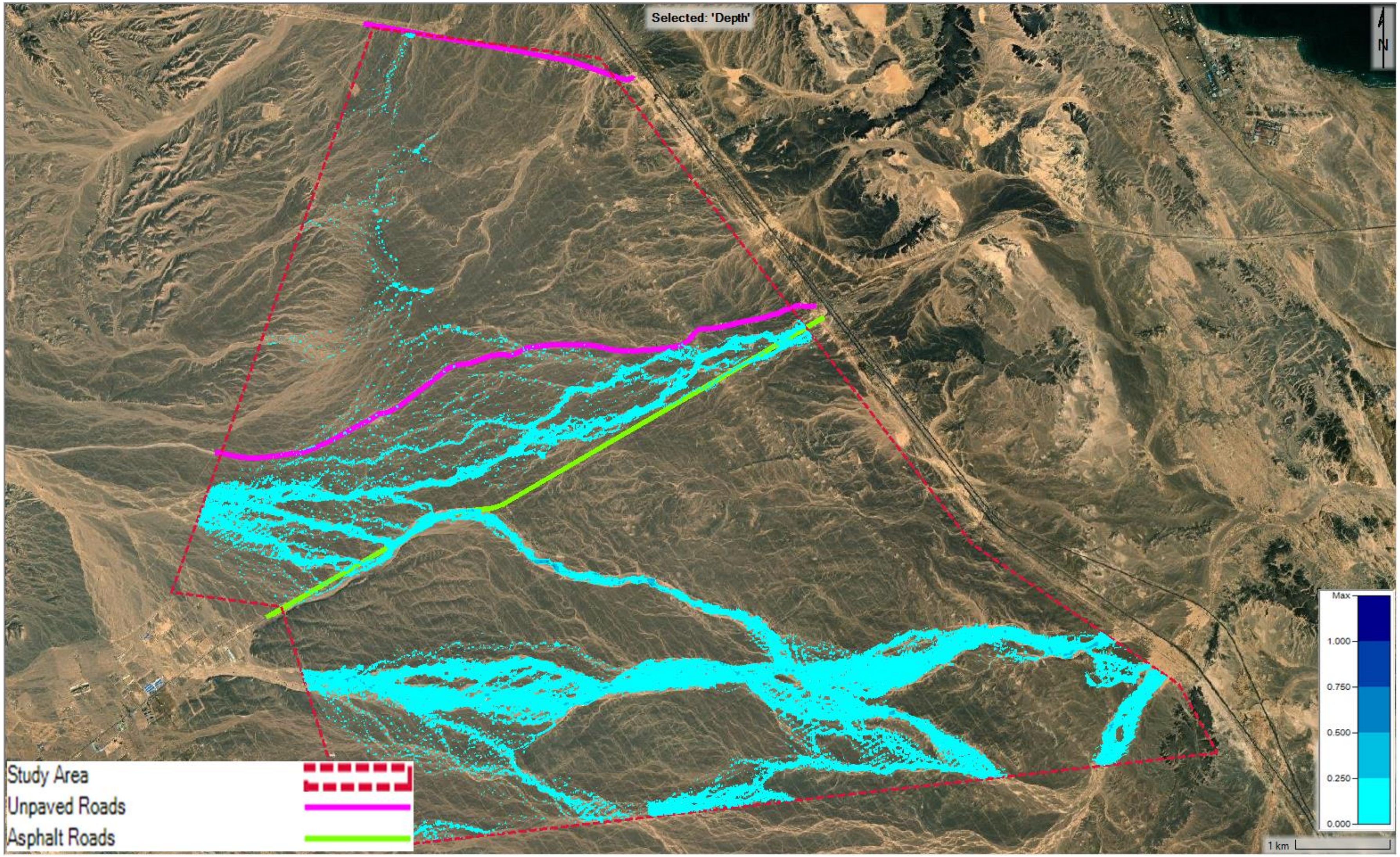

Figure 7.11: Depth map for return period of 5 years

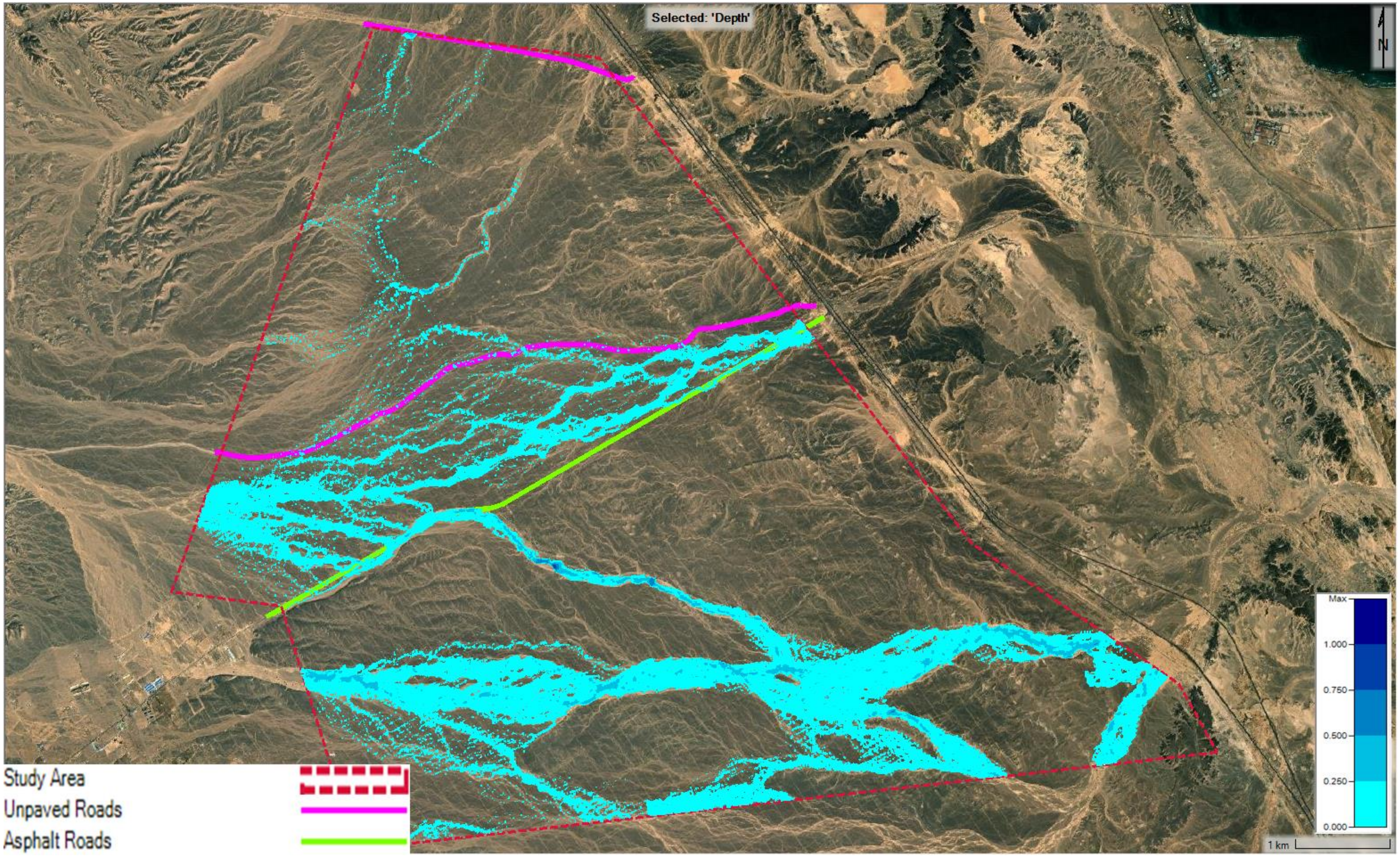

Figure 7.12: Depth map for return period of 10 years

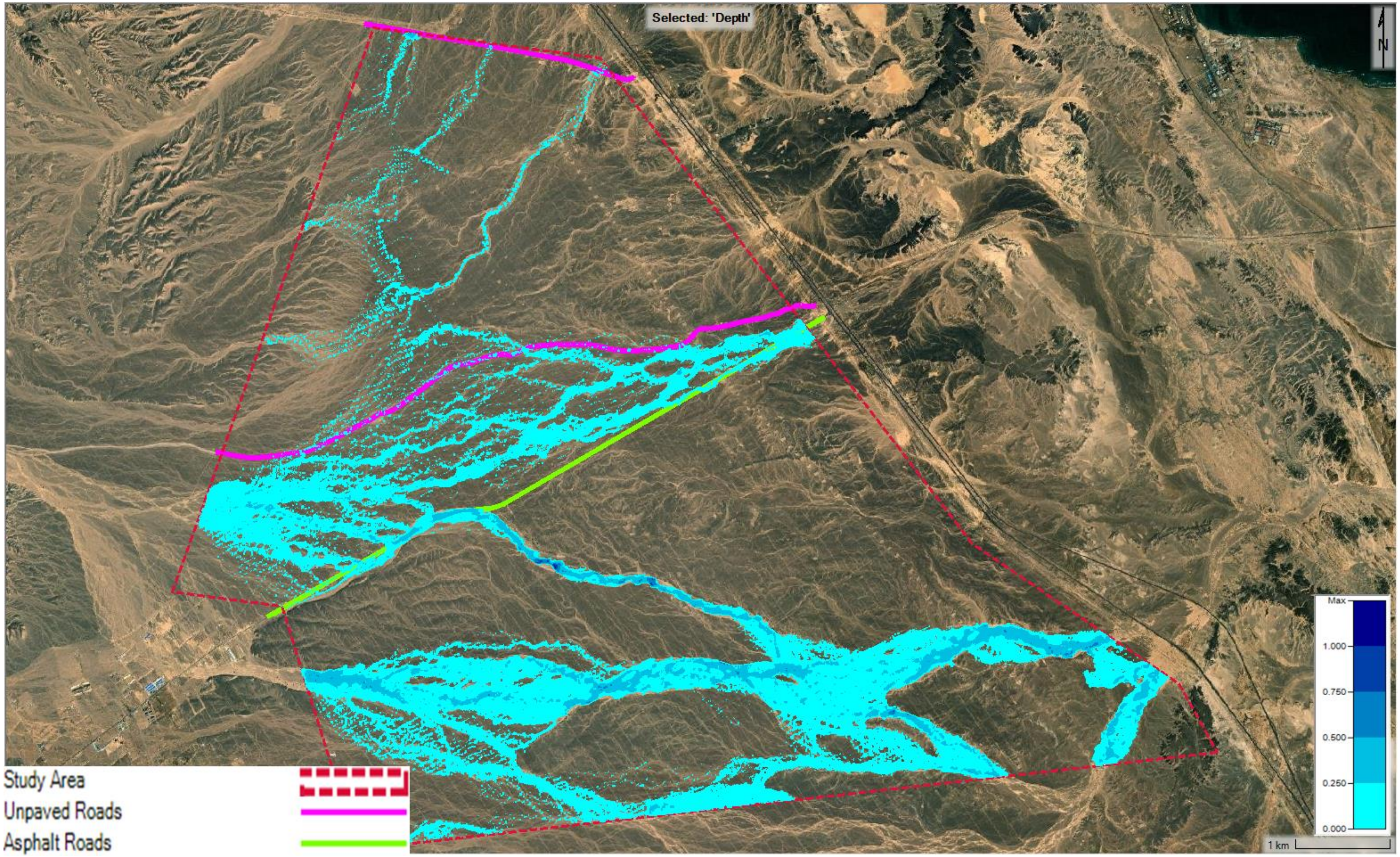

Figure 7.13: Depth map for return period of 20 years

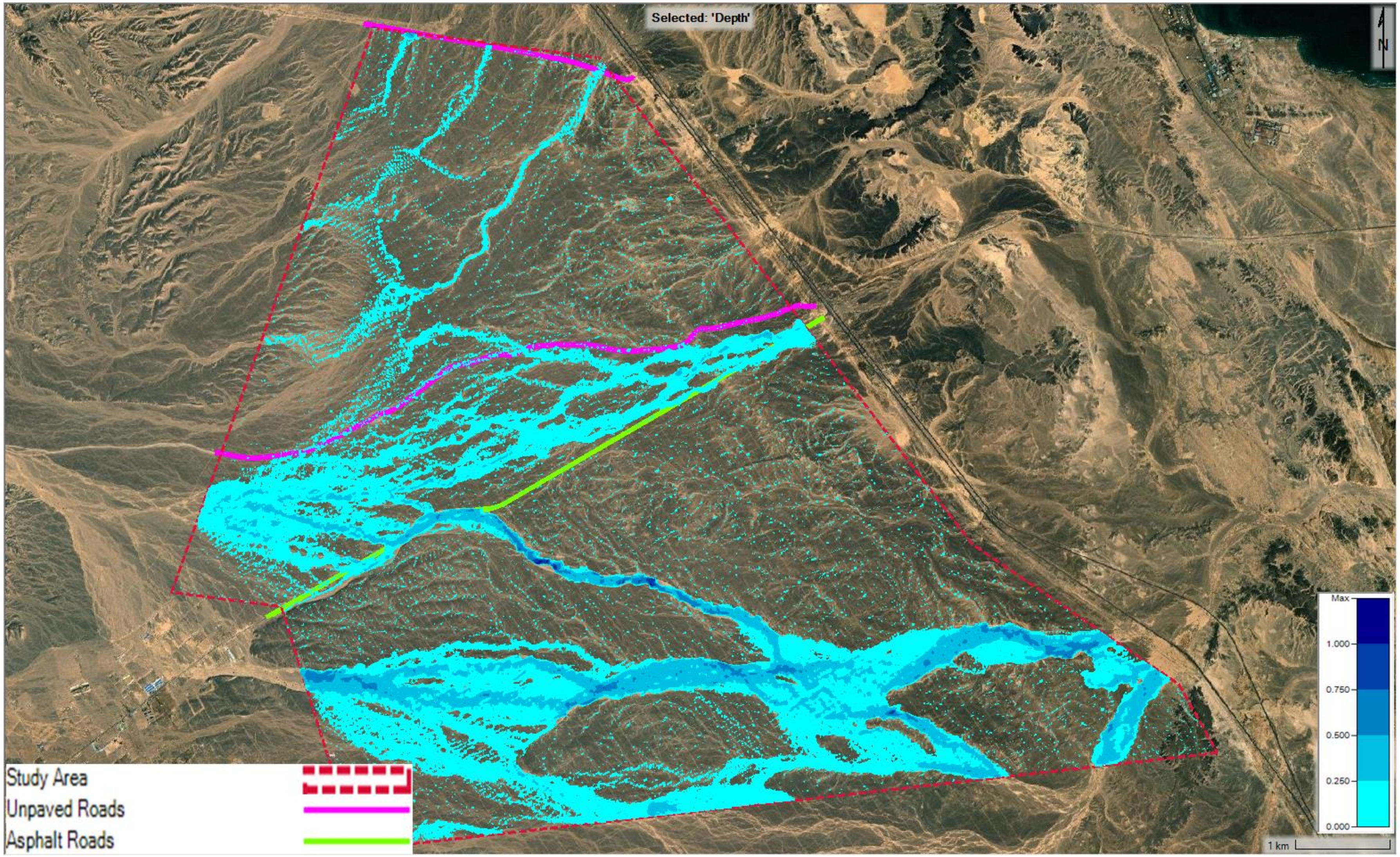

Figure 7.14: Depth map for return period of 50 years

EGEC

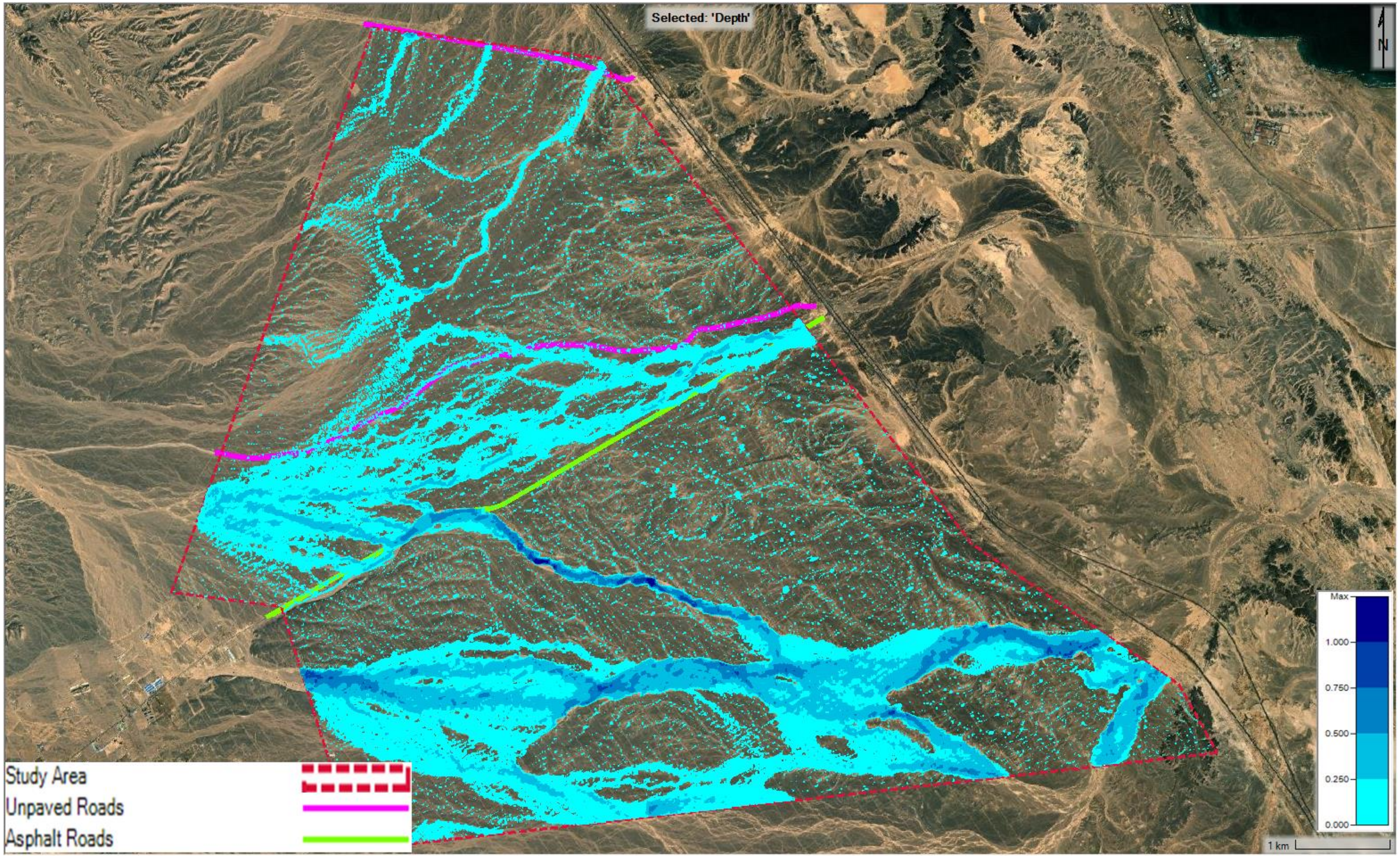

Figure 7.15: Depth map for return period of 100 years

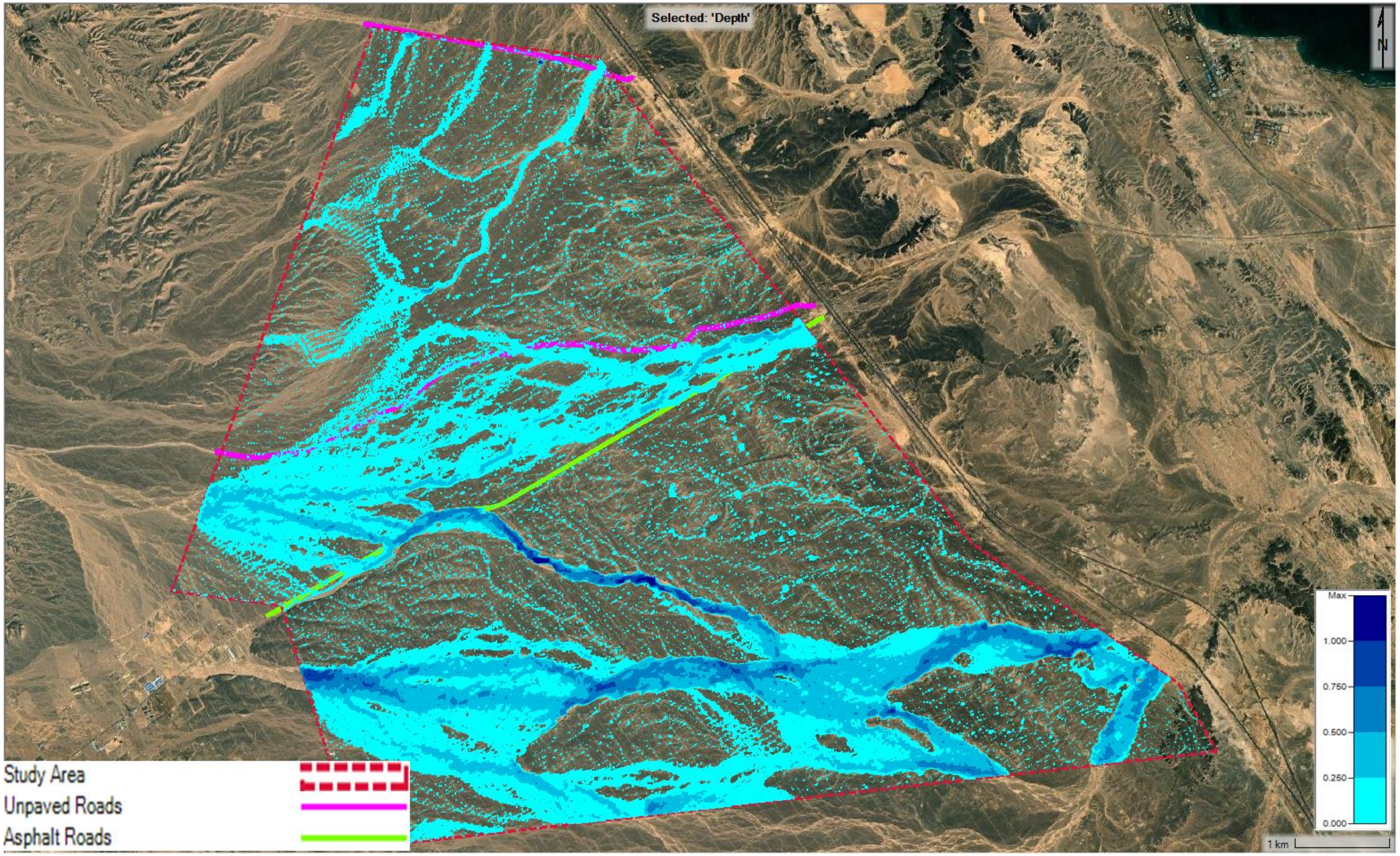

Figure 7.16: Depth map for return period of 100 years taking climate change into consideration

