
RAS GHAREB PLOT (NORTH 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



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TABLE OF CONTENTS

1. INTRODUCTION.....	6
1.1. General.....	6
1.2. Hydrological Study Objectives	7
1.3. Elements of Hydrological Study.....	7
2. SITE VISIT	8
3. STUDY METHODOLOGY.....	16
3.1. Morphological Study Methodology	18
3.2. Geological Study Methodology	18
3.3. Meteorological Study Methodology.....	19
3.4. Methodology of Estimating Surface Flow.....	20
3.5. Impact of Climate Change	23
4. GEOLOGICAL STUDY	24
4.1. Introduction	24
4.2. Sedimentary Rocks.....	26
4.3. Basement Rocks (go).....	26
4.4. Geologic Structures	27
5. MORPHOLOGICAL STUDY	27
5.1. Introduction	27
5.2. Morphological Characteristics of Wadis Affecting Ras Ghareb Plot.....	27
5.3. Design Return Period	31
6. METEOROLOGICAL STUDY AND FLOW ESTIMATION.....	31
6.1. Introduction	31
6.2. Estimation of Design Storms.....	32
6.3. Rainfall Analysis.....	35
6.4. Peak Flows and Runoff Hydrographs.....	38
7. HYDRAULIC MODELING	38
7.1. Existing Structures (Dams).....	38
7.2. Hydraulic Model Development.....	44
7.3. Existing Condition Scenarios	51
7.4. 2D Hydraulic Models Outputs	51
7.5. Flood Risk Assessment.....	68
8. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	78
LIMITATION	
APPENDIX A	
REFERENCE	

List of Tables

Table 3.1: Most important morphological characteristics of Wadi Basins	18
Table 3.2: CN0.05 corresponding to CN0.20	22
Table 5.1: Most important morphological characteristics of Wadis affecting Ras Ghareb Plot	29
Table 6.1: Coordinates of five meteorological stations & their heights above sea level.....	33
Table 6.2: Main characteristics of data of five meteorological stations	35
Table 6.3: Rainstorms for different frequency periods from 1 to 2000 years.....	37
Table 6.4: Morphological characteristics for catchment areas and model results.....	41
Table 7.1: Dam 01 data.....	44
Table 7.2: Determination of debris factor	69
Table 7.3: Hazard classification	69
Table 8.1: Proposed Irish crossings data	82
Table 8.2: Proposed culvert data	82

List of Figures

Figure 1.1: Proposed locations of 1.1 GW Wind Project	6
Figure 3.1: Work methodology	16
Figure 3.2: Hydrology and hydraulic study methodology and work plan	17
Figure 3.3: Soil conservation service Type II storm duration curve	24
Figure 4.1: Hydrologic basins originating from highly mountainous areas in the West	25
Figure 4.2: Geology of area under consideration	25
Figure 5.1: WMS Wadis affecting Ras Ghareb Plot	28
Figure 5.2: Main streams and catchments affecting Ras Ghareb Plot (Satellite Image)	28
Figure 6.1: Locations of meteorological stations	32
Figure 6.2: Maximum rainfall depth (mm/day) for Hurghada meteorological station	33
Figure 6.3: Maximum rainfall depth (mm/day) for Suez meteorological station.....	33
Figure 6.4: Maximum rainfall depth (mm/day) for Ras Sedr meteorological station.....	34
Figure 6.5: Maximum rainfall depth (mm/day) for Abu Rudeis meteorological station	34
Figure 6.6: Maximum rainfall depth (mm/day) for Al-Tur meteorological station	34
Figure 6.7: Thiessen Polygon for the meteorological stations.....	35
Figure 6.8: Rainfall measured at Abu Rudeis station compared to calculated lognormal probability distribution (95% confidence)	36
Figure 6.9: Intensity-Duration-frequency curves for Abu Rudeis meteorological station	37
Figure 6.10: Flow calculations from HEC - HMS software.....	40
Figure 7.1: Dam 01 location on satellite image.....	44
Figure 7.2: Dam 01 flow hydrograph for return period of 100 years.....	45
Figure 7.3: Dam 01 flow hydrograph for return period of 100 years + CC	45

Figure 7.4: Site boundary and hydraulic model boundary conditions BC	46
Figure 7.5: Boundary conditions (BC) for return period of 2 years (Hydrographs)	47
Figure 7.6: Boundary conditions (BC) for return period of 5 years (Hydrographs)	47
Figure 7.7: Boundary conditions (BC) for return period of 10 years (Hydrographs)	48
Figure 7.8: Boundary conditions (BC) for return period of 20 years (Hydrographs)	48
Figure 7.9: Boundary conditions (BC) for return period of 50 years (Hydrographs)	49
Figure 7.10: Boundary conditions (BC) for return period of 100 years (Hydrographs)	49
Figure 7.11: Boundary conditions (BC) for return period of 100 years Climate Change	50
Figure 7.12: Boundary conditions (BC) for return period of 200 years (Hydrographs)	50
Figure 7.13: Simulation / Run time for each scenario.....	51
Figure 7.14: Depth map for return period of 2 years	52
Figure 7.15: Depth map for return period of 5 years	53
Figure 7.16: Depth map for return period of 10 years	54
Figure 7.17: Depth map for return period of 20 years	55
Figure 7.18: Depth map for return period of 50 years	56
Figure 7.19: Depth map for return period of 100 years	57
Figure 7.20: Depth map for return period of 100 years taking climate change into consideration	58
Figure 7.21: Depth map for return period of 200 years	59
Figure 7.22: Velocity map for return period of 2 years	60
Figure 7.23: Velocity map for return period of 5 years	61
Figure 7.24: Velocity map for return period of 10 years	62
Figure 7.25: Velocity map for return period of 20 years	63
Figure 7.26: Velocity map for return period of 50 years	64
Figure 7.27: Velocity map for return period of 100 years	65
Figure 7.28: Velocity map for return period of 100 years taking climate change into consideration	66
Figure 7.29: Velocity map for return period of 200 years	67
Figure 7.30: Methodology used to derive flood risk maps	68
Figure 7.31: Hazard map for return period of 2 years	70
Figure 7.32: Hazard map for return period of 5 years	71
Figure 7.33: Hazard map for return period of 10 years	72
Figure 7.34: Hazard map for return period of 20 years	73
Figure 7.35: Hazard map for return period of 50 years	74
Figure 7.36: Hazard map for return period of 100 years	75
Figure 7.37: Hazard map for return period of 100 years taking climate change into consideration	76
Figure 7.38: Hazard map for return period of 200 years	77
Figure 8.1: Depth map for return period of 100 years taking climate change into consideration and excluding flood depths below 0.15m	79
Figure 8.2: Velocity map for return period of 100 years taking climate change into	

consideration and excluding velocities below 0.5 m/s.....	80
Figure 8.3: Hazard map for return period of 100 years taking climate change into consideration and excluding low hazard areas	81
Figure 8.4 : Proposed grouted riprap protection around wind towers.....	82
Figure 8.5: Locations of proposed protection measures on satellite image	83
Figure 8.6: Culvert analysis report.....	84
Figure 8.7: Proposed Irish crossings locations on Depth Map for return period 100 years + CC.....	86
Figure 8.8: Proposed Irish crossings locations on Velocity Map for return period 100 years + CC.....	87
Figure 8.9: Proposed Irish crossings locations on Hazard Map for return period 100 years + CC.....	88
Figure 8.10: Proposed Irish crossing Details.....	89
Figure 8.11: Proposed Protection Measures locations for the asphalt road at the intersection with Wadi Hawashi on satellite image.....	90
Figure 8.12: Proposed Culvert and Channel on Depth Map for return period 100 years + CC.....	91
Figure 8.13: Proposed Culvert and Channel on Velocity Map for return period 100 years + CC.....	92
Figure 8.14: Proposed Culvert and Channel on Hazard Map for return period 100 years + CC.....	93

List of Photos

Photo 2.1: Top of Dam No. 1 with its sides at Wadi Hawashi	9
Photo 2.2: Middle spillway of Dam No. 1 at Wadi Hawashi.....	9
Photo 2.3: Lake located in front of Dam No. 2 at Wadi Hawashi inside North Plot site.....	10
Photo 2.4: One of the Wadis after attacking the road inside the site, and the cut that occurred in the road as a result of attacking the valley.....	10
Photo 2.5: Landfill at the side of the road in an attempt to protect it from torrential rains.....	11
Photo 2.6: One of Wadis after attacking road inside the site, and the cut that occurred in road as a result of attacking the valley.....	11
Photo 2.7: Road with high rubble beside it, and cutting in road as a result of torrential rains	12
Photo 2.8: Road with high rubble beside it, and cutting in road as a result of torrential rains	12
Photo 2.9: One of the places where plants appear, which indicates the path of valleys within the site	13
Photo 2.10: Another place where plants appear, which indicates the path of valleys within the site	14
Photo 2.11: A culvert having a diameter of 0.5 m is shown below the road	15

1. INTRODUCTION

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 Ghareb Plot, which the North 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.

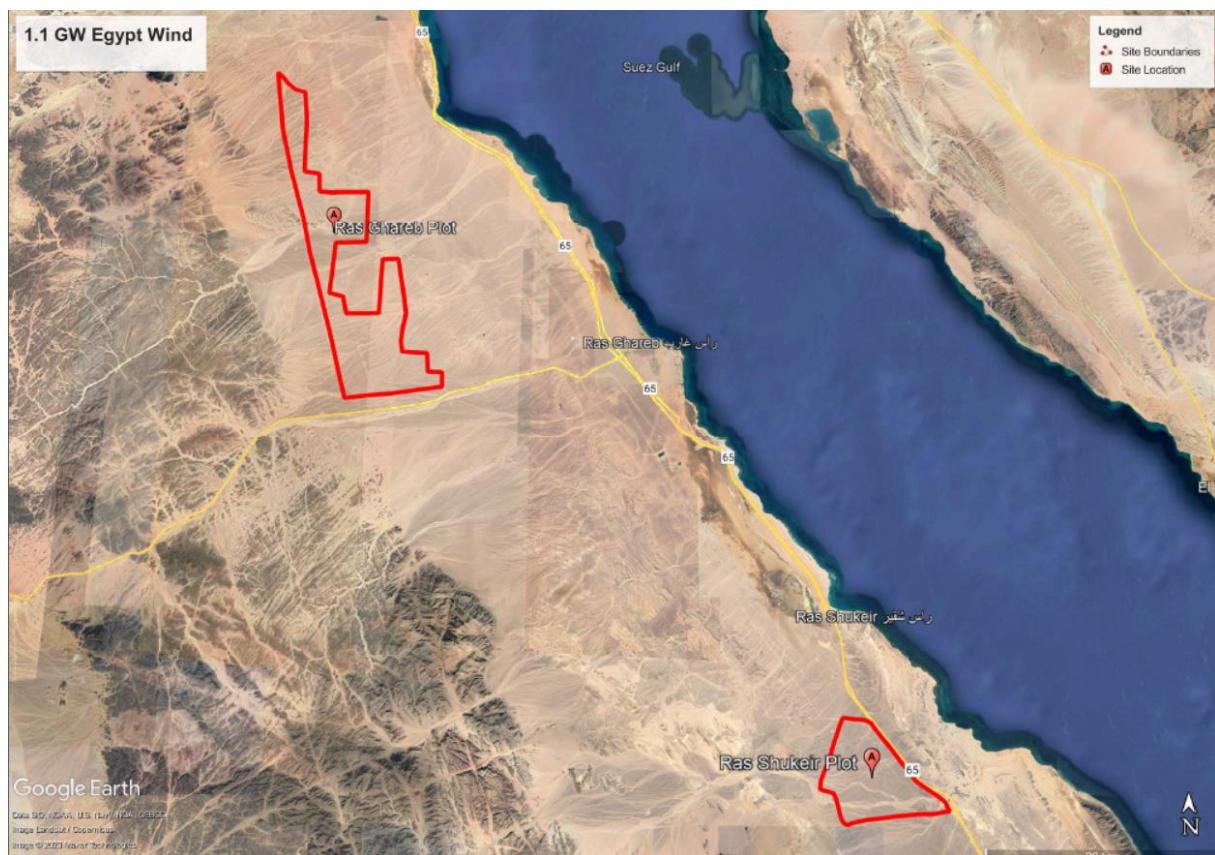


Figure 1.1: Proposed locations of 1.1 GW Wind Project

Flash floods are natural phenomena occurring because of heavy rainfall over catchment areas (Wadi 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 Ghareb Plot (North 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 (North 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 Ghareb 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 Ghareb 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 2.11 show the topographic nature, existing structures, and wadis within the site boundaries of Ras Ghareb Plot (North Plot) - 1.1 GW Egypt Wind project.