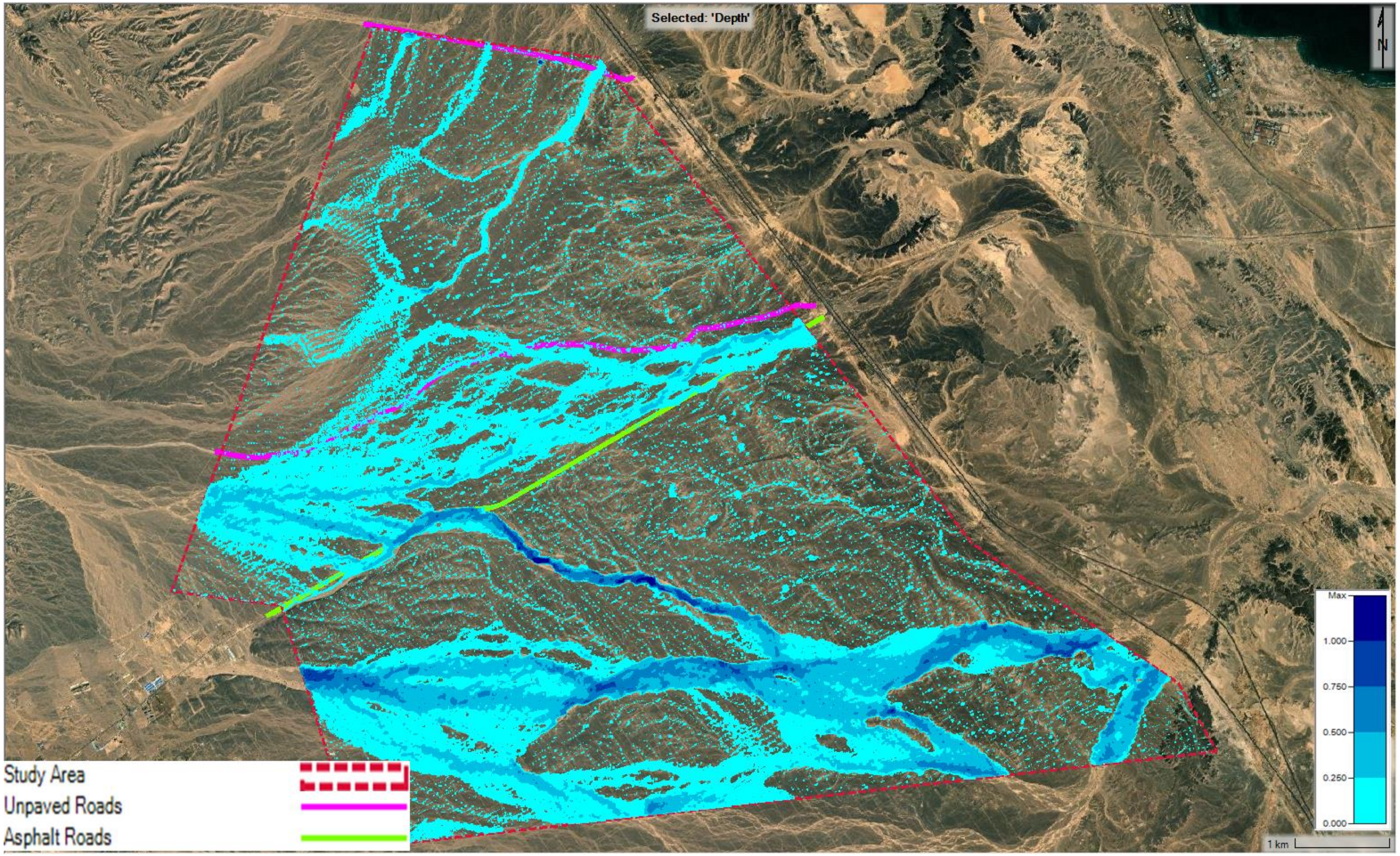

Figure 7.17: Depth map for return period of 200 years

- ***Velocity Maps***

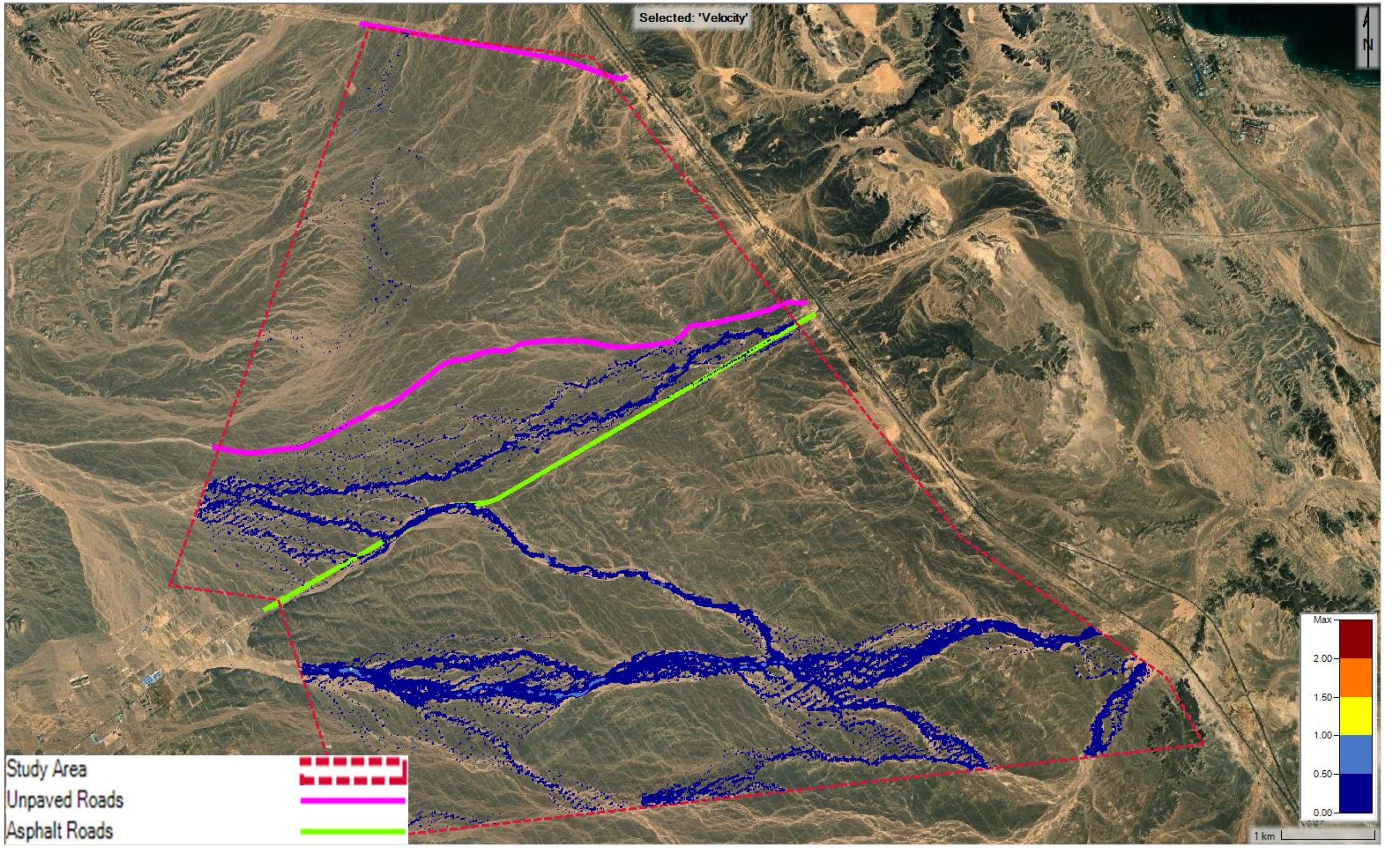

Figure 7.18: Velocity map for return period of 2 years

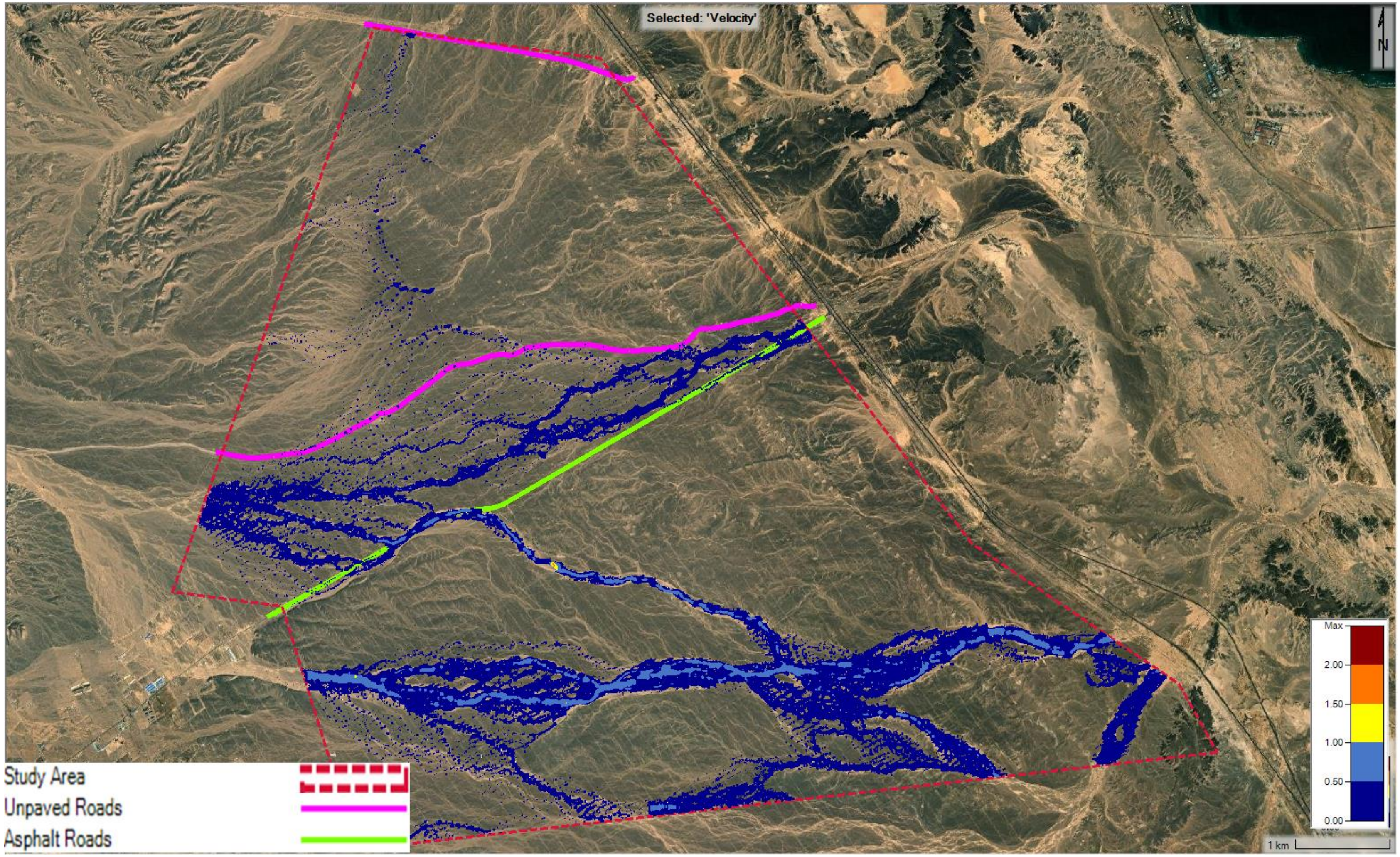

Figure 7.19: Velocity map for return period of 5 years

EGEC

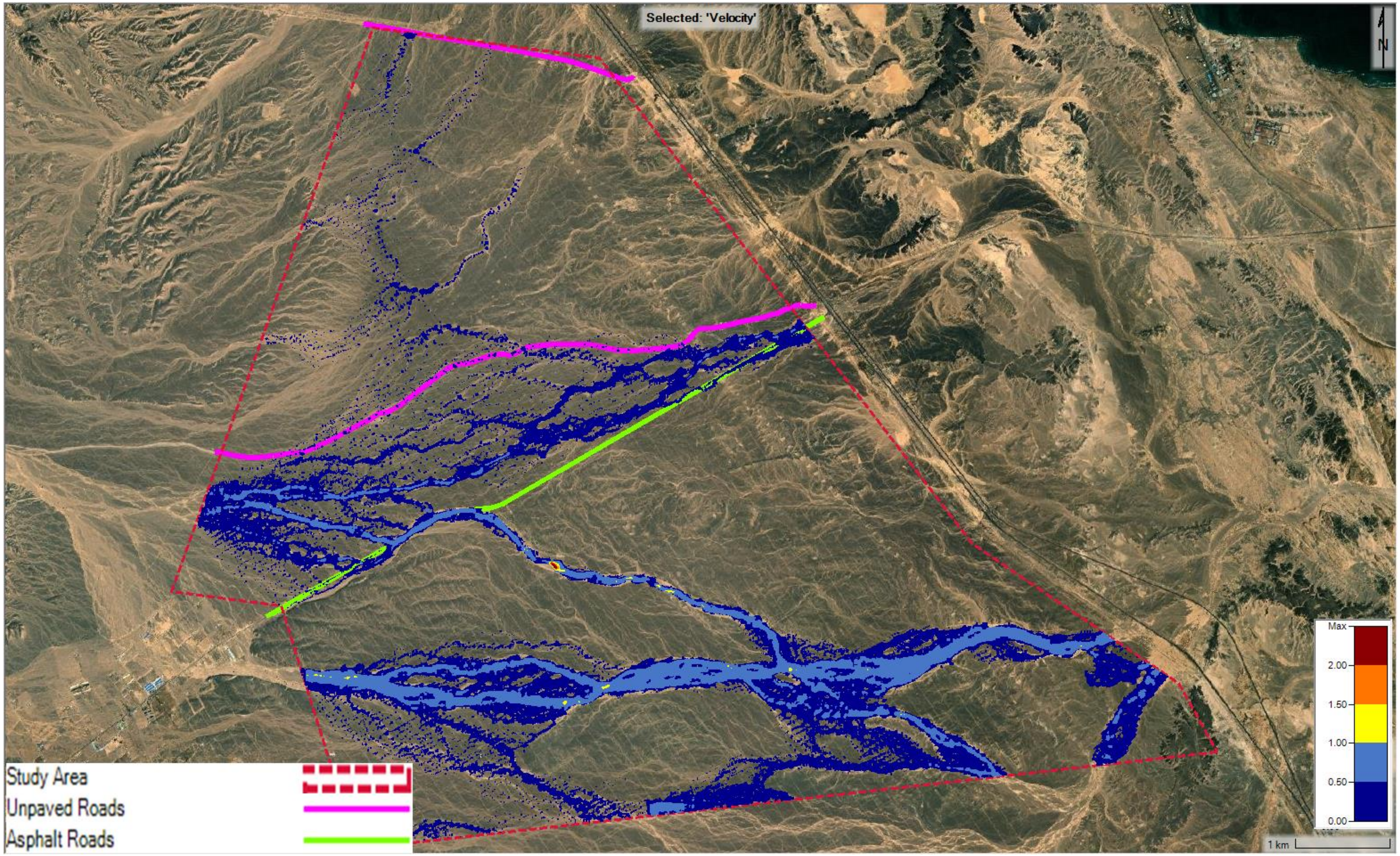

Figure 7.20: Velocity map for return period of 10 years

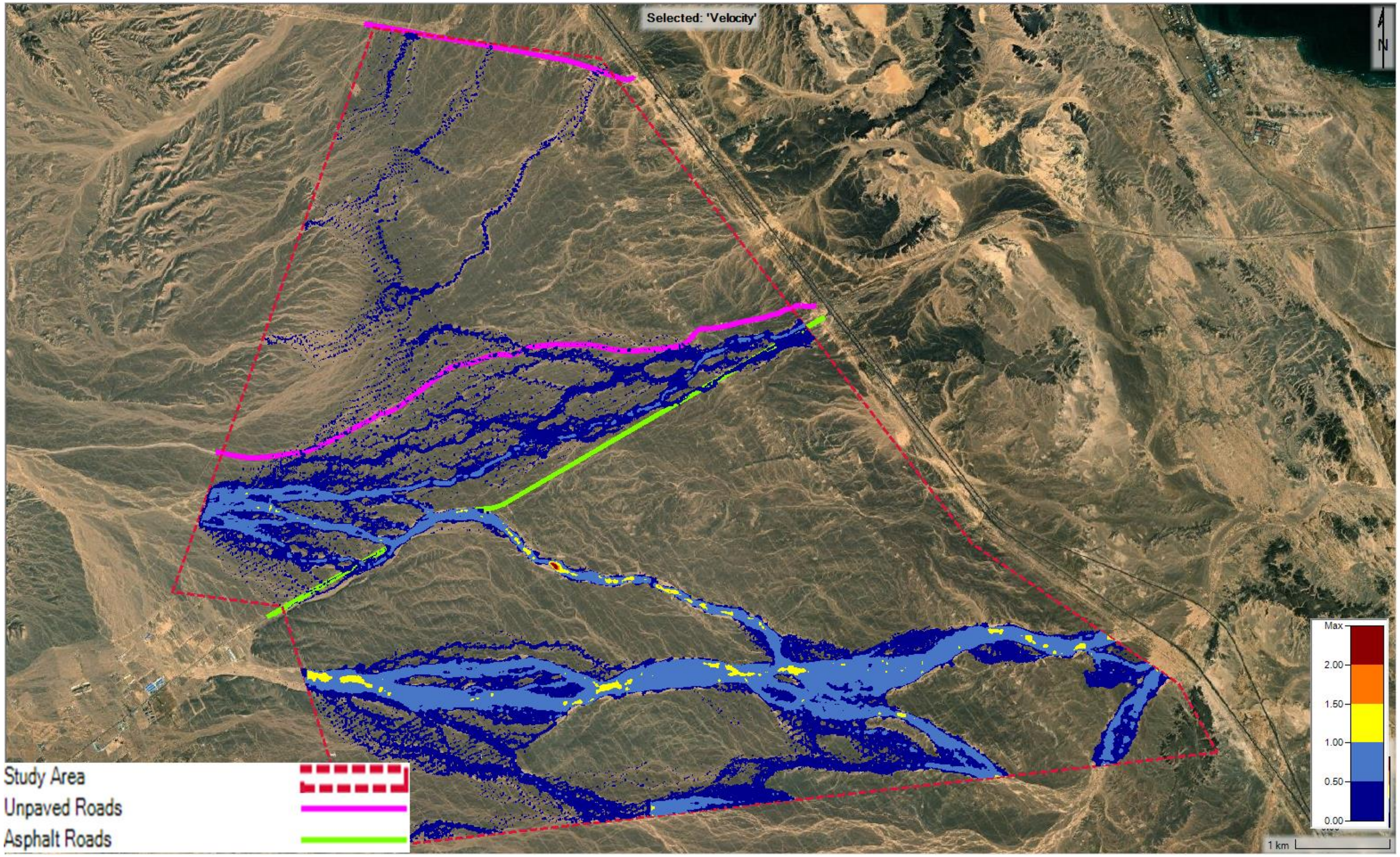

Figure 7.21: Velocity map for return period of 20 years

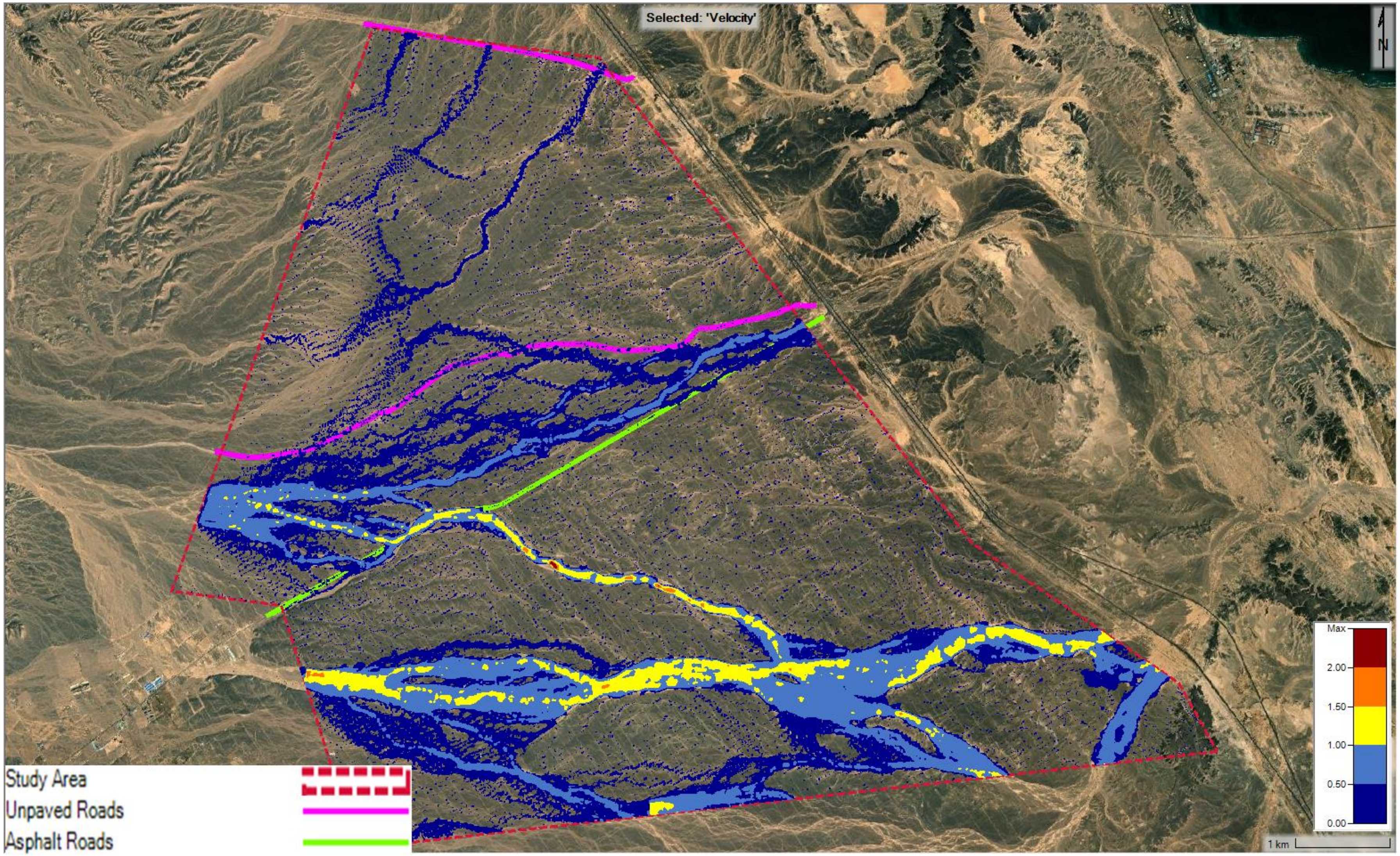

Figure 7.22: Velocity map for return period of 50 years

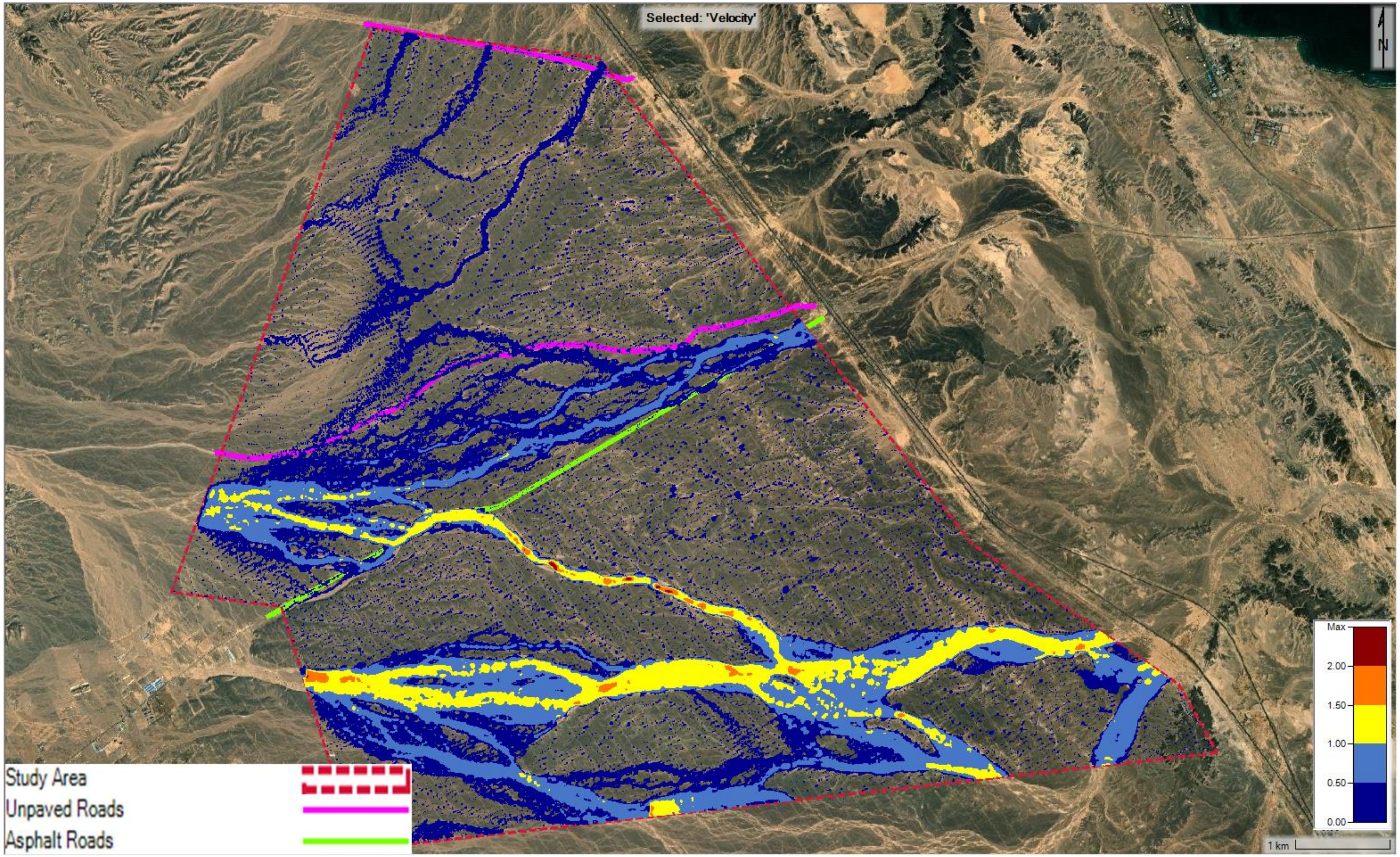

Figure 7.23: Velocity map for return period of 100 years

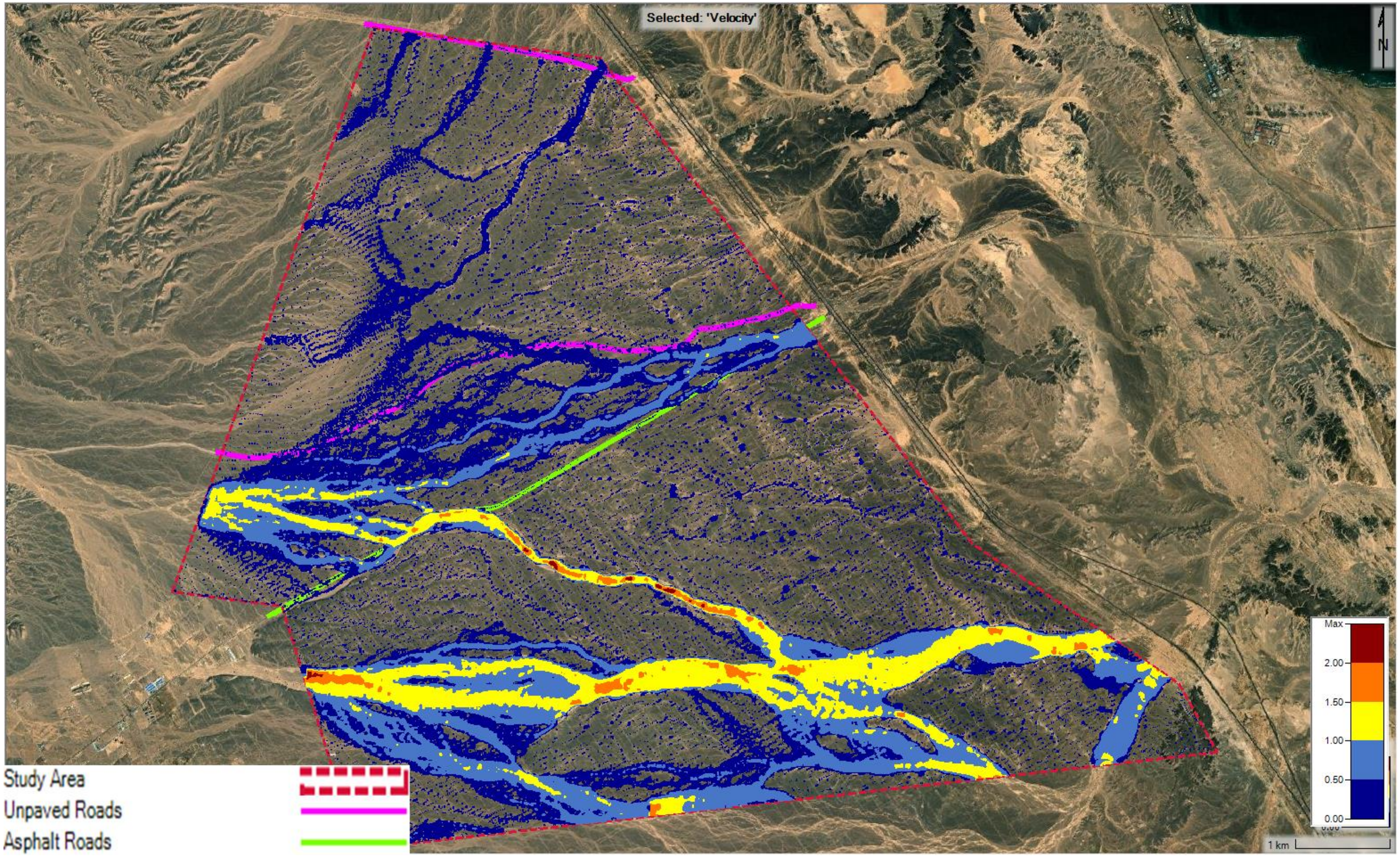

Figure 7.24: Velocity map for return period of 100 years taking climate change into consideration

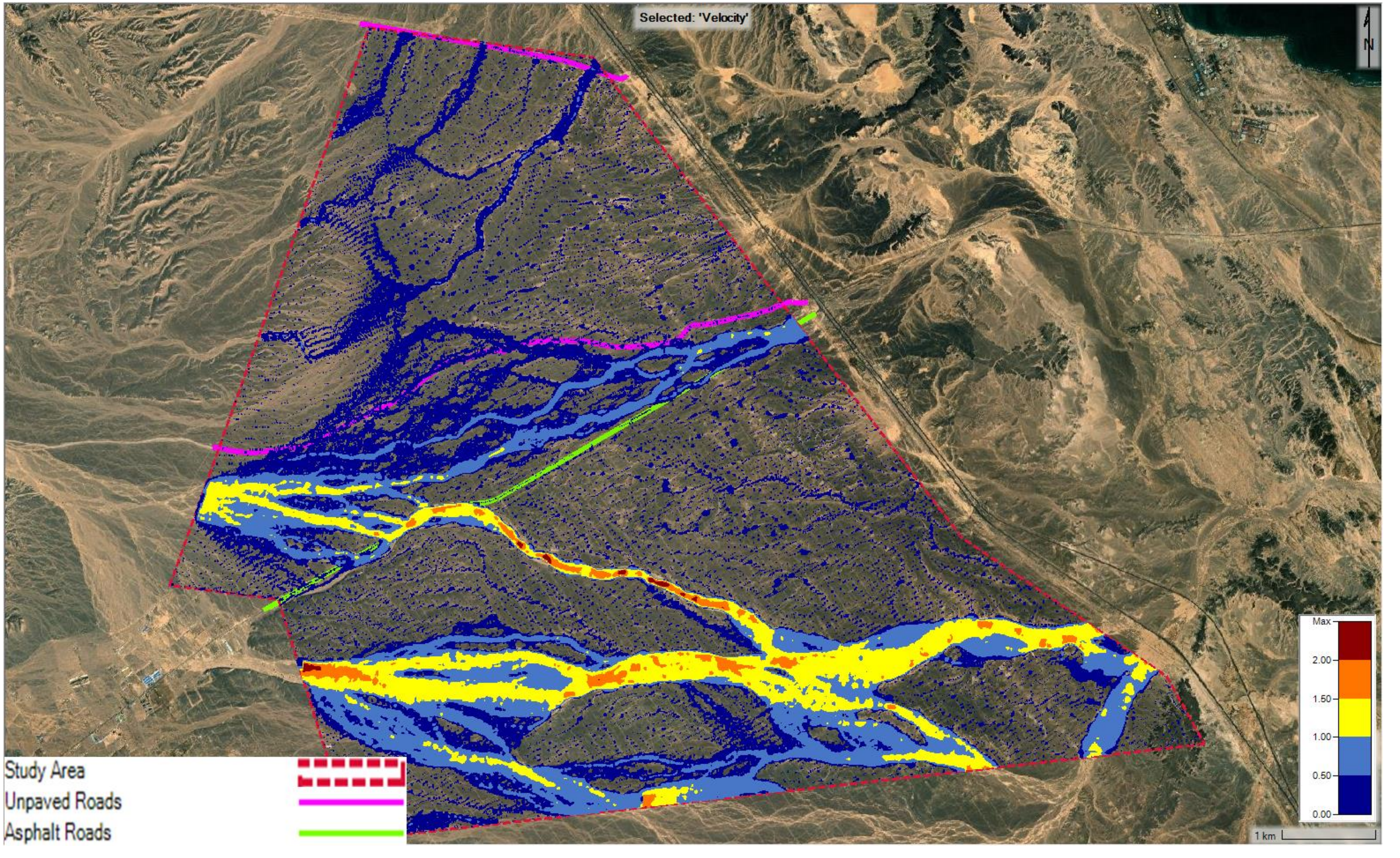

Figure 7.25: Velocity map for return period of 200 years

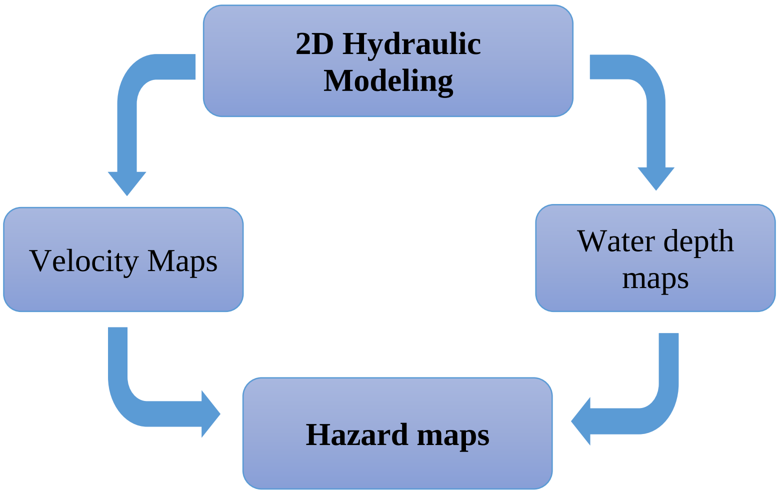

Figure 7.26: Methodology used to derive flood risk maps

- Equal intervals: They distribute the range of values equally for each class.
- Standard Deviation: It distributes the range of values based on the standard deviation of each field for all values.
- Natural Breaks: It is a way to find the best distribution based on the distribution of values for the number of points.