Photo 2.1: Top of Dam No. 1 with its sides at Wadi Hawashi



Photo 2.2: Middle spillway of Dam No. 1 at Wadi Hawashi



Photo 2.3: Lake located in front of Dam No. 2 at Wadi Hawashi inside North Plot site



Photo 2.4: One of the Wadis after attacking the road inside the site, and the cut that occurred in the road as a result of attacking the valley



Photo 2.5: Landfill at the side of the road in an attempt to protect it from torrential rains



Photo 2.6: One of the Wadis after attacking the road inside the site, and the cut that occurred in road as a result of attacking the valley



Photo 2.7: Road with high rubble beside it, and cutting in road as a result of torrential rains



Photo 2.8: Road with high rubble beside it, and cutting in road as a result of torrential rains



Photo 2.9: One of the places where plants appear, which indicates the path of valleys within the site



Photo 2.10: Another place where plants appear, which indicates the path of valleys within the site



Photo 2.11: A culvert having a diameter of 0.5 m is shown below the road

3. STUDY METHODOLOGY

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.

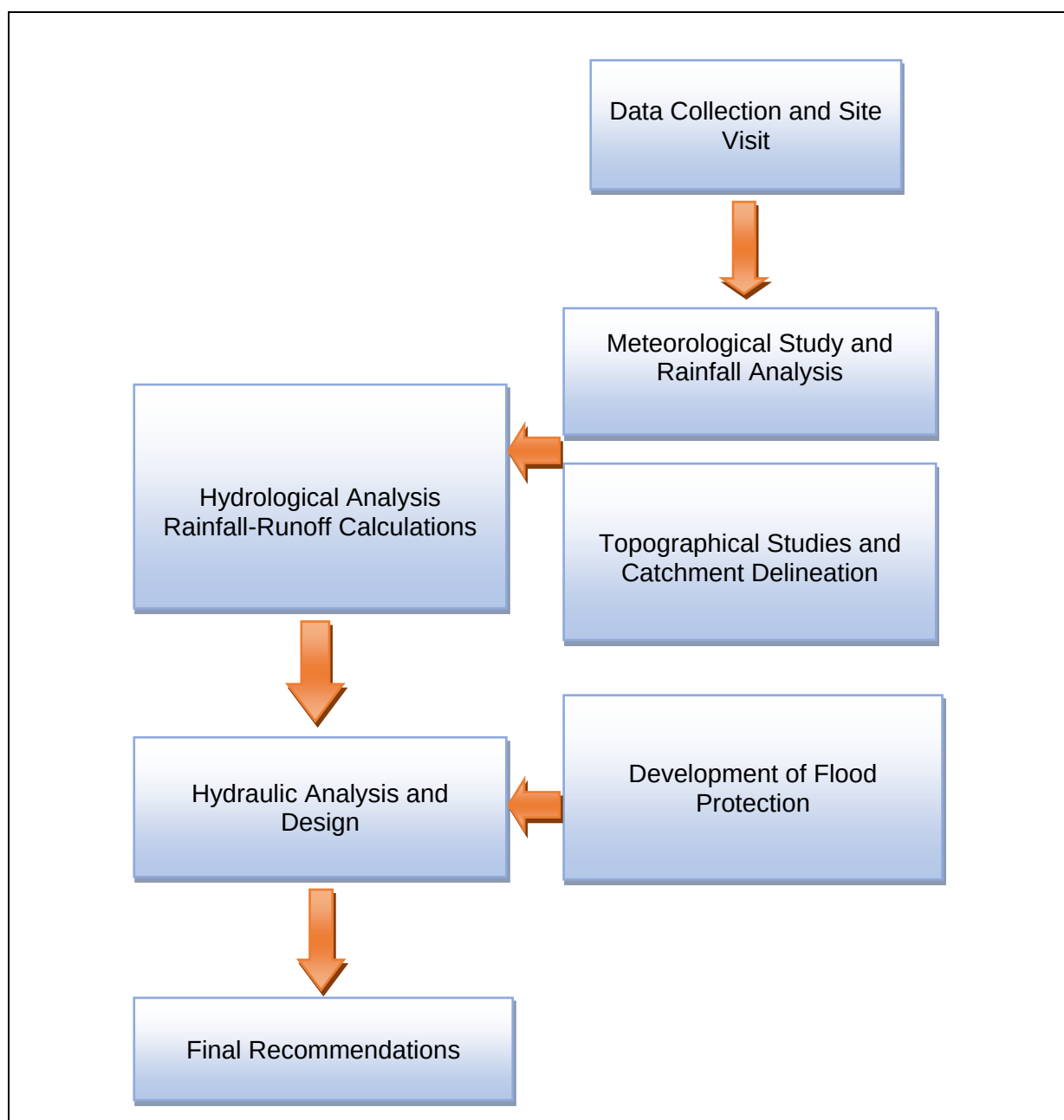


Figure 3.1: Work methodology

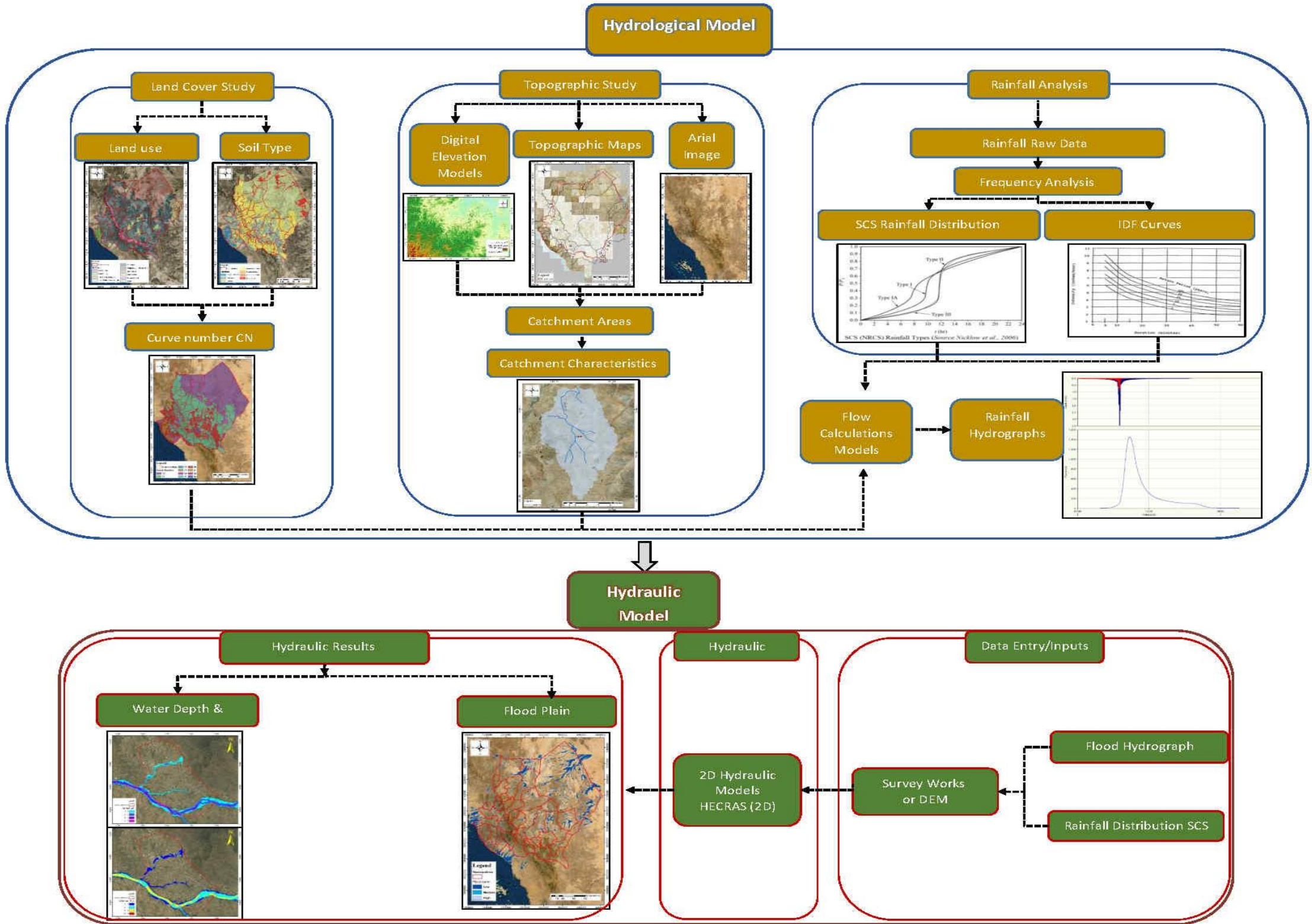


Figure 3.2: Hydrology and hydraulic study methodology and work plan

3.1. 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.

3.2. 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 wadi 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.

3.3. Meteorological Study Methodology

This study aims at determining the locations of meteorological stations affecting the area of Ras Ghareb 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 Ghareb Plot for different recurring periods (5, 10, 25, 50, and 100 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.

3.4. 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:

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

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

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 I_a (I_a the initial loss) is not a constant from storm to storm or watershed to watershed, and that the assumption of $I_a/S = 0.20$ is unusually high.

From their results, it is obvious that a more appropriate "rounded" value of I_a 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 $I_a/S = 0.05$ must be determined. Using $I_a = 0.05$, the runoff equation become:

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

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 (I_a), the data is fitted by least squares method to the CN equation for each case; i.e. for $I_a/S = 0.05$ and for the traditional value of $I_a/S = 0.20$. 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 (R^2) and lower Root Mean Square Error (RMSE).

The relationship between the values of $S_{0.05}$ and $S_{0.20}$ is found to be:

$$S_{0.05} = 1.33 * S_{0.20} \quad (3-4)$$

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:

$$CN_{0.05} = \frac{100}{1.879 \left(\frac{100}{CN_{0.20}} - 1 \right)^{1.15} + 1} \quad (3-5)$$

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 (I_a/S) value of about 0.05 fits the observed rainfall-runoff data much better than does the handbook value of 0.20.

Altering (I_a/S) requires a change of handbook CNs; i.e. if (I_a/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: CN0.05 corresponding to CN0.20

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 furthestmost 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:

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

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:

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

The Concentration Time (T_C) is given as follows:

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

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:

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

in which

q_{pUH} = Maximum unit hydrograph flow (m³/sec).

A = Catchment area (km²).

T_p = Time to peak flow (hours).

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

$$T_p = 0.67 T_C \quad (3-10)$$

3.5. 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

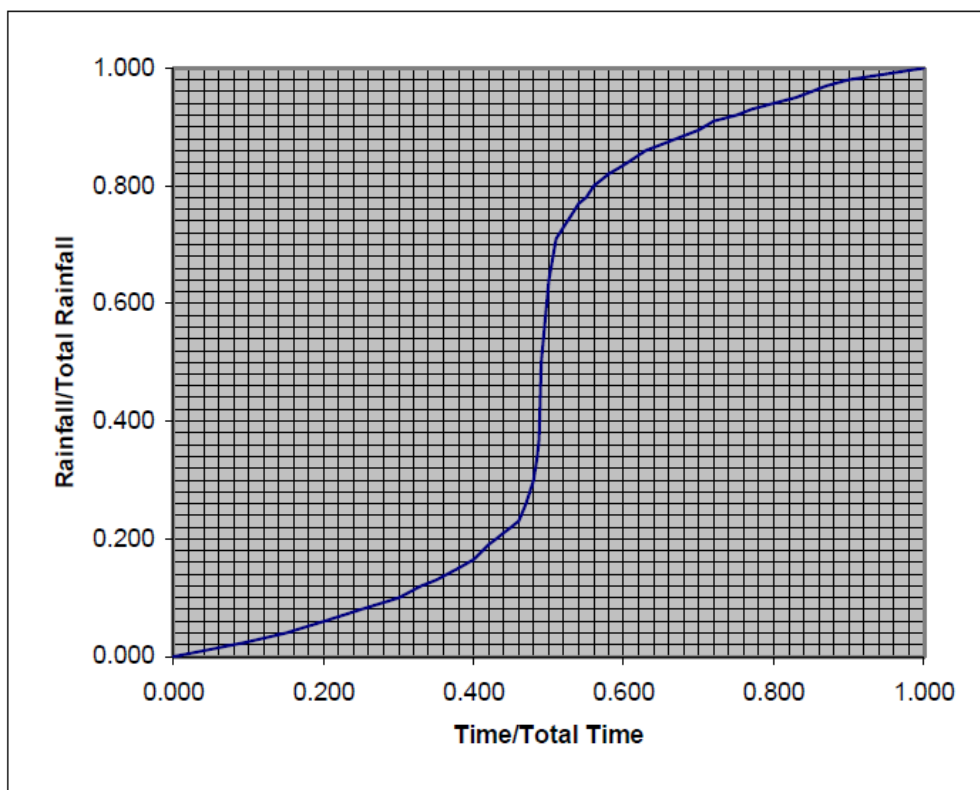


Figure 3.3: Soil conservation service Type II storm duration curve

4. GEOLOGICAL STUDY

4.1. Introduction

Ras Ghareb Plot is located at the Northern part of the Egyptian Eastern Desert West of Ras Ghareb along the Gulf of Suez as shown in Figure 1.1. The hydrologic basins 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 are shown in Figure 4.1 for Ras Ghareb Plot (North 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 largest basin includes the sedimentary and basement rocks. The sedimentary rocks include the Recent and Quaternary, Tertiary, Cretaceous and Jurassic ages at the upper reaches of the basin and in the wadi floor until the Red Sea coast (Section 4.2). The basement rocks of the Precambrian age cover the largest area of the basin (50%) and are about 30% of the small basin (Section 4.3).