The Equal intervals method is used in this study. The values of velocity and depth are used to create single values expressing the intensity of the flood.

The hazard is calculated using DEFRA equation as follows:

$$HR = D * (V + 0.5) + DF \qquad (7\text{-}1)$$

in which

HR = Hazard rating

D = Water depth (m).

V = Velocity (m/s).

DF = Debris factor

The debris factor is calculated as shown in Table 7.1*:* . Then the classification of hazards is concluded as shown in Table 7.2, while Figures 7.27 to 7.34 show the hazard maps for return periods from 2 to 200 years.

Table 7.1: Determination of debris factor

Debris Factor	Depths (m)
0.5	0 to 0.25
1	0.25 to 0.75
1	Larger than 0.75 depth or larger than 2 m/s velocity

Table 7.2: Hazard classification

Hazard Classification	Value of Hazard Rating
Low Hazard	<0.75
Medium Hazard	0.75 - 1.25
High Hazard	1.25 - 2.0
Extreme Hazard	>2.0

The hazard maps (Figures 7.27 to 7.34) indicate that the flood hazard for each return period is as follows:

- The flood hazard for the 2-year return period is mostly low.
- The flood hazard for the 5-year return period is mostly low.
- The flood hazard for the 10-year return period is mostly low outside the wadis, while inside wadis it is mostly low with some points medium.
- The flood hazard for the 20-year return period is mostly low outside the wadis, while inside wadis it varies between medium and low.
- The flood hazard for return period 50 is mostly low outside the wadis, while inside wadis it is mostly medium with some points high.
- The flood hazard for the 100-year return period is mostly low outside the wadis, while inside wadis it varies between high and very high.
- The flood hazard map for the 100-year return period, taking climate change into consideration, is mostly low outside the wadis, while inside wadis it varies between high and very high.
- The flood hazard for the 200-year return period is mostly low outside the wadis, while inside wadis it varies between high and very high.

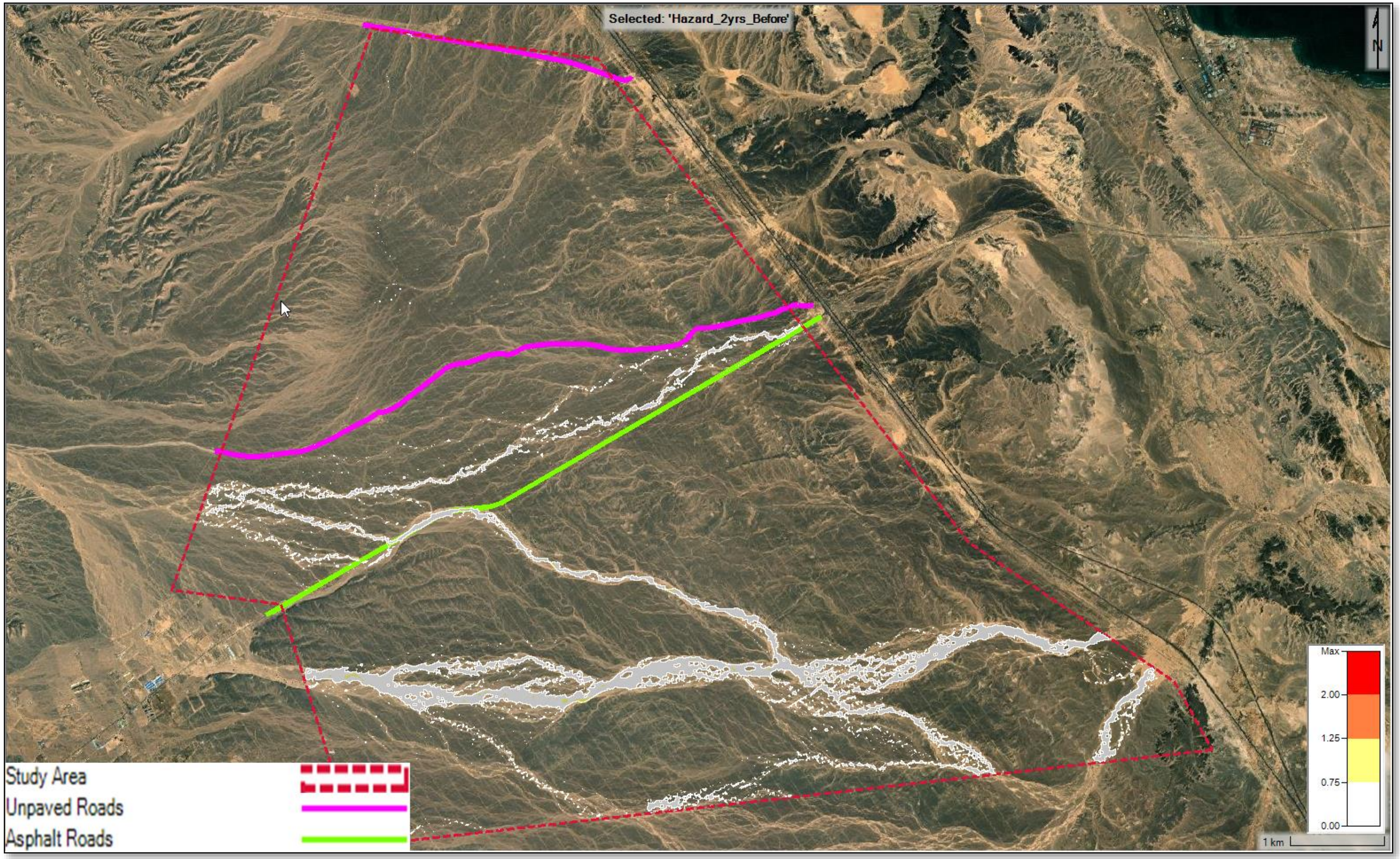

Figure 7.27: Hazard map for return period of 2 years

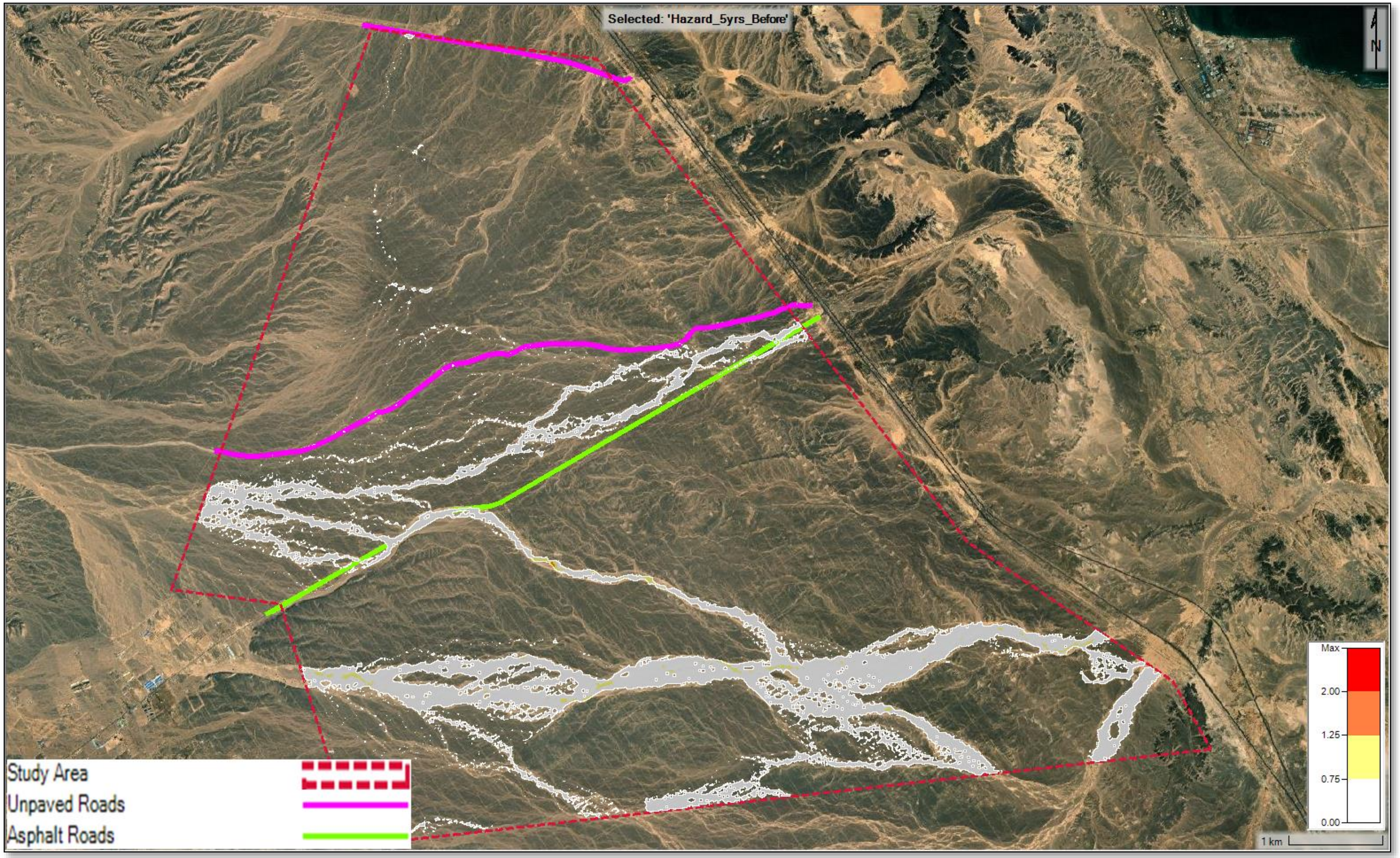

Figure 7.28: Hazard map for return period of 5 years

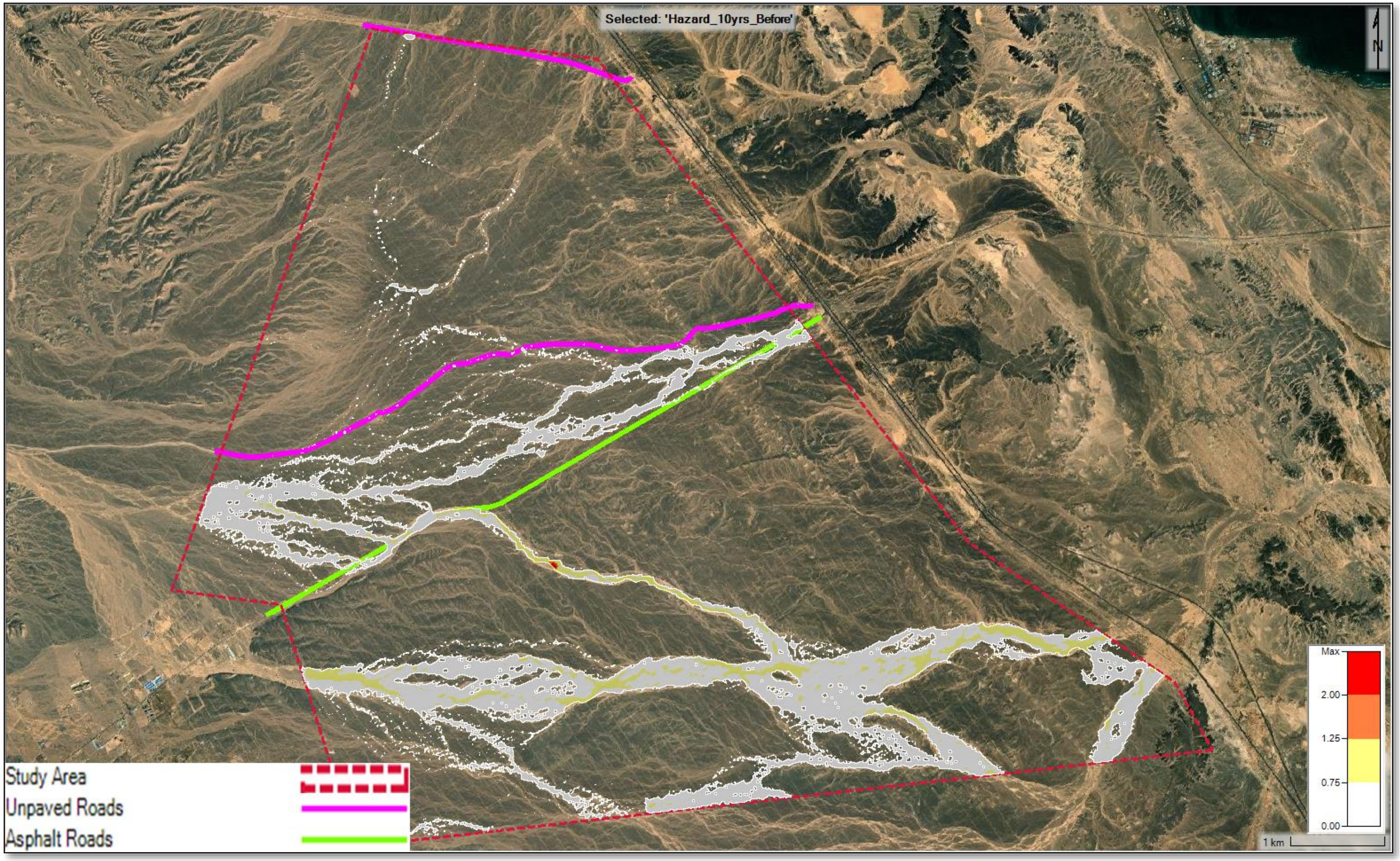

Figure 7.29: Hazard map for return period of 10 years

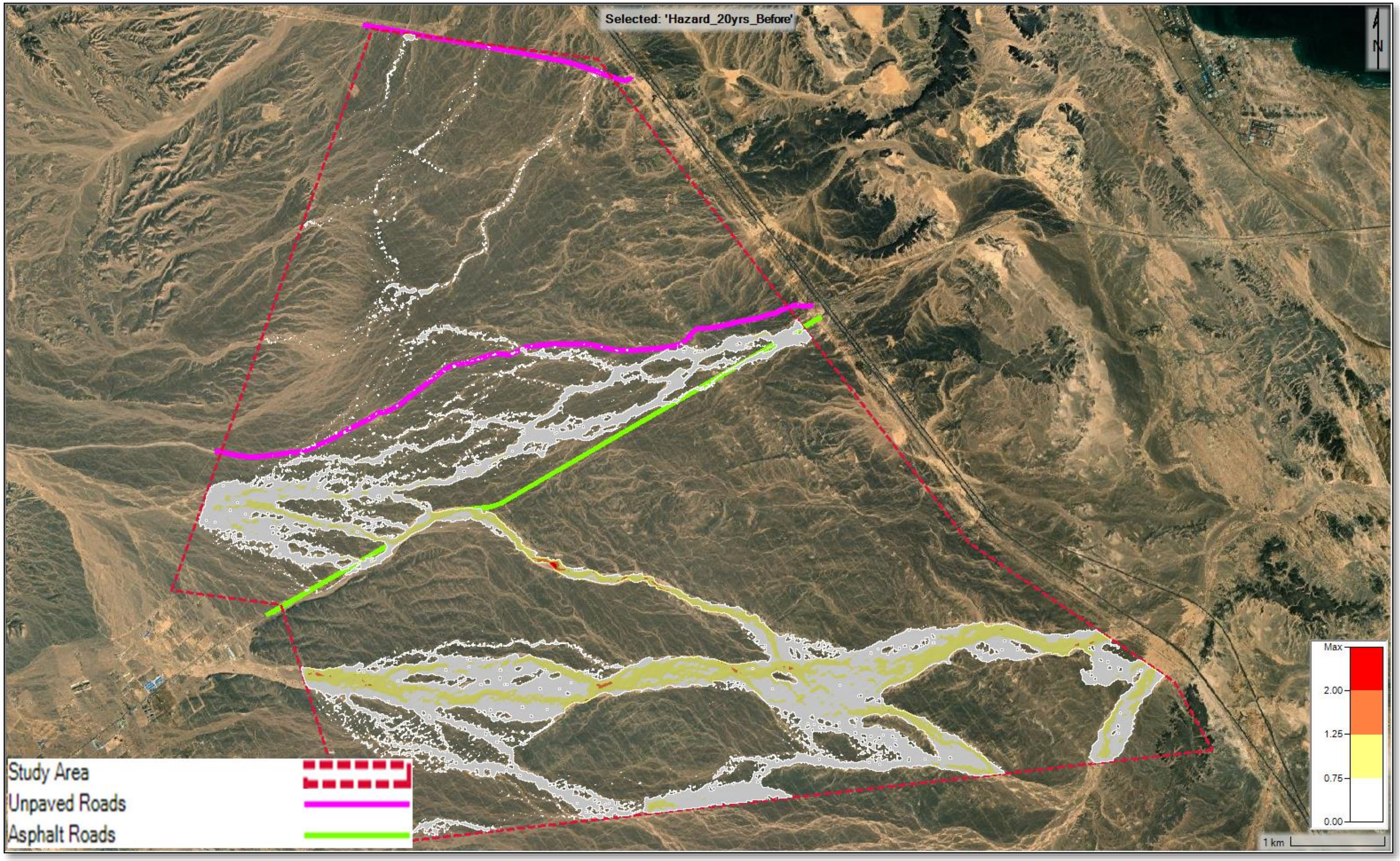

Figure 7.30: Hazard map for return period of 20 years