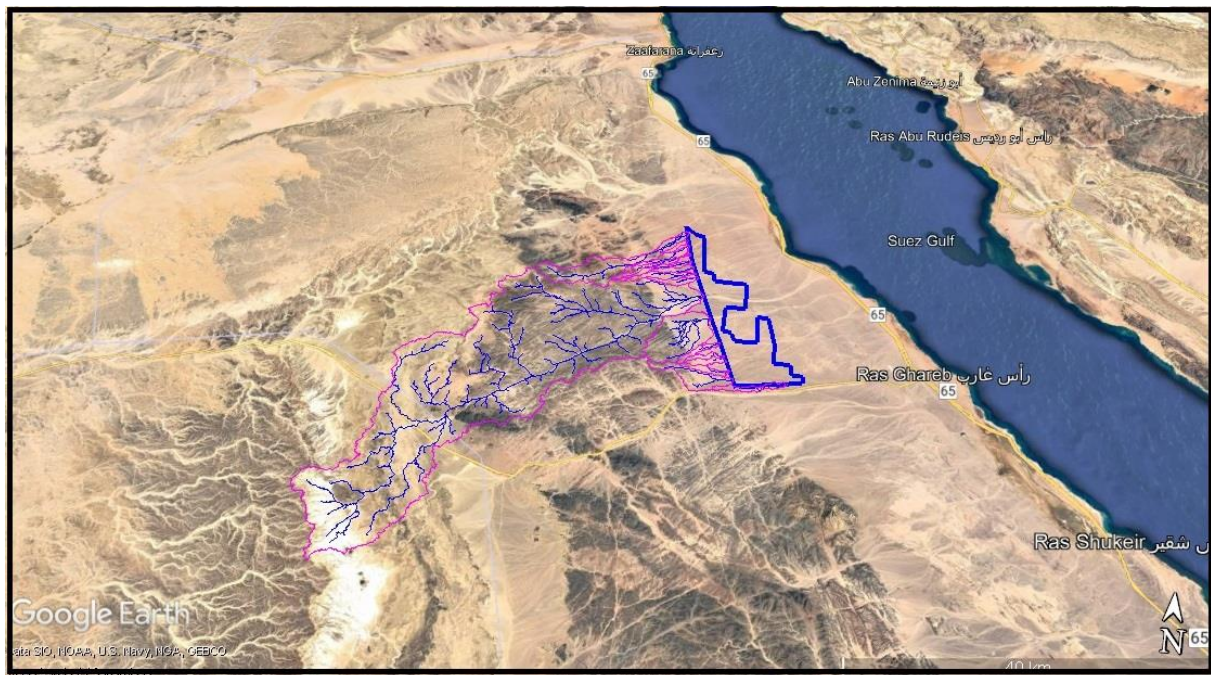


Figure 4.1: Hydrologic basins originating from highly mountainous areas in the West

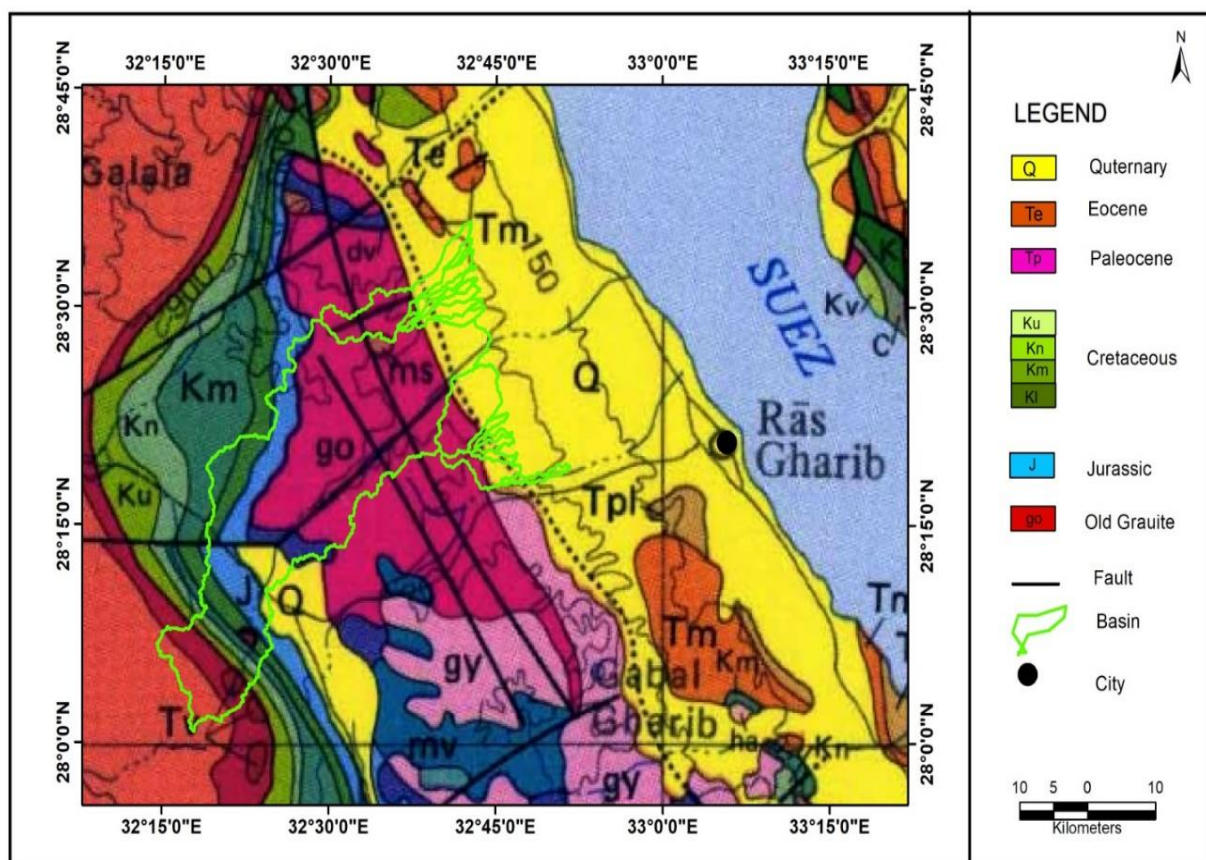


Figure 4.2: Geology of area under consideration

4.2. Sedimentary Rocks

In general, the sedimentary rocks occupy about 50% 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, silt) as a result of erosion of limestone and basement rocks covering the hydrologic basins. These sediments cover the floor of streams and delta.

4.2.2 Paleocene (Tp)

The Paleocene (Tp) consists of the lower part of Esna shale and upper part of Sudr chalk. The Paleocene rocks are distributed in local areas at the upper reaches of the basin and along the Gulf of Suez coast.

4.2.2 Eocene Rocks (Te)

The Eocene rocks (Te) consist of thick marine limestone rich in foraminifera fauna with cherty bands and minor clay. The Eocene limestone is well represented at the upper reach of the basin and is named Mokattam group.

4.2.4 Cretaceous Rocks (ku, kn, and km)

The Cretaceous Rocks (ku, kn, and km) consist of sandstone, shale, limestone, chalk and phosphate of the upper Cretaceous age. These rocks are distributed on the upper reaches of the hydrologic basins.

4.2.5 Jurassic Rocks (J)

The Jurassic Rocks (J) are represented by marine and associated fluvio-marine beds and thick sandstone at the upper western part of the basin with the Cretaceous rocks (Figure 4.2).

4.3. Basement Rocks (go)

In general, the basement rocks occupy about 50% of the total basin area and about 20% of the small basin. The older granitoids rocks (go) are the main rock type in the area. They consist of Calc-Alkaline and alkaline deformed and foliated Quartzdioritic, deeply weathered. The basement rocks are well distributed at a large scale in the study area at the center of the basin.

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 deformed 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 80 and 85.

5. MORPHOLOGICAL STUDY

5.1. Introduction

This study aims to identify the Wadis affecting the study area (Ras Ghareb 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 this 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 Ghareb 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 pwithin the study area and affecting Ras Ghareb 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 Ghareb Plot to be protected from the flash flood hazards. Figures 5.1 and 5.2 show the Wadis, streams, and catchments affecting the project area while Table 5.1 indicates the most important morphological characteristics of the Wadis affecting the plot.

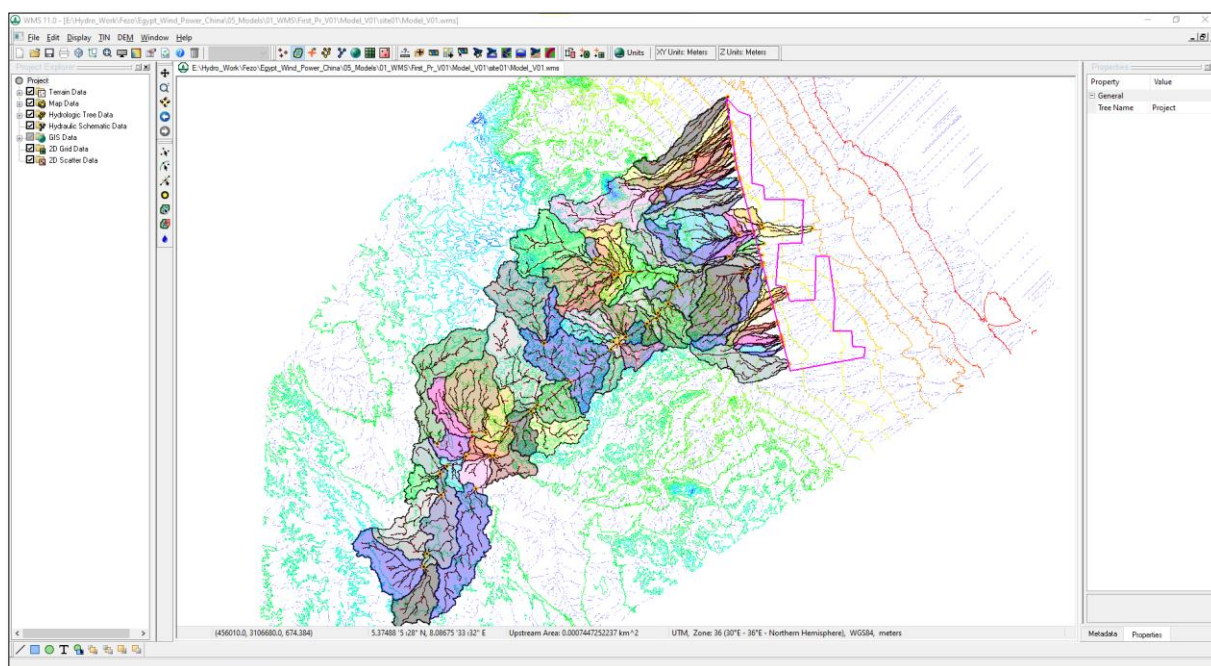


Figure 5.1: WMS Wadis affecting Ras Ghareb Plot

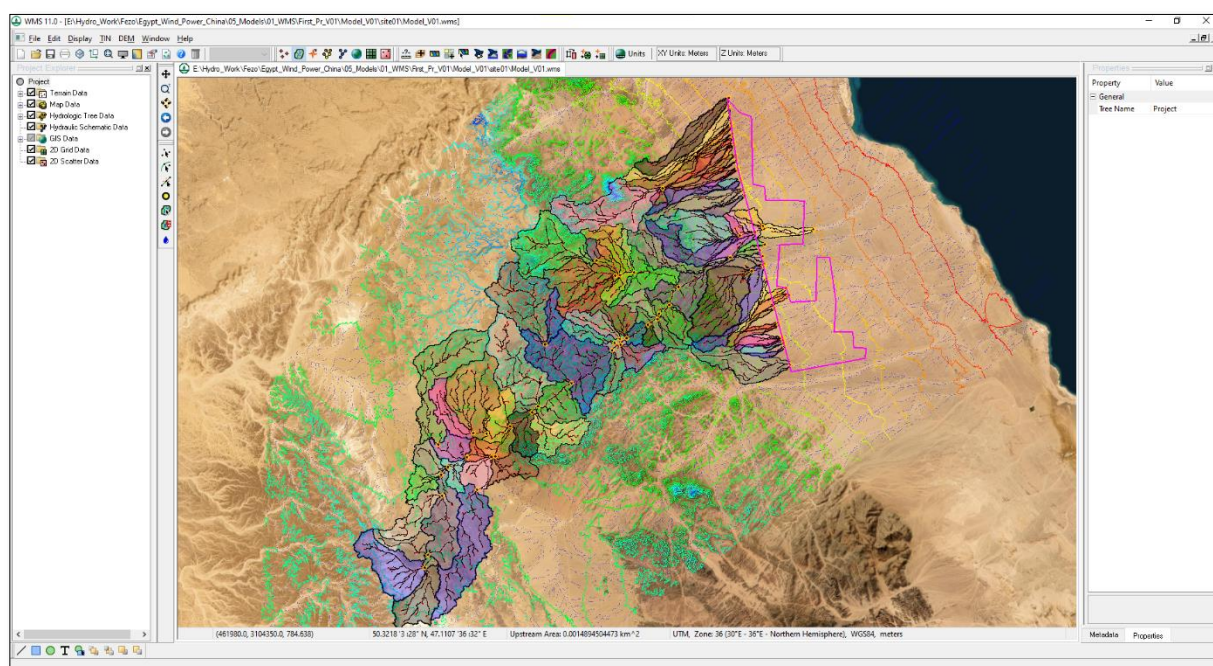


Figure 5.2: Main streams and catchments affecting Ras Ghareb Plot (Satellite Image)