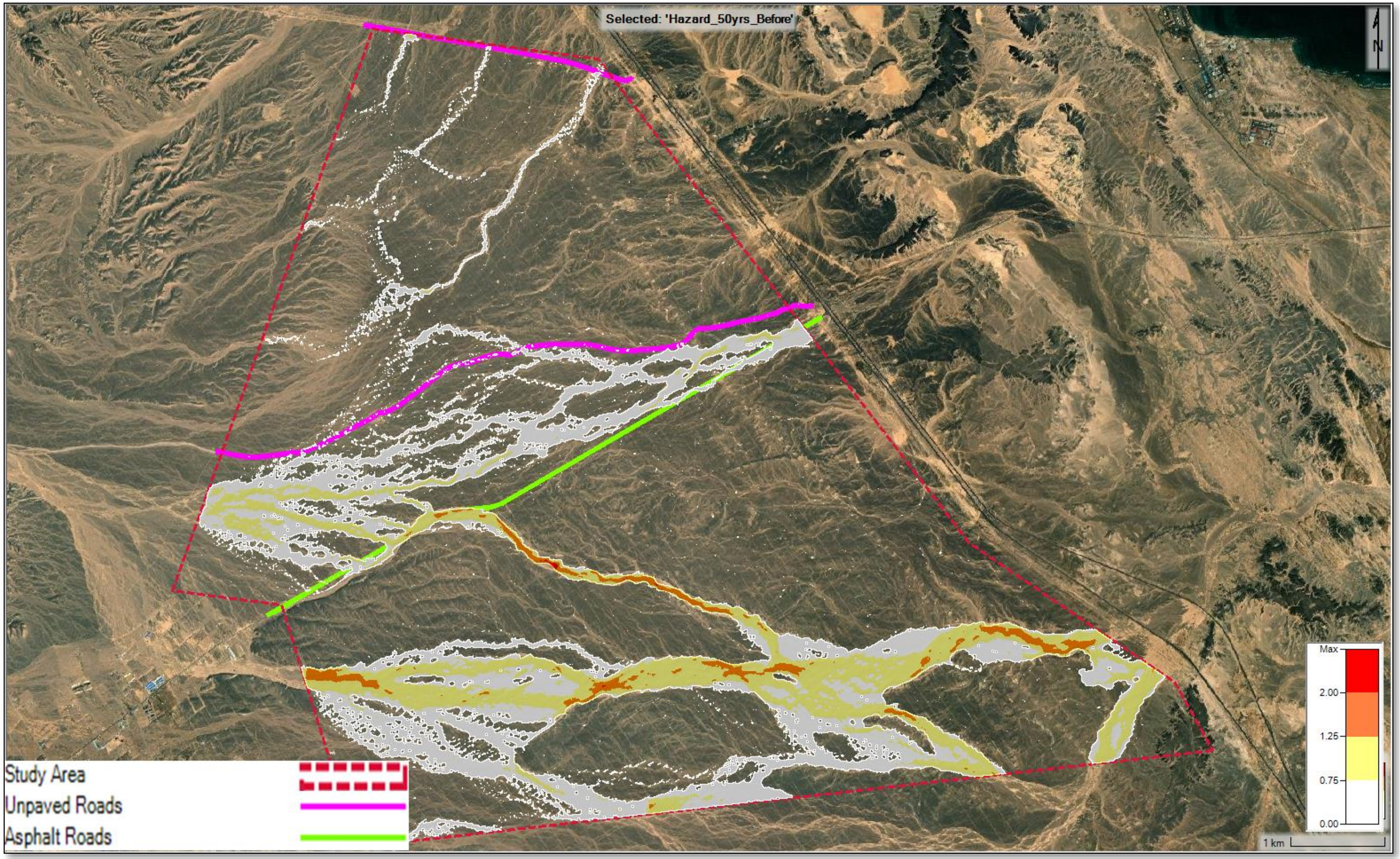

Figure 7.31: Hazard map for return period of 50 years

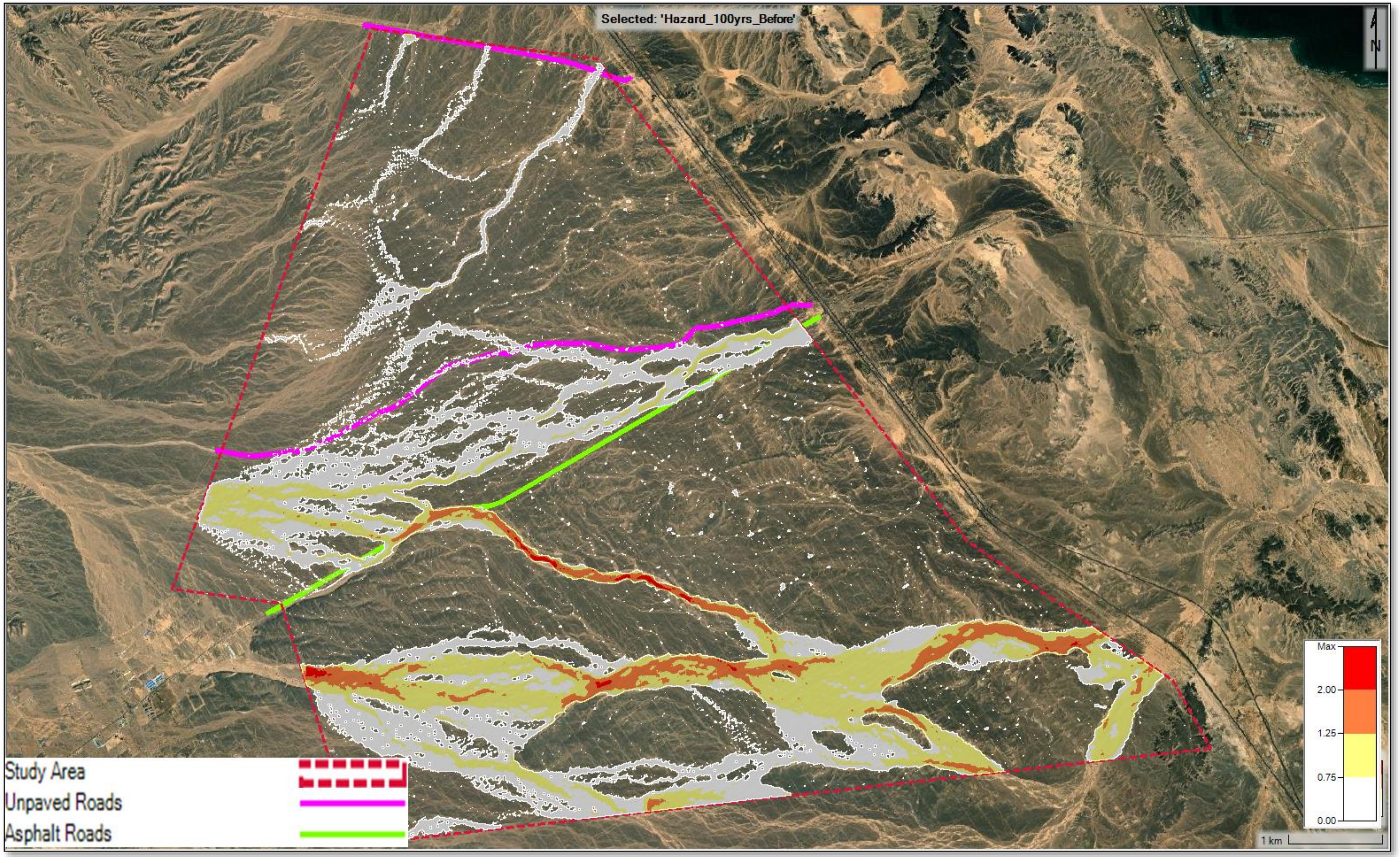

Figure 7.32: Hazard map for return period of 100 years

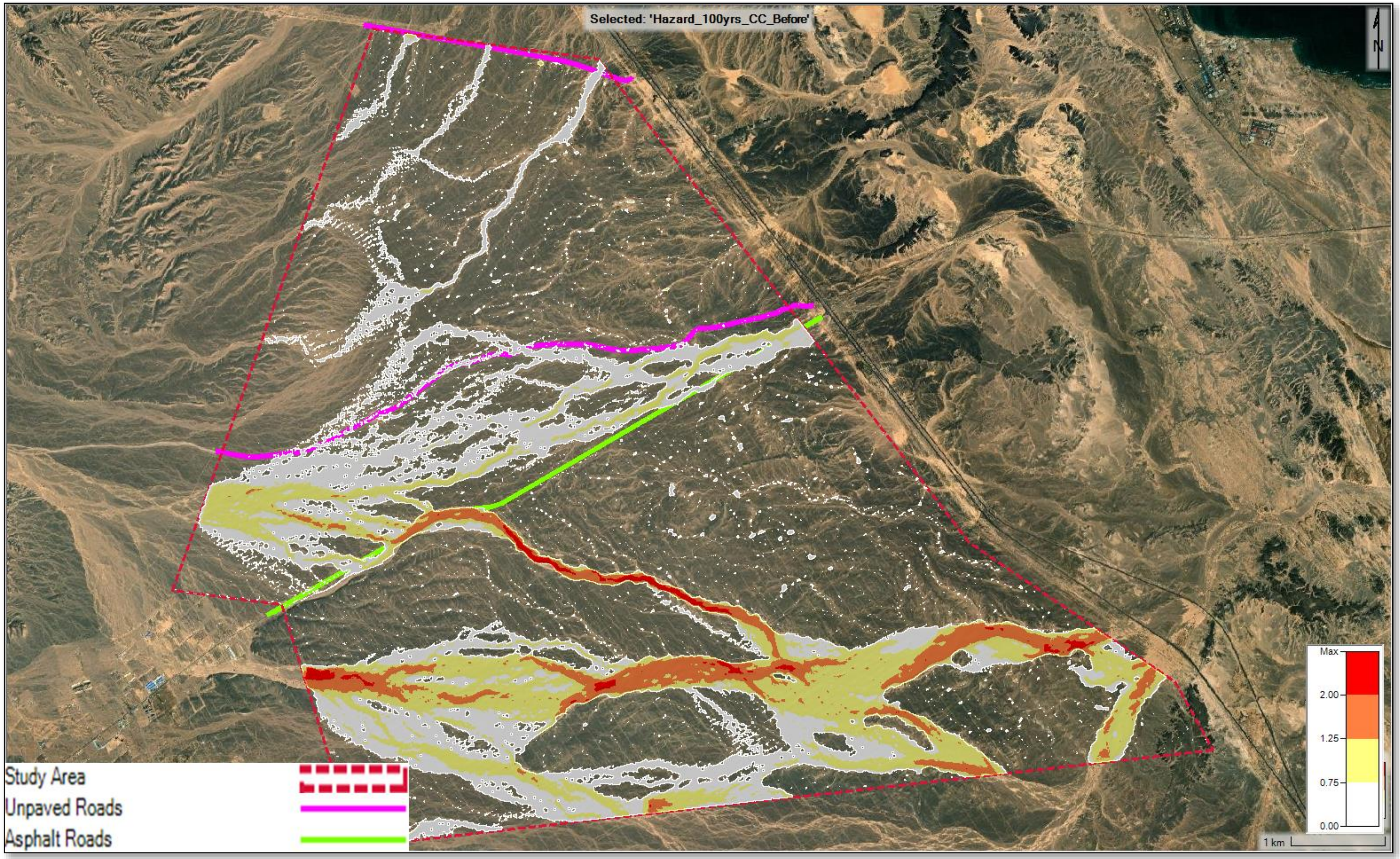

Figure 7.33: Hazard map for return period of 100 years taking climate change into consideration

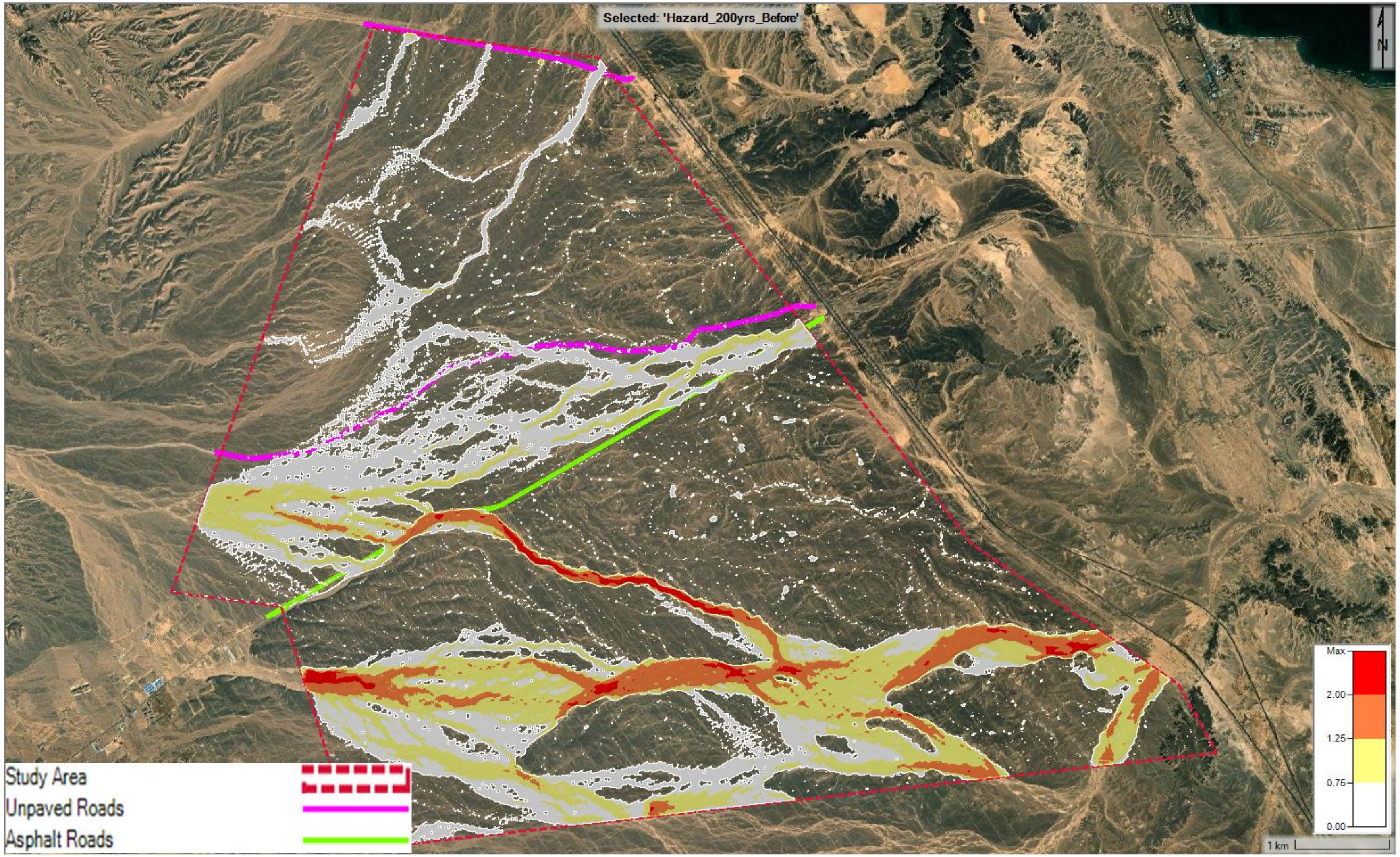

Figure 7.34: Hazard map for return period of 200 years

8. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

- The hydraulic model was carried out for return periods of 2 to 200 years and for a return period of 100 years taking climate change into consideration.
- Figure 8.1 shows the depth map after excluding water depths below 0.15 m to give a realistic and clear illustration of the wadi paths.
- Figure 8.2 shows the velocity map after excluding water velocities below 0.5 m/s
- Figure 8.3 shows the hazard map after excluding the areas of low hazards.
- Therefore, it is recommended to use Figures 8.1 to 8.3 when selecting the wind tower locations such that they are far away from the shown main streams' paths, where they will be safe from flash floods.
- Most flow paths have a minor water depth, which results from the wide widths of wadis and steep slopes.
- It is recommended to add surrounded grouted riprap protection around each wind tower foundation to prevent scour and to protect the wind towers from direct precipitation effects with a minimum grading slope around the tower to direct the flow of the surface water to the wadi direction without any water accumulation beside tower foundations. The detail of the proposed grouted riprap protection around the wind towers is shown in Figure 8.4.
- The locations of internal asphalt roads have been included in the hydraulic 2D model to simulate the effect of the wadis on them.
- Two Irish crossings are proposed at the intersection between internal asphalt roads and main streams to protect the internal roads from flash floods.

Table 8.1 shows the data of the proposed Irish crossings. In addition, Figure 8.5 shows the locations of the Irish crossings on a satellite image while Figure 8.5 shows the details of the Irish crossings.

Table 8.1: Proposed Irish crossings data

No.	Easting (m)	Northing (m)	Length (m)
Irish Crossing 1	471676	3163052	71
Irish Crossing 2	471513	3160124	79

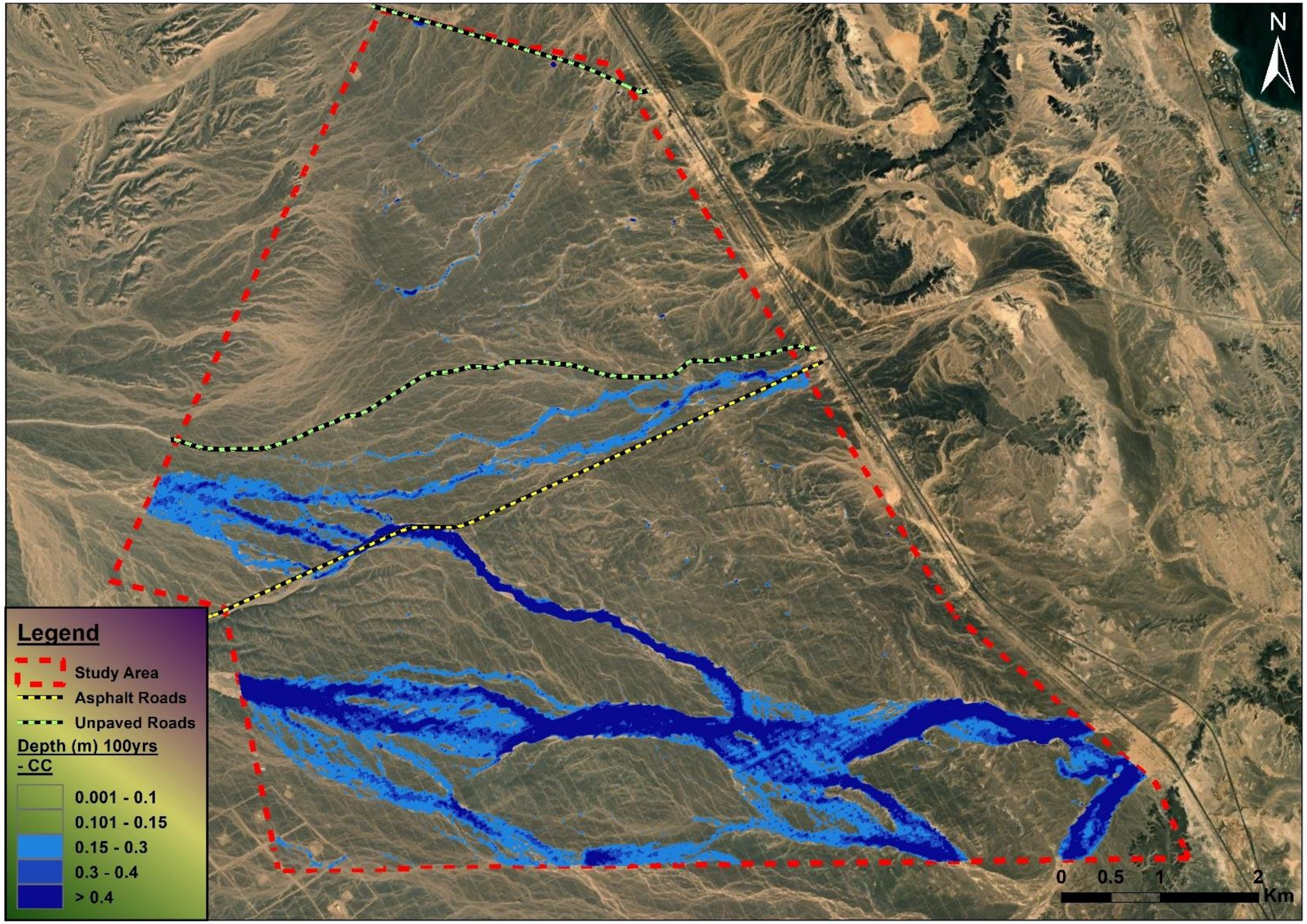

Figure 8.1: Depth map for return period of 100 years taking climate change into consideration and excluding flood depths below 0.15m

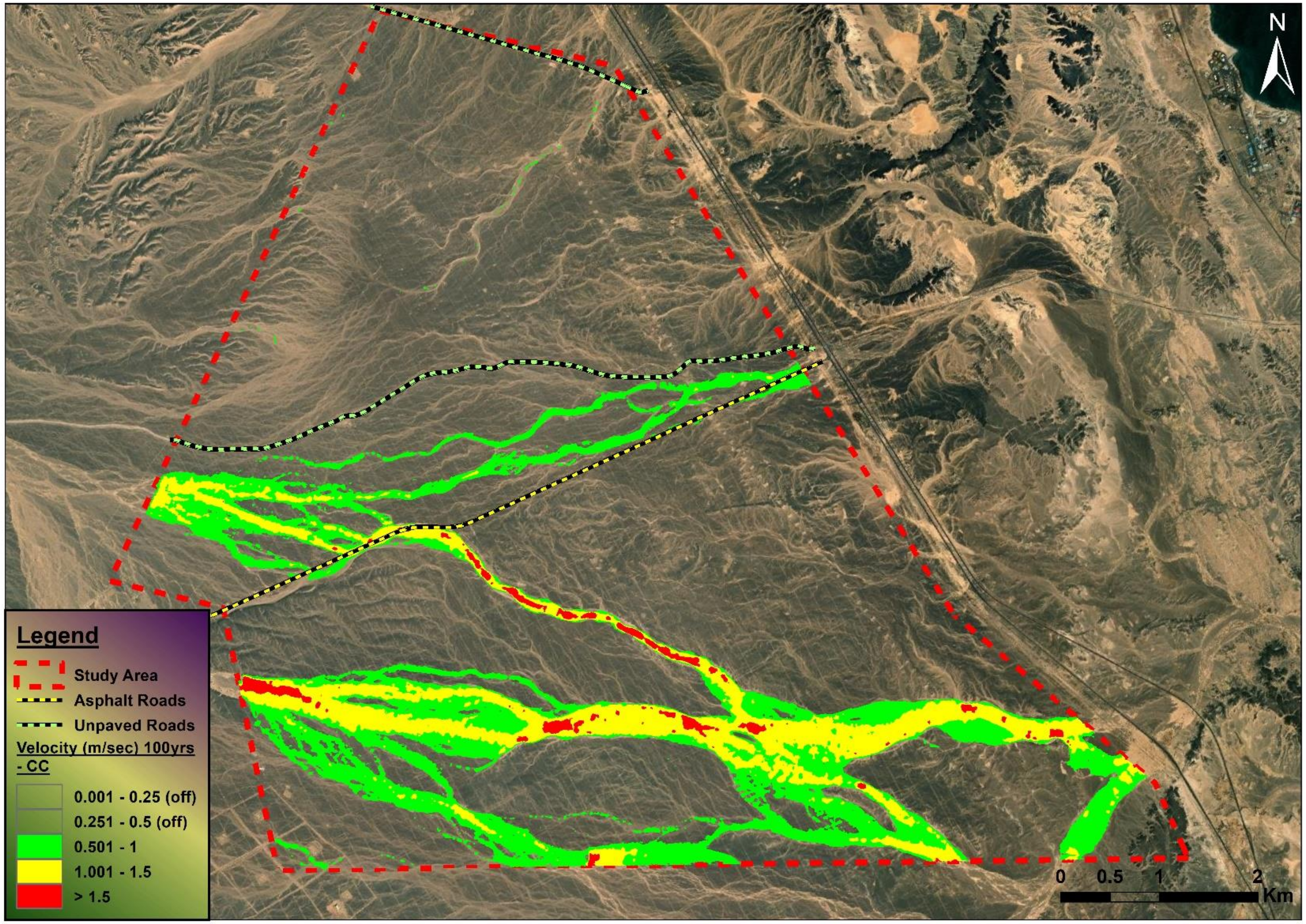

Figure 8.2: Velocity map for return period of 100 years taking climate change into consideration and excluding velocities below 0.5 m/s