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

Basin Name	Basin Area (km ²)	CN _{0.2}	CN _{0.05}	Basin Slope m/m	Basin Slope %	MFD (m)	T _{Lag} (hrs.)
103B	4.07	77	68	0.013664	1.366	3980.0	178.9
111B	1.47	77	68	0.016887	1.689	2776.5	120.6
112B	3.82	80	72	0.025005	2.501	7347.4	194.9
113B	2.86	77	68	0.029001	2.900	4538.9	136.4
114B	1.14	77	68	0.016655	1.666	2307.1	104.7
115B	4.05	78	69	0.032412	3.241	4125.1	115.6
116B	1.71	81	74	0.023707	2.371	5477.6	150.0
117B	1.87	77	68	0.015001	1.500	3281.9	146.3
118B	3.01	77	68	0.019058	1.906	4123.2	155.8
11B	7.30	77	68	0.011234	1.123	7737.2	335.8
122B	29.12	82	76	0.03507	3.507	14751.0	256.2
12B	4.11	77	68	0.017249	1.725	5343.2	201.5
13B	4.41	77	68	0.017719	1.772	3037.0	126.5
14B	3.95	77	68	0.018825	1.883	3960.8	151.8
15B	5.40	77	68	0.010214	1.021	5137.9	253.8
16B	28.53	80	72	0.029966	2.997	11374.7	253.0
17B	22.09	82	76	0.031655	3.166	15461.1	281.7
18B	21.41	85	79	0.020199	2.020	18651.9	368.0
19B	25.92	84	79	0.020648	2.065	14248.3	299.8
1B	22.84	78	70	0.024346	2.435	15435.8	377.7
20B	20.10	85	80	0.027581	2.758	12076.1	220.4
21B	12.62	85	80	0.071449	7.145	6296.7	81.3
22B	8.18	85	80	0.025381	2.538	6271.2	136.0
23B	5.21	85	80	0.071886	7.189	3535.9	51.1
24B	6.36	85	80	0.079363	7.936	5006.2	64.2
25B	5.10	85	80	0.037159	3.716	3625.6	72.5
26B	3.55	85	80	0.084422	8.442	2841.9	39.6
27B	4.83	85	80	0.037968	3.797	5419.0	99.0
28B	19.89	85	80	0.029386	2.939	9621.9	178.1
29B	6.26	85	80	0.019624	1.962	5009.9	129.3
2B	13.89	79	71	0.026578	2.658	18030.4	393.5
30B	27.63	85	79.6	0.02628	2.628	9484.1	186.1
31B	10.91	85	80	0.02583	2.583	9085.2	181.4
32B	11.90	85	80	0.032396	3.240	6834.3	129.0
33B	3.72	85	80	0.035274	3.527	2908.0	62.4
34B	10.99	85	80	0.044321	4.432	5896.9	98.0
35B	11.72	85	80	0.032282	3.228	7839.8	144.2
36B	9.49	85	80	0.03111	3.111	7447.5	141.0
37B	59.16	85	80	0.016468	1.647	18273.3	397.3

Basin Name	Basin Area (km ²)	CN _{0.2}	CN _{0.05}	Basin Slope m/m	Basin Slope %	MFD (m)	T _{Lag} (hrs.)
38B	8.58	85	80	0.0375	3.750	7277.4	126.1
39B	3.25	85	80	0.033807	3.381	2210.5	51.2
3B	3.08	77	68	0.019149	1.915	8987.1	289.9
40B	47.57	85	80	0.028654	2.865	13729.4	240.6
41B	21.46	85	80	0.024613	2.461	9791.2	197.3
42B	48.03	83	77	0.014924	1.492	19855.8	488.1
43B	2.84	85	80	0.047569	4.757	3185.9	57.8
44B	44.29	84	78	0.01872	1.872	15392.1	345.7
45B	8.71	85	80	0.025321	2.532	6929.5	147.5
46B	14.66	85	80	0.027983	2.798	6491.7	133.2
47B	21.08	85	80	0.025786	2.579	10366.6	201.8
48B	15.85	79	71	0.010549	1.055	7630.4	319.9
49B	8.98	80	73	0.011891	1.189	5888.7	230.9
4B	1.92	77	68	0.018713	1.871	3231.4	129.4
50B	44.67	77	69	0.01911	1.911	13504.5	397.7
51B	4.32	77	68	0.014024	1.402	4104.7	181.0
52B	14.89	79	71	0.010797	1.080	7401.6	308.9
53B	12.26	77	68	0.004658	0.466	6323.7	443.8
54B	15.23	77	68	0.008688	0.869	9657.2	455.9
55B	11.46	77	68	0.003436	0.344	5490.1	461.4
56B	7.34	77	68	0.006323	0.632	5719.1	351.5
57B	52.80	77	68	0.00802	0.802	23465.1	965.4
58B	10.60	77	68	0.006922	0.692	7760.9	428.8
59B	34.34	77	68	0.007262	0.726	16753.7	774.9
5B	11.83	80	72	0.02328	2.328	15003.8	355.7
60B	9.47	77	68	0.01243	1.243	5904.9	257.2
61B	52.21	77	68	0.01075	1.075	23773.3	842.6
62B	19.36	77	68	0.017107	1.711	11999.7	386.6
63B	13.53	77	68	0.019017	1.902	8477.2	277.7
64B	1.97	77	68	0.018671	1.867	2121.2	92.5
65B	35.76	77	68	0.010103	1.010	10733.7	460.1
66B	25.34	77	68	0.01647	1.647	10071.7	342.5
67B	1.01	77	68	0.018728	1.873	1420.8	67.0
68B	4.75	77	68	0.017574	1.757	7804.0	270.3
69B	1.14	77	68	0.018141	1.814	3801.7	149.7
6B	5.64	77	68	0.018519	1.852	8481.5	281.5
70B	6.22	79	70	0.026894	2.689	11914.7	288.5
71B	49.50	85	80	0.017712	1.771	17658.1	372.8
72B	1.13	85	80	0.061988	6.199	996.9	20.0
73B	1.37	77	68	0.01714	1.714	3264.7	136.3
74B	1.57	77	68	0.015863	1.586	1671.2	82.9

Basin Name	Basin Area (km ²)	CN _{0.2}	CN _{0.05}	Basin Slope m/m	Basin Slope %	MFD (m)	T _{Lag} (hrs.)
75B	10.02	80	72	0.027299	2.730	13359.0	299.3
77B	17.42	79	71	0.031152	3.115	13464.8	294.3
78B	4.41	77	68	0.014488	1.449	5316.6	219.0
7B	3.08	77	68	0.01863	1.863	5773.3	206.3
90B	1.94	77	68	0.010746	1.075	2371.5	133.3
91B	1.11	77	68	0.010069	1.007	1719.2	106.5
92B	1.91	77	68	0.014922	1.492	1845.1	92.6
93B	17.11	80	73	0.036031	3.603	17000.6	309.8
94B	1.01	77	68	0.010322	1.032	1707.9	104.6
95B	0.58	77	68	0.010377	1.038	659.1	48.7
96B	0.81	77	68	0.009613	0.961	1175.4	80.4
97B	3.93	77	68	0.010952	1.095	3655.5	186.7
98B	3.34	77	68	0.019746	1.975	6822.0	229.0
99B	45.29	81	74	0.039987	3.999	13908.9	244.8

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

This study 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 will be 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 (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 Abu Rudeis station is the one that affects the study area (Ras Ghareb Plot).