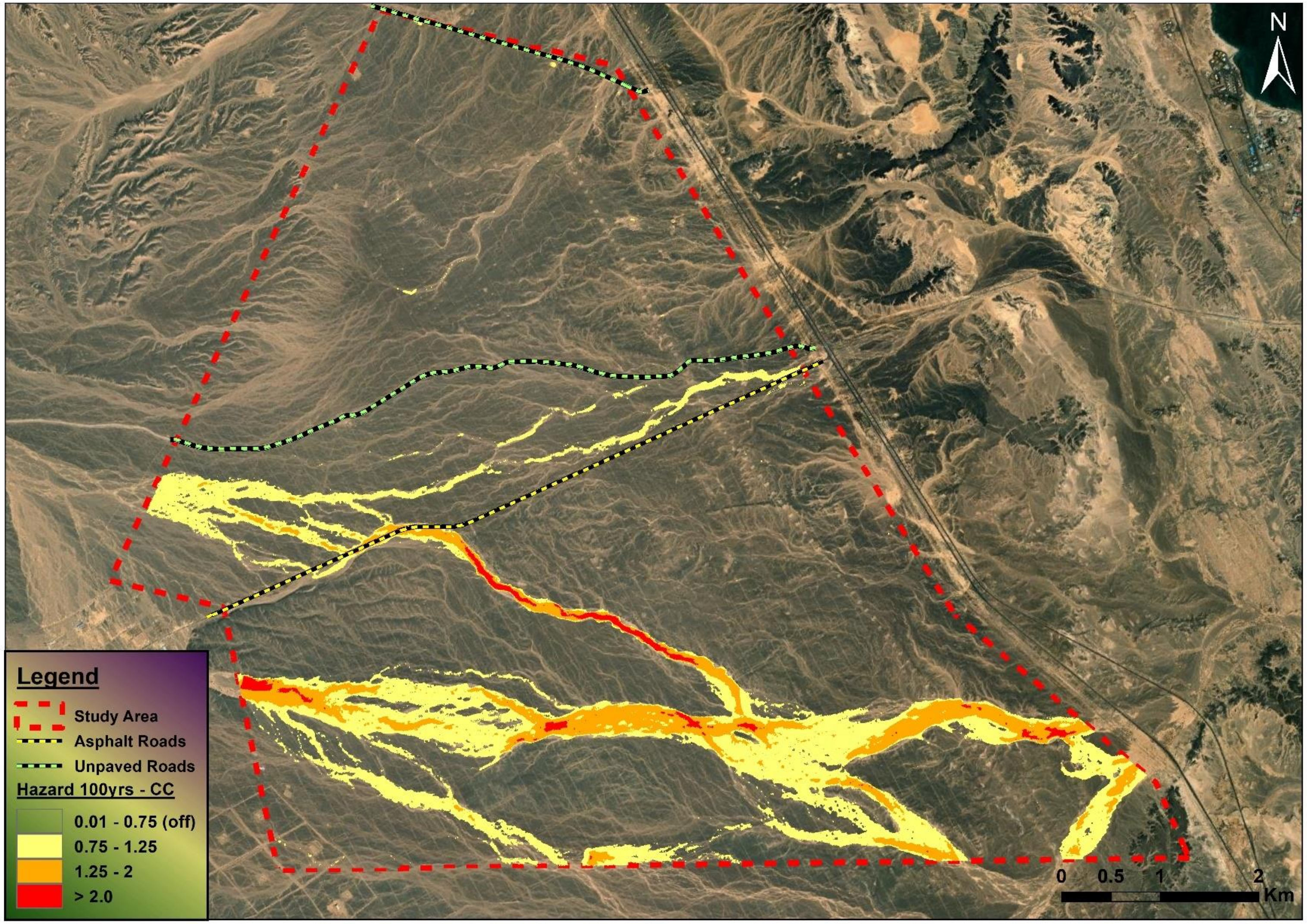

Figure 8.3: Hazard map for return period of 100 years taking climate change into consideration and excluding low hazard areas

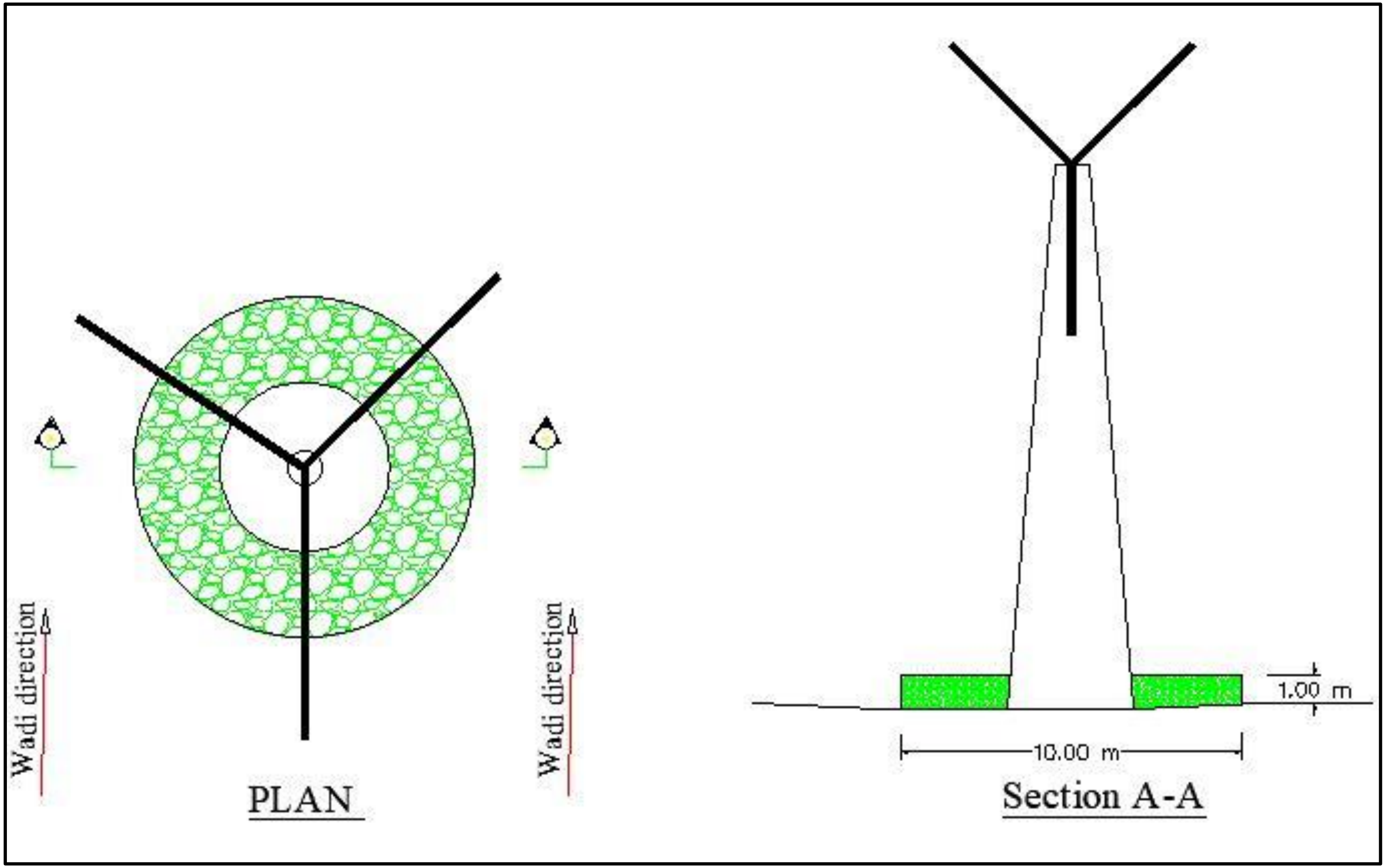

Figure 8.4 : Proposed grouted riprap protection around wind towers

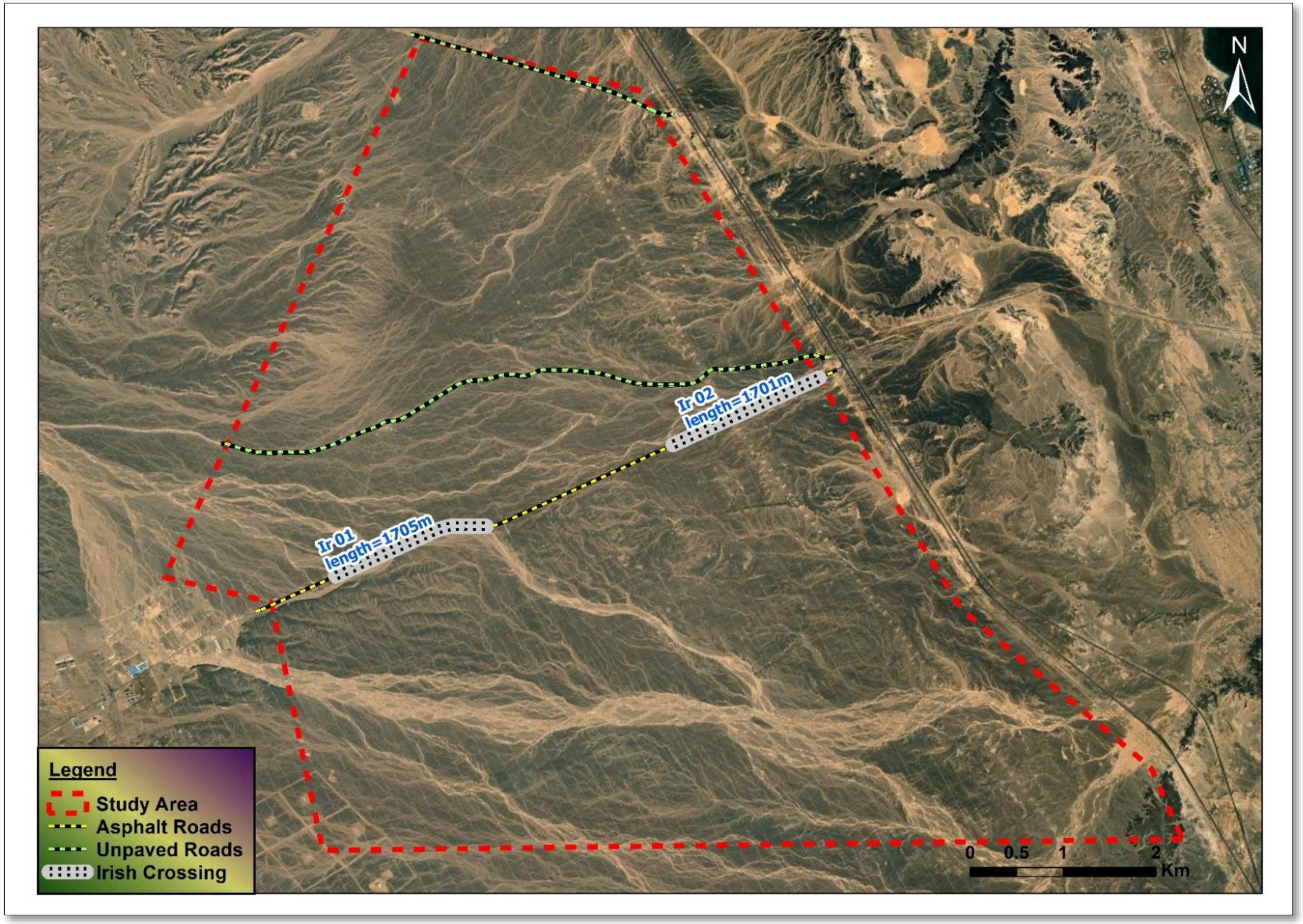

Figure 8.5: Proposed Irish crossings location on satellite image

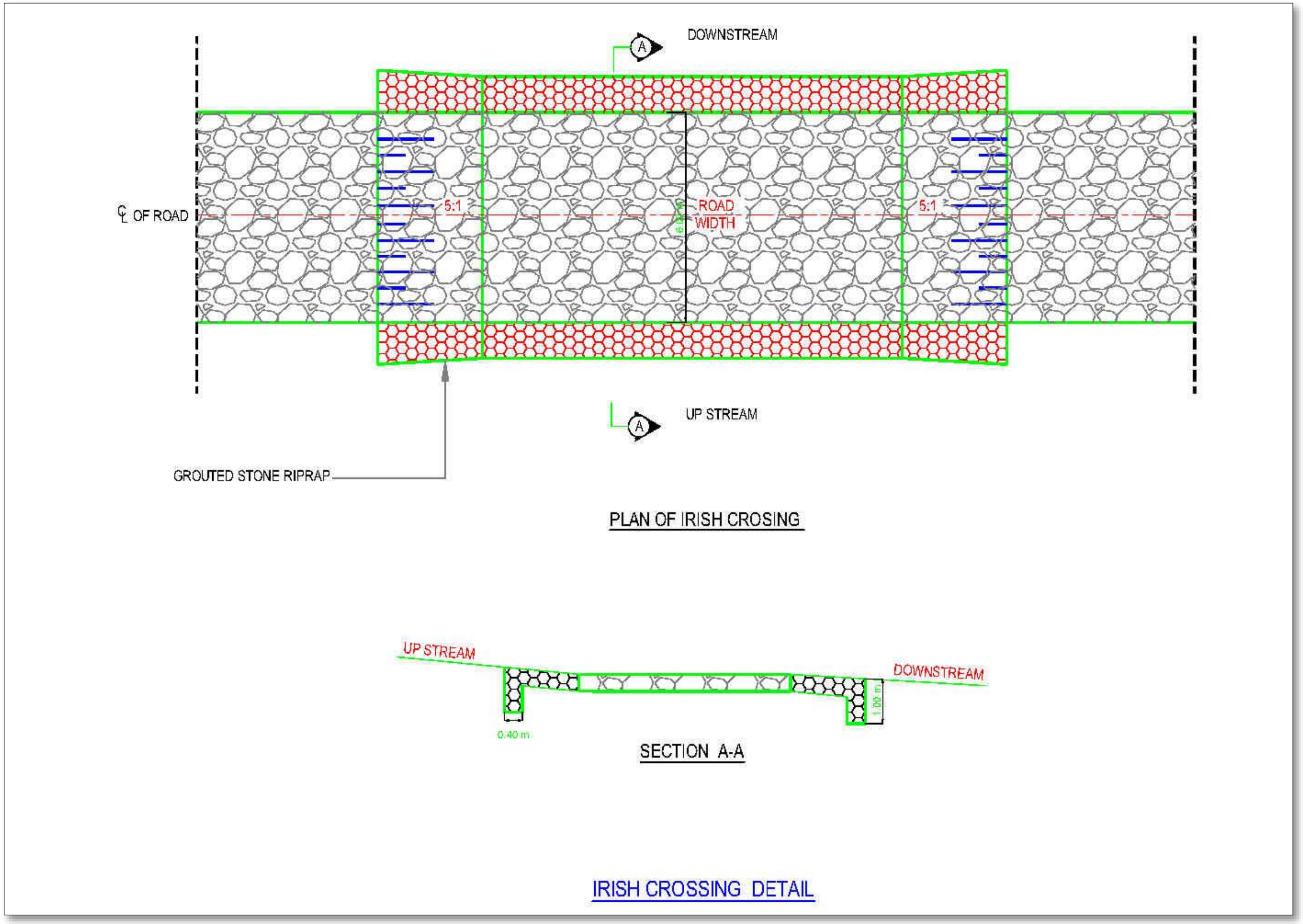

Figure 8.6: Proposed Irish crossing details

Appendix A

Appendix A includes the results of two-dimensional hydraulic modeling for different storm return periods (2, 5, 10, 20, 50, 100, 100+ climatic changes, and 200 years).

Reference

Woodward, D. E., Hawkins, R. H., Jiang, R., Hjelmfelt, Jr, A. T., Van Mullem, J. A., and Quan, Q. D. (2003). *Runoff curve number method: Examination of the initial abstraction ratio*. World Water & Environmental Resources Congress, 2003 (pp. 1-10).