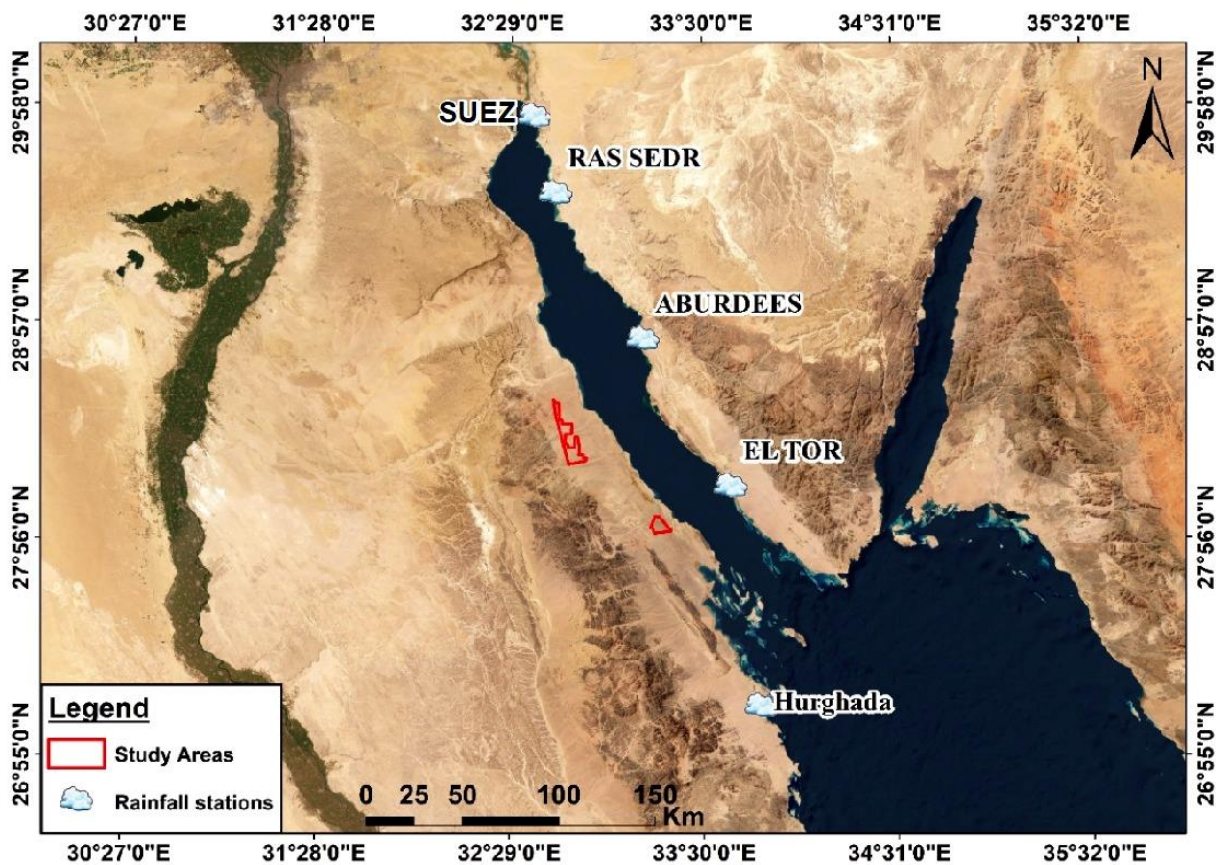


Figure 6.1: Locations of meteorological stations

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

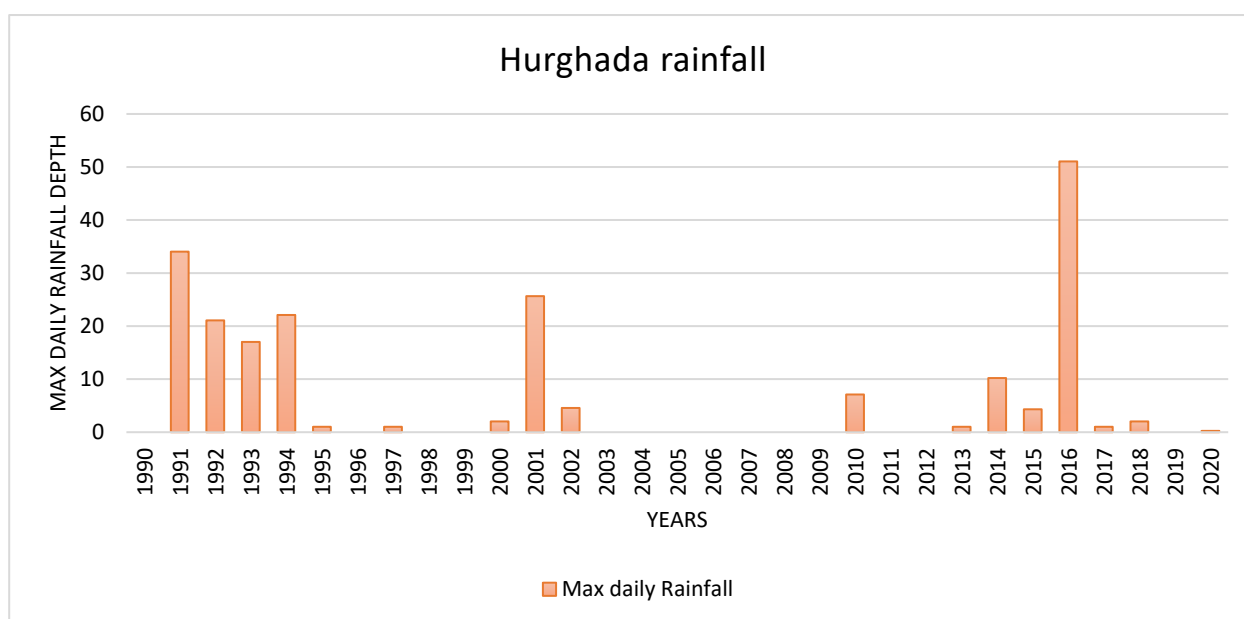


Figure 6.2: Maximum rainfall depth (mm/day) for Hurghada meteorological station

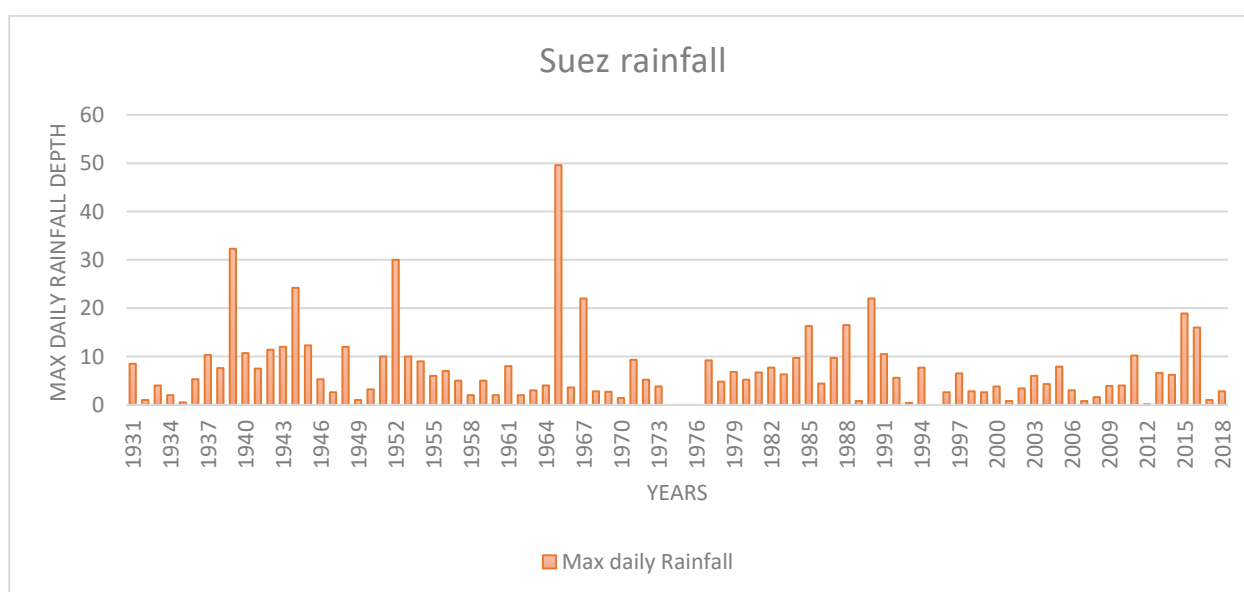


Figure 6.3: Maximum rainfall depth (mm/day) for Suez meteorological station

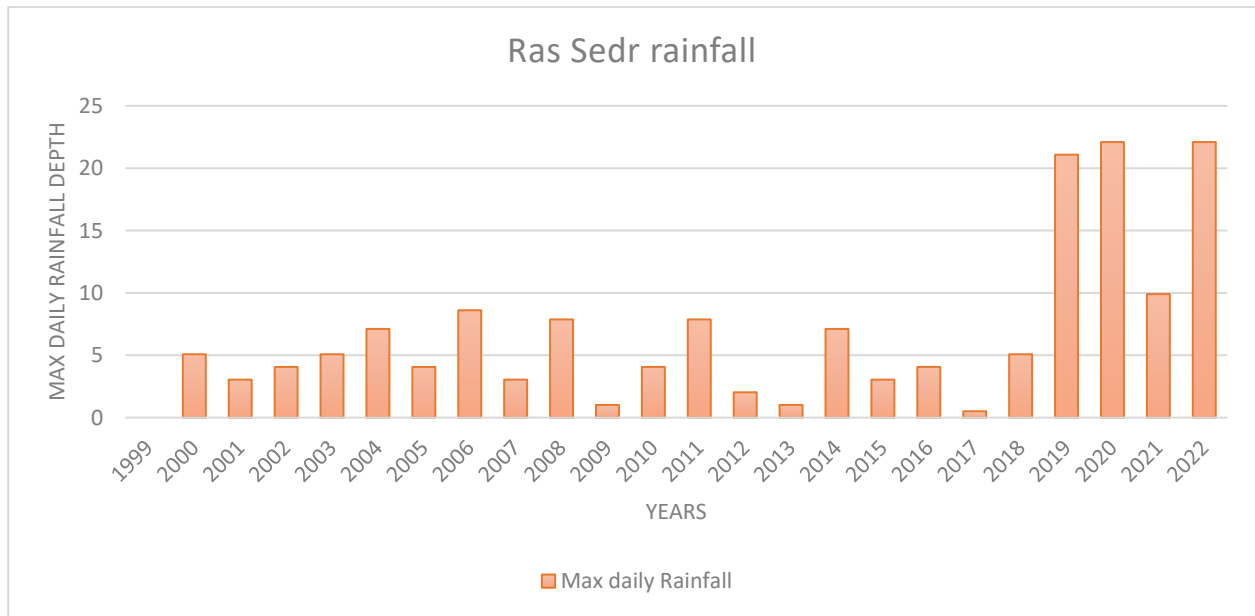


Figure 6.4: Maximum rainfall depth (mm/day) for Ras Sedr meteorological station

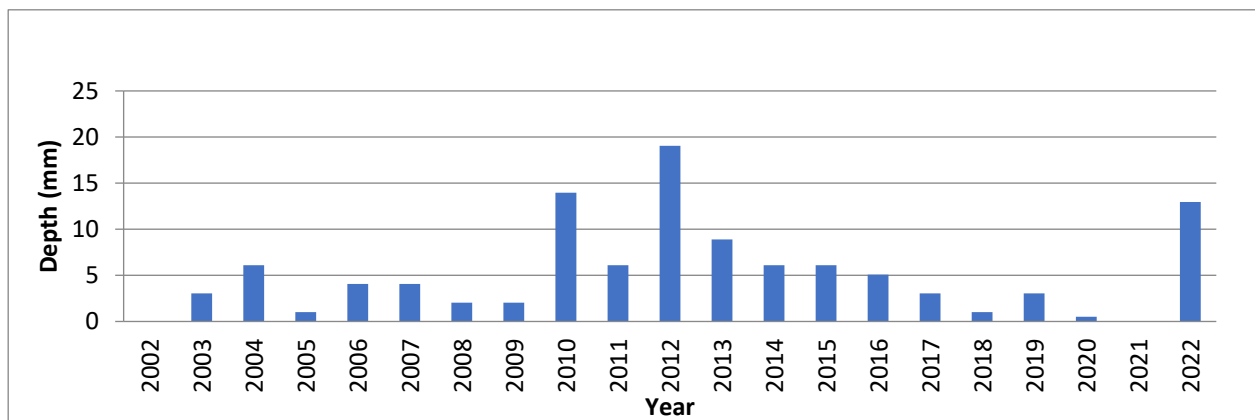


Figure 6.5: Maximum rainfall depth (mm/day) for Abu Rudeis meteorological station

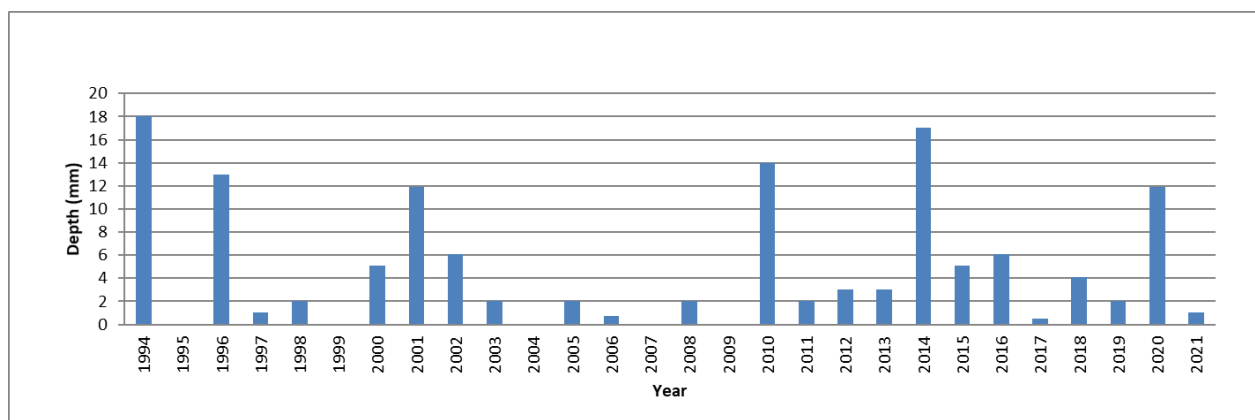
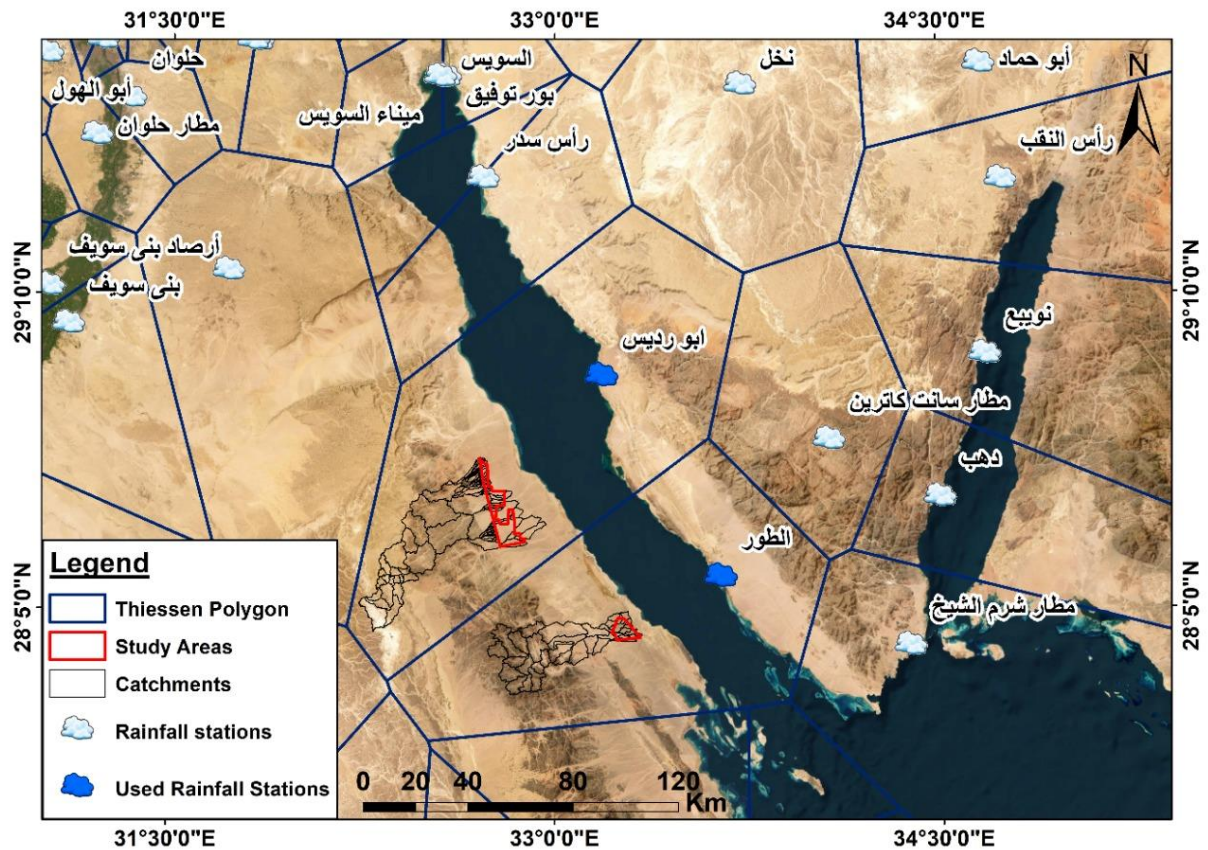


Figure 6.6: Maximum rainfall depth (mm/day) for Al-Tur meteorological station

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

6.3. Rainfall Analysis

The Abu Rudeis 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 Abu Rudeis 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%.

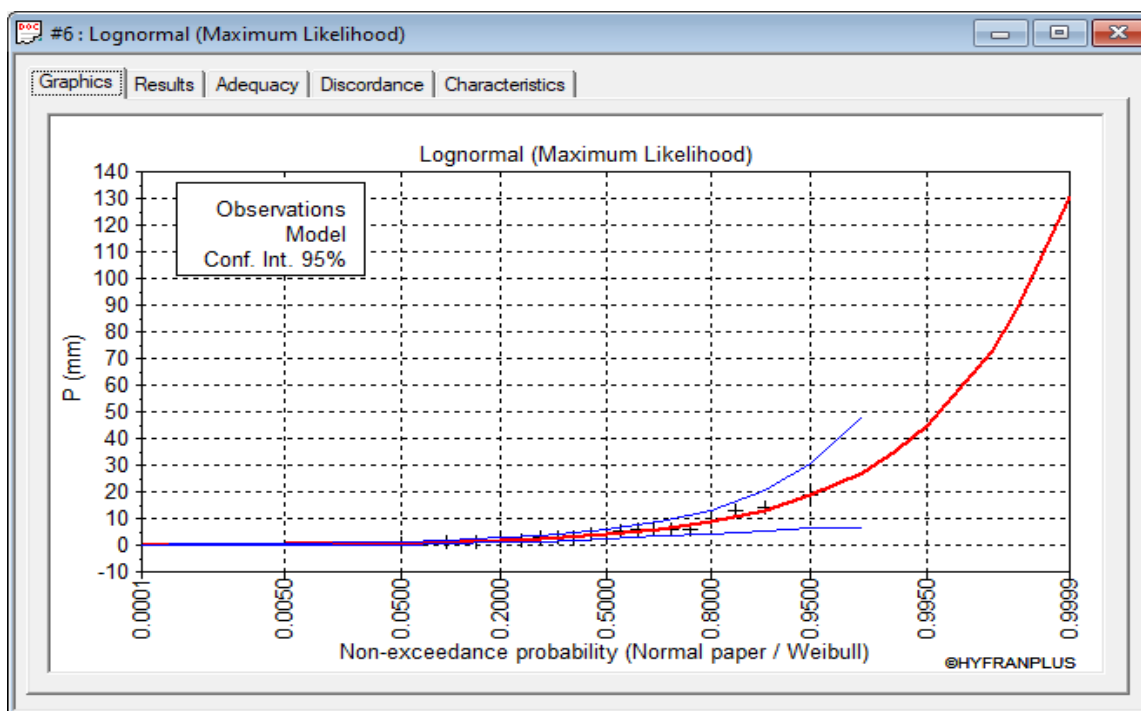


Figure 6.8: Rainfall measured at Abu Rudeis station compared to calculated lognormal probability distribution (95% confidence)

The Lognormal probability distribution of the rainfall data of Abu Rudeis Meteorological Station is used to estimate the rain storms corresponding to the frequency times from 2 to 2000 years, as shown in Table 6.3. 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 35.3 mm for Abu Rudeis 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 6.9. These curves have several useful uses, including estimating the surface flow (floodwater) of small Wadis within 1 km² area using simple mathematical models such as the Rational Method, as well as designing rainwater drainage networks.

**Table 6.3: Rainstorms for different frequency periods from 2 to 2000 years
for Abu Rudeis meteorological station**

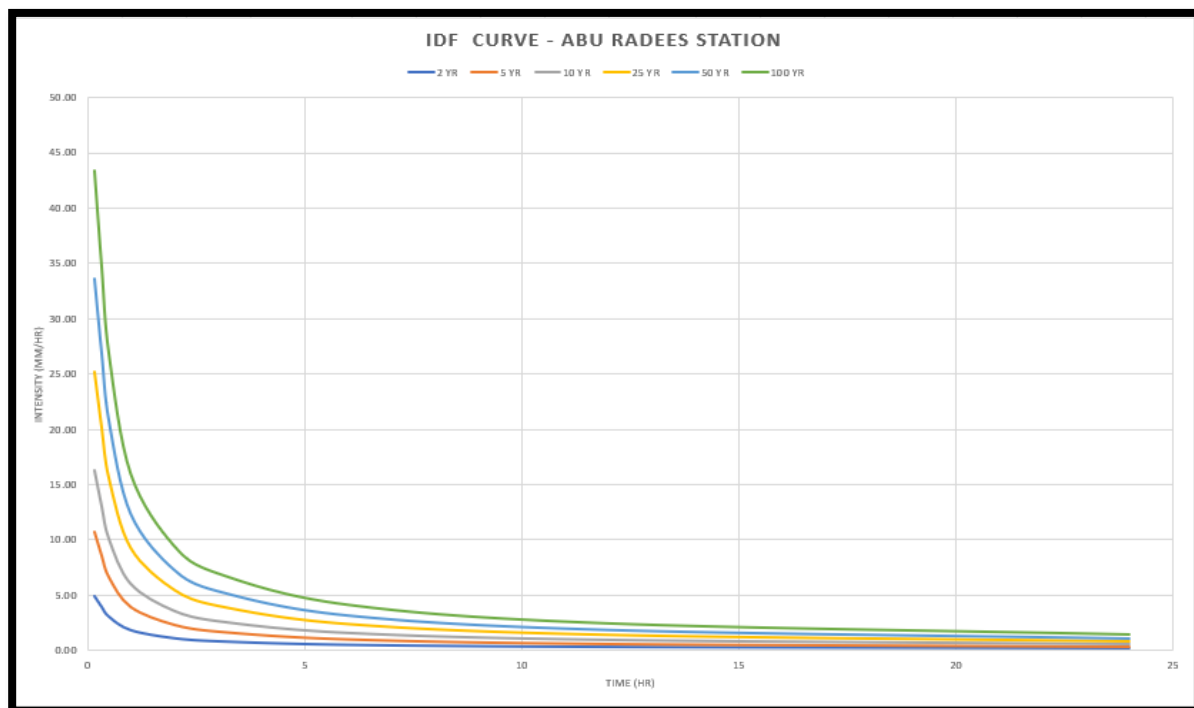
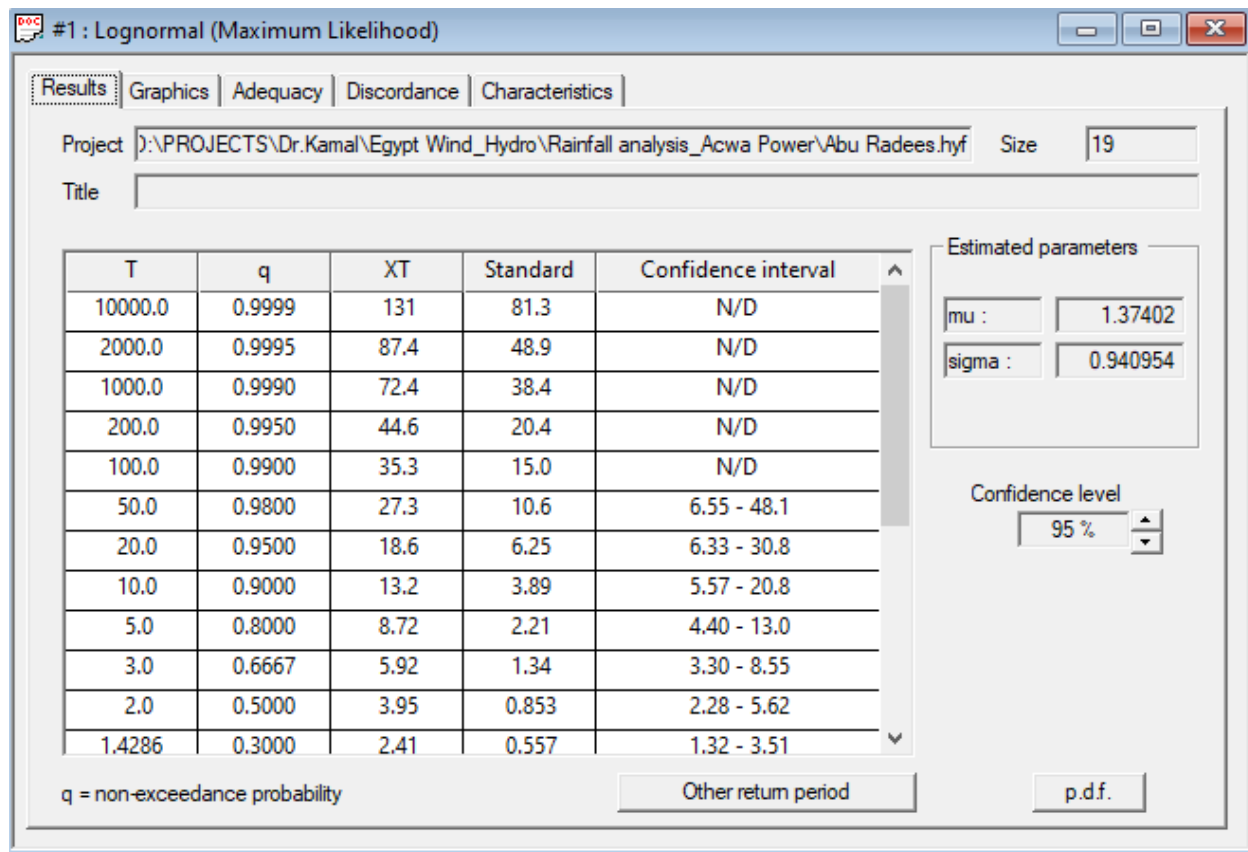


Figure 6.9: Intensity-Duration-frequency curves for Abu Rudeis meteorological station

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 6.10). 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 6.4 gives the morphological parameters and the model results of wadi discharges affecting the project boundary for different return periods.

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 flood extend and estimate the flood hazards affecting the site boundary. 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. Existing Structures (Dams)

Dams are considered one of the oldest means that humans used to tame the violence of natural waterways. They are usually classified according to their forms and materials used in their construction and the goals they were built for. The aim could be organizing and managing the available water resources and providing needs for potable water and agriculture or simply staving off danger is a frequent occurrence, such as flash floods and floods, or for both ends.

Figure 7.1 shows location of the existing dam (Dam No. 1) on satellite image and its location relative to the study area (Ras Ghareb Plot). Figure 7.2 and 7.3 show the flow hydrographs on the dam for return period 100 + CC years. In addition, Table 7.1 gives the main characteristics of the existing dam.

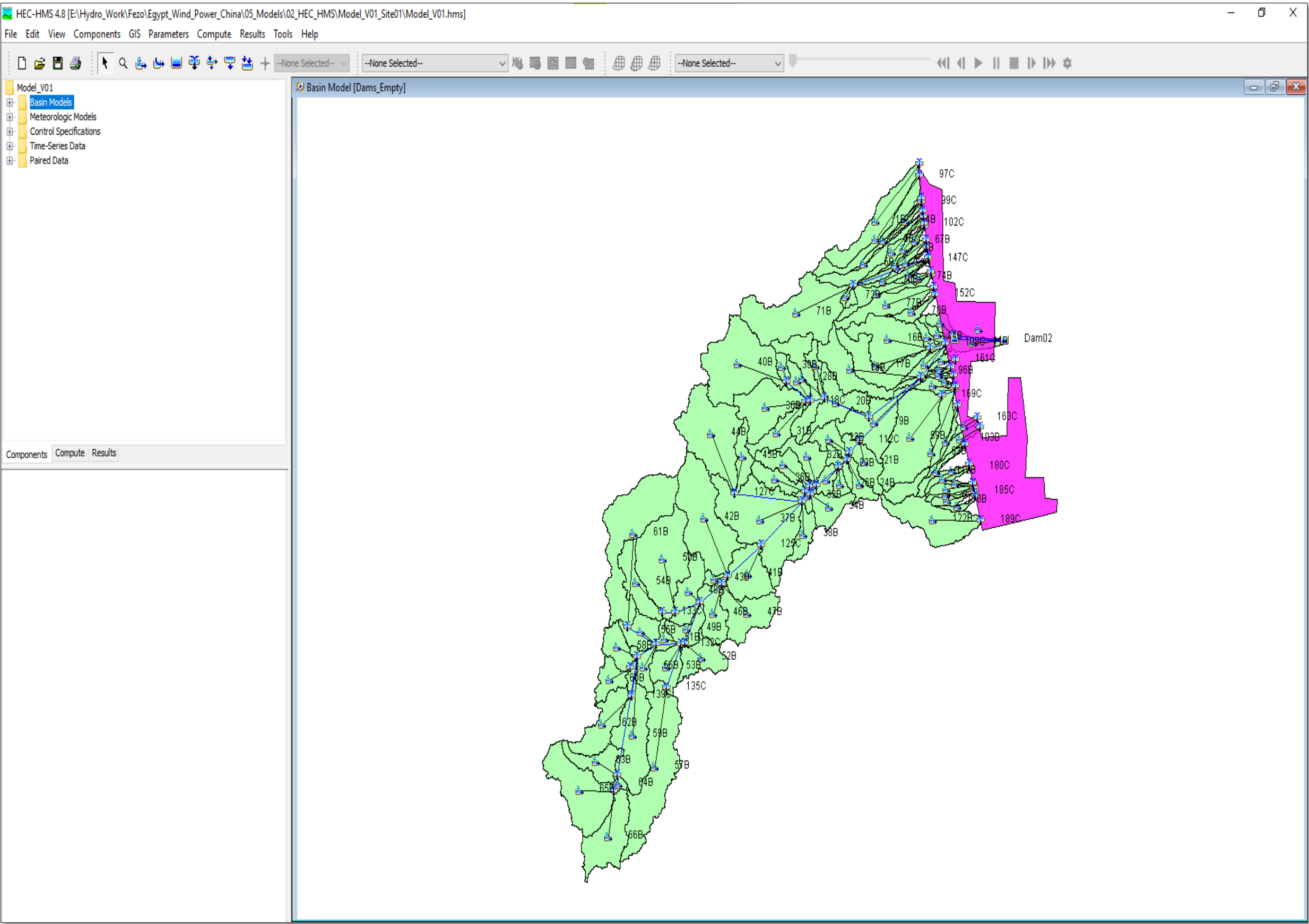


Figure 6.10: Flow calculations from HEC-HMS software

Table 6.4: Morphological characteristics for catchment areas and model results

Basin Name	Basin Area (km ²)	CN _{0.2}	CN _{0.05}	ARF	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. (m ³ /s)	Q 100 yrs. (m ³ /s)	Q 100 yrs. + CC (m ³ /s)	Q 200 yrs. (m ³ /s)
103B	4.07	77	68	No ARF	0.0	0.1	0.2	0.4	0.9	1.4	2.0	2.2
111B	1.47	77	68	No ARF	0.0	0.0	0.1	0.2	0.4	0.7	1.0	1.0
112B	3.82	80	72	No ARF	0.0	0.1	0.2	0.4	0.9	1.4	2.0	2.2
113B	2.86	77	68	No ARF	0.0	0.1	0.2	0.4	0.8	1.2	1.7	1.9
114B	1.14	77	68	No ARF	0.0	0.0	0.1	0.2	0.4	0.6	0.8	0.9
115B	4.05	78	69	No ARF	0.0	0.1	0.3	0.6	1.3	2.1	2.8	3.1
116B	1.71	81	74	No ARF	0.0	0.1	0.1	0.3	0.5	0.8	1.2	1.3
117B	1.87	77	68	No ARF	0.0	0.1	0.1	0.2	0.5	0.8	1.0	1.1
118B	3.01	77	68	No ARF	0.0	0.1	0.2	0.4	0.7	1.2	1.6	1.8
11B	7.30	77	68	No ARF	0.0	0.1	0.3	0.5	1.0	1.6	2.2	2.4
122B	29.12	82	76	No ARF	0.1	0.8	1.8	3.3	6.6	10.4	14.2	15.5
12B	4.11	77	68	No ARF	0.0	0.1	0.2	0.4	0.8	1.3	1.8	2.0
13B	4.41	77	68	No ARF	0.0	0.1	0.3	0.6	1.3	2.0	2.8	3.0
14B	3.95	77	68	No ARF	0.0	0.1	0.2	0.5	1.0	1.6	2.2	2.4
15B	5.40	77	68	No ARF	0.0	0.1	0.2	0.4	0.9	1.4	2.0	2.2
16B	28.53	80	72	No ARF	0.1	0.6	1.4	2.7	5.6	8.8	12.1	13.2
17B	22.09	82	76	No ARF	0.1	0.6	1.2	2.3	4.7	7.3	10.0	10.9
18B	21.41	85	79	No ARF	0.1	0.5	1.2	2.2	4.3	6.7	9.0	9.8
19B	25.92	84	79	No ARF	0.1	0.7	1.6	3.0	5.9	9.2	12.4	13.5
1B	22.84	78	70	No ARF	0.1	0.4	0.8	1.5	3.0	4.8	6.7	7.3
20B	20.10	85	80	No ARF	0.1	0.7	1.6	3.1	6.0	9.4	12.7	13.8
21B	12.62	85	80	No ARF	0.2	1.0	2.2	4.1	8.0	12.5	16.9	18.4
22B	8.18	85	80	No ARF	0.1	0.4	1.0	1.8	3.5	5.5	7.4	8.1

Basin Name	Basin Area (km ²)	CN _{0.2}	CN _{0.05}	ARF	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. (m ³ /s)	Q 100 yrs. (m ³ /s)	Q 100 yrs. + CC (m ³ /s)	Q 200 yrs. (m ³ /s)
23B	5.21	85	80	No ARF	0.1	0.6	1.3	2.4	4.7	7.3	9.9	10.8
24B	6.36	85	80	No ARF	0.1	0.6	1.3	2.4	4.8	7.5	10.2	11.1
25B	5.10	85	80	No ARF	0.1	0.4	1.0	1.8	3.5	5.5	7.5	8.1
26B	3.55	85	80	No ARF	0.1	0.5	1.0	1.9	3.8	6.0	8.1	8.8
27B	4.83	85	80	No ARF	0.1	0.3	0.7	1.3	2.7	4.1	5.6	6.1
28B	19.89	85	80	No ARF	0.1	0.9	1.9	3.6	7.0	10.9	14.8	16.1
29B	6.26	85	80	No ARF	0.1	0.3	0.8	1.4	2.8	4.4	5.9	6.4
2B	13.89	79	71	No ARF	0.0	0.2	0.5	0.9	1.9	3.0	4.1	4.5
30B	27.63	85	79.6	No ARF	0.2	1.2	2.5	4.8	9.4	14.6	19.8	21.6
31B	10.91	85	80	No ARF	0.1	0.5	1.0	1.9	3.8	5.9	8.0	8.7
32B	11.90	85	80	No ARF	0.1	0.7	1.4	2.7	5.4	8.3	11.3	12.3
33B	3.72	85	80	No ARF	0.1	0.4	0.8	1.5	2.9	4.5	6.1	6.6
34B	10.99	85	80	No ARF	0.1	0.7	1.6	3.1	6.1	9.5	12.8	14.0
35B	11.72	85	80	No ARF	0.1	0.6	1.3	2.5	4.9	7.5	10.2	11.1
36B	9.49	85	80	No ARF	0.1	0.5	1.1	2.0	4.0	6.2	8.4	9.2
37B	59.16	85	80	No ARF	0.2	1.4	3.1	5.8	11.3	17.6	23.7	25.8
38B	8.58	85	80	No ARF	0.1	0.5	1.1	2.0	3.9	6.1	8.3	9.0
39B	3.25	85	80	No ARF	0.1	0.4	0.8	1.5	2.9	4.5	6.2	6.7
3B	3.08	77	68	No ARF	0.0	0.1	0.1	0.2	0.5	0.7	1.0	1.1
40B	47.57	85	80	No ARF	0.3	1.6	3.6	6.7	13.3	20.6	27.9	30.3
41B	21.46	85	80	No ARF	0.1	0.9	1.9	3.6	7.0	10.9	14.7	16.0
42B	48.03	83	77	No ARF	0.1	0.8	1.8	3.5	6.9	10.8	14.7	16.0
43B	2.84	85	80	No ARF	0.0	0.3	0.6	1.2	2.3	3.6	4.9	5.4
44B	44.29	84	78	No ARF	0.2	1.1	2.3	4.3	8.6	13.5	18.3	19.9
45B	8.71	85	80	No ARF	0.1	0.4	1.0	1.8	3.5	5.5	7.5	8.1

Basin Name	Basin Area (km ²)	CN _{0.2}	CN _{0.05}	ARF	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. (m ³ /s)	Q 100 yrs. (m ³ /s)	Q 100 yrs. + CC (m ³ /s)	Q 200 yrs. (m ³ /s)
46B	14.66	85	80	No ARF	0.1	0.8	1.7	3.3	6.5	10.0	13.6	14.8
47B	21.08	85	80	No ARF	0.1	0.8	1.8	3.4	6.8	10.5	14.2	15.5
48B	15.85	79	71	No ARF	0.0	0.3	0.6	1.2	2.5	3.9	5.4	5.9
49B	8.98	80	73	No ARF	0.0	0.2	0.5	1.0	1.9	3.1	4.2	4.6
4B	1.92	77	68	No ARF	0.0	0.1	0.1	0.3	0.5	0.9	1.2	1.3
50B	44.67	77	69	No ARF	0.1	0.6	1.4	2.7	5.4	8.6	11.9	13.0
51B	4.32	77	68	No ARF	0.0	0.1	0.2	0.5	0.9	1.5	2.1	2.3
52B	14.89	79	71	No ARF	0.0	0.3	0.6	1.2	2.4	3.8	5.2	5.7
53B	12.26	77	68	No ARF	0.0	0.2	0.3	0.7	1.3	2.1	3.0	3.2
54B	15.23	77	68	No ARF	0.0	0.2	0.4	0.8	1.6	2.6	3.6	4.0
55B	11.46	77	68	No ARF	0.0	0.1	0.3	0.6	1.2	1.9	2.7	2.9
56B	7.34	77	68	No ARF	0.0	0.1	0.2	0.5	1.0	1.5	2.1	2.3
57B	52.80	77	68	No ARF	0.1	0.4	0.8	1.6	3.2	5.1	7.0	7.6
58B	10.60	77	68	No ARF	0.0	0.1	0.3	0.6	1.2	1.9	2.6	2.9
59B	34.34	77	68	No ARF	0.0	0.3	0.6	1.2	2.5	3.9	5.4	5.9
5B	11.83	80	72	No ARF	0.0	0.2	0.5	0.9	1.8	2.8	3.9	4.3
60B	9.47	77	68	No ARF	0.0	0.2	0.4	0.8	1.6	2.5	3.5	3.8
61B	52.21	77	68	No ARF	0.1	0.4	0.9	1.7	3.5	5.6	7.7	8.4
62B	19.36	77	68	No ARF	0.0	0.3	0.6	1.2	2.4	3.8	5.2	5.7
63B	13.53	77	68	No ARF	0.0	0.2	0.5	1.0	2.1	3.4	4.7	5.1
64B	1.97	77	68	No ARF	0.0	0.1	0.2	0.3	0.7	1.1	1.6	1.7
65B	35.76	77	68	No ARF	0.1	0.4	1.0	1.9	3.8	6.1	8.4	9.2
66B	25.34	77	68	No ARF	0.1	0.0	0.9	1.7	3.4	5.4	7.5	8.2
67B	1.01	77	68	No ARF	0.0	0.0	0.1	0.2	0.5	0.7	1.0	1.1
68B	4.75	77	68	No ARF	0.0	0.0	0.2	0.4	0.8	1.2	1.7	1.8

Basin Name	Basin Area (km ²)	CN _{0.2}	CN _{0.05}	ARF	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. (m ³ /s)	Q 100 yrs. (m ³ /s)	Q 100 yrs. + CC (m ³ /s)	Q 200 yrs. (m ³ /s)
69B	1.14	77	68	No ARF	0.0	0.0	0.1	0.1	0.3	0.5	0.6	0.7
6B	5.64	77	68	No ARF	0.0	0.1	0.2	0.4	0.9	1.4	1.9	2.1
70B	6.22	79	70	No ARF	0.0	0.0	0.3	0.5	1.0	1.6	2.3	2.5
71B	49.50	85	80	No ARF	0.0	0.2	2.7	5.1	10.0	15.4	20.8	22.7
72B	1.13	85	80	No ARF	0.0	0.0	0.5	1.0	2.0	3.0	4.1	4.5
73B	1.37	77	68	No ARF	0.0	0.0	0.1	0.2	0.4	0.6	0.8	0.9
74B	1.57	77	68	No ARF	0.0	0.0	0.2	0.3	0.6	1.0	1.3	1.5
75B	10.02	80	72	No ARF	0.0	0.0	0.4	0.9	1.7	2.7	3.8	4.1
77B	17.42	79	71	No ARF	0.0	0.1	0.7	1.4	2.9	4.6	6.3	6.9
78B	4.41	77	68	No ARF	0.0	0.0	0.2	0.4	0.8	1.3	1.8	2.0
7B	3.08	77	68	No ARF	0.0	0.0	0.2	0.3	0.6	1.0	1.3	1.5
90B	1.94	77	68	No ARF	0.0	0.0	0.1	0.3	0.5	0.8	1.2	1.3
91B	1.11	77	68	No ARF	0.0	0.0	0.1	0.2	0.4	0.6	0.8	0.9
92B	1.91	77	68	No ARF	0.0	0.0	0.2	0.3	0.7	1.1	1.5	1.7
93B	17.11	80	73	No ARF	0.0	0.1	0.8	1.5	3.0	4.7	6.4	7.0
94B	1.01	77	68	No ARF	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.8
95B	0.58	77	68	No ARF	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.8
96B	0.81	77	68	No ARF	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.8
97B	3.93	77	68	No ARF	0.0	0.0	0.2	0.4	0.8	1.3	1.8	2.0
98B	3.34	77	68	No ARF	0.0	0.0	0.2	0.3	0.6	1.0	1.3	1.5
99B	45.29	81	74	No ARF	0.0	0.2	2.5	4.8	9.7	15.3	21.0	22.9

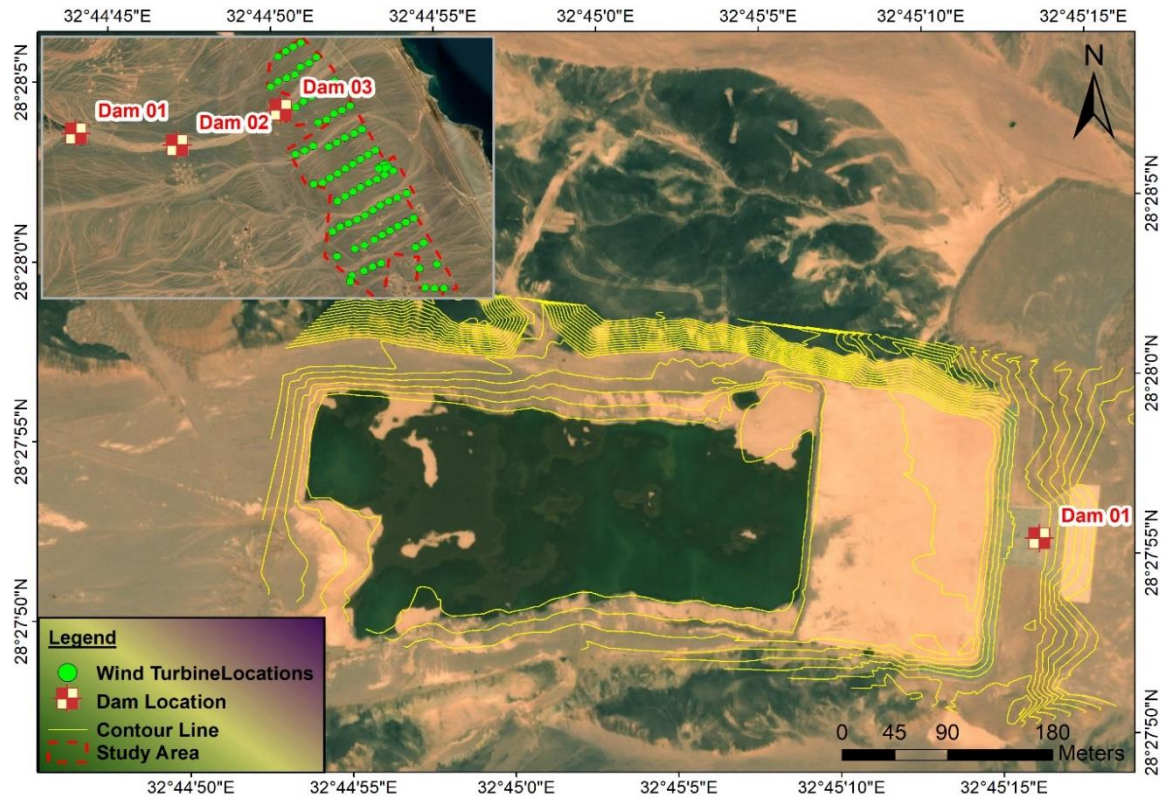


Figure 7.1: Dam 01 location on satellite image

Table 7.1: Dam 01 data

Dam 01 data.	
Dam Name	Dam 01
Purpose	Flood Protection
Easting	475998
Northing	3148771
Storage capacity (m ³)	600,000
Dam Height (m)	5
Dam Length (m)	300
Spillway Height (m)	4
Spillway length (m)	50

7.2. Hydraulic Model Development

The following data have been used to develop the hydraulic models for both the study area (Ras Ghareb Plot) and Wadi Hawashi with the existing Dam:

- Boundary Conditions /Catchments Hydrographs.
- Topographic Survey.
- Existing Dam Survey.

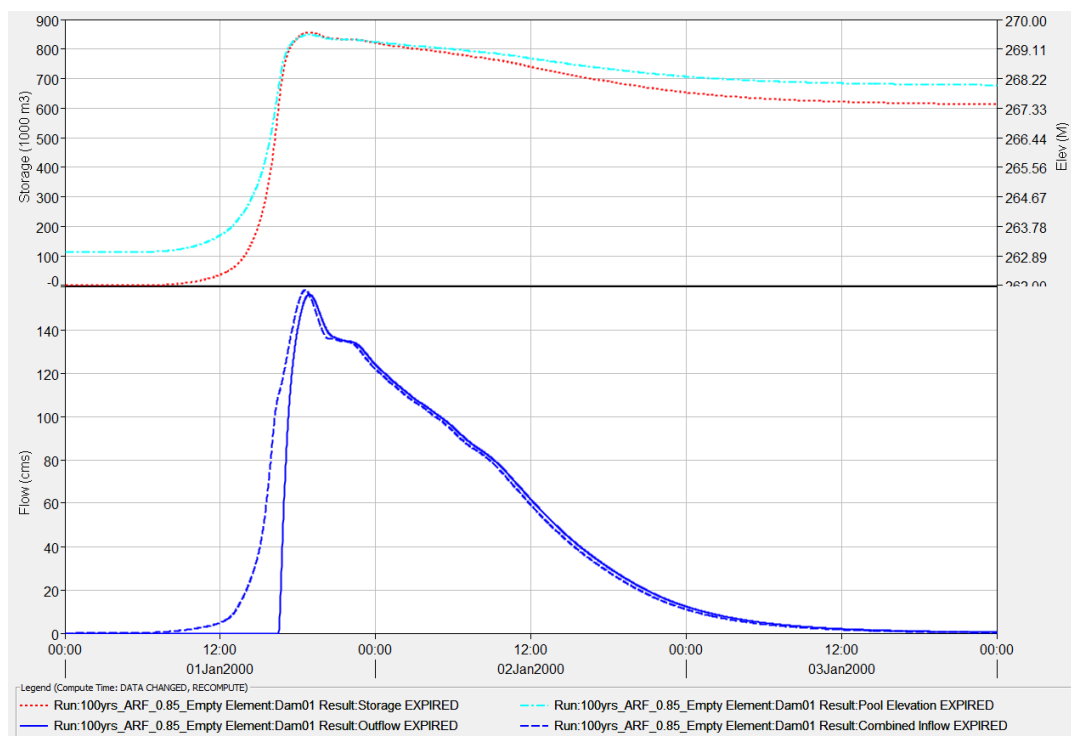


Figure 7.2: Dam 01 flow hydrograph for return period of 100 years

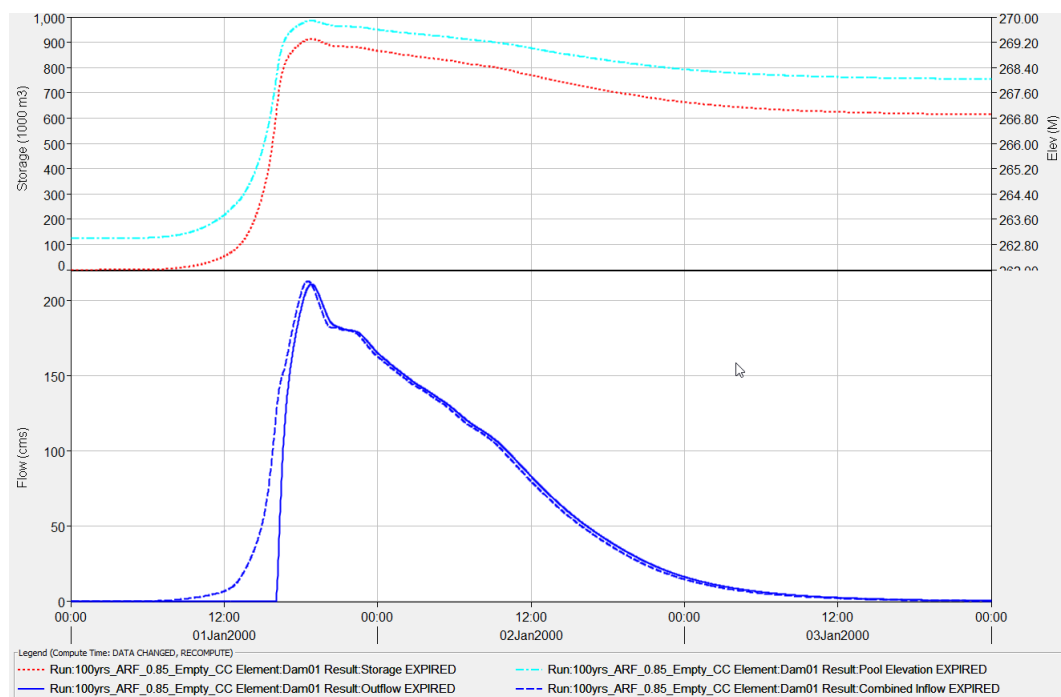


Figure 7.3: Dam 01 flow hydrograph for return period of 100 years + CC

Figure 7.4 shows Ras Ghareb Plot site boundary and hydraulic model boundary conditions BC. Figures 7.5 to 7.12 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.

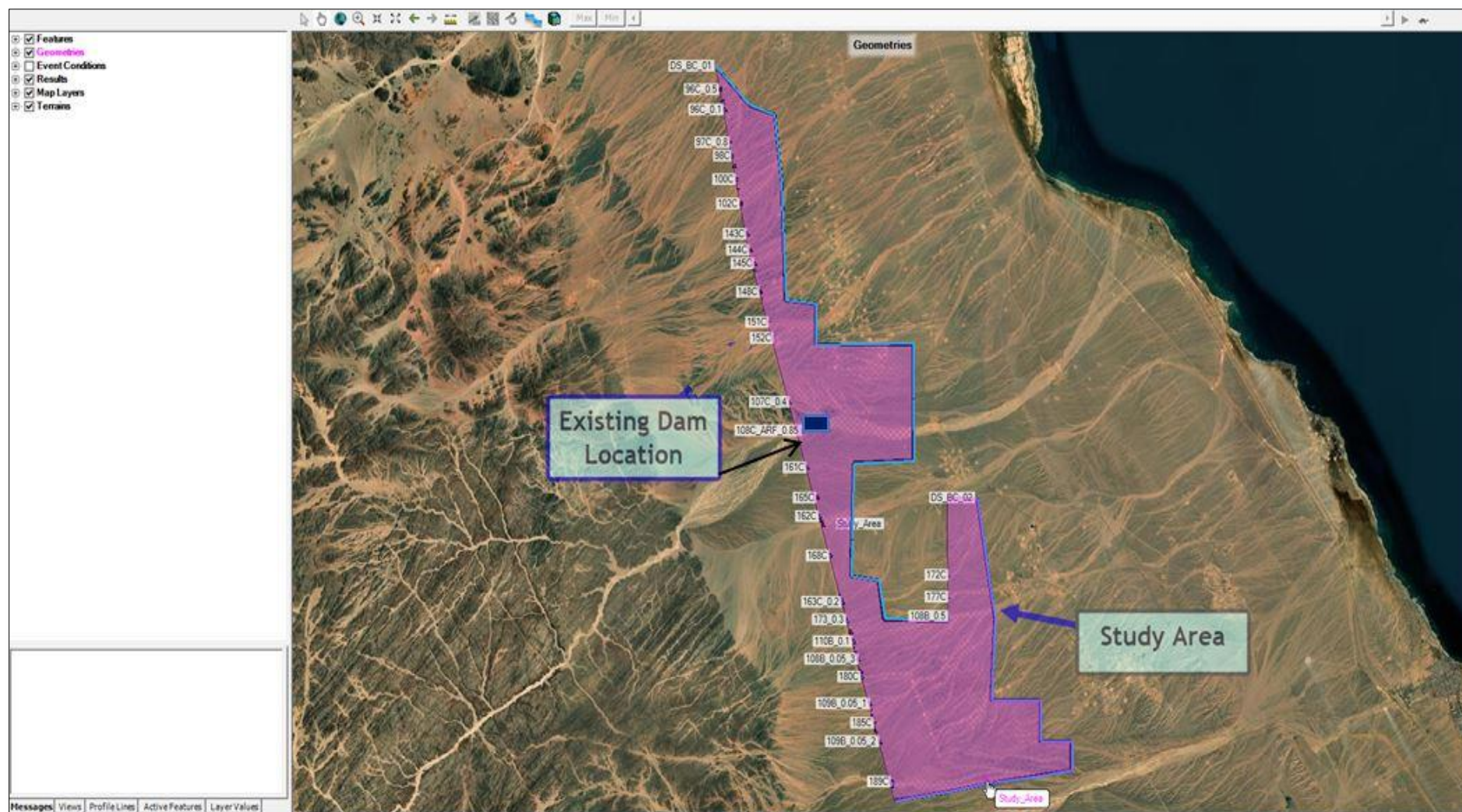


Figure 7.4: Site boundary and hydraulic model boundary conditions (BC)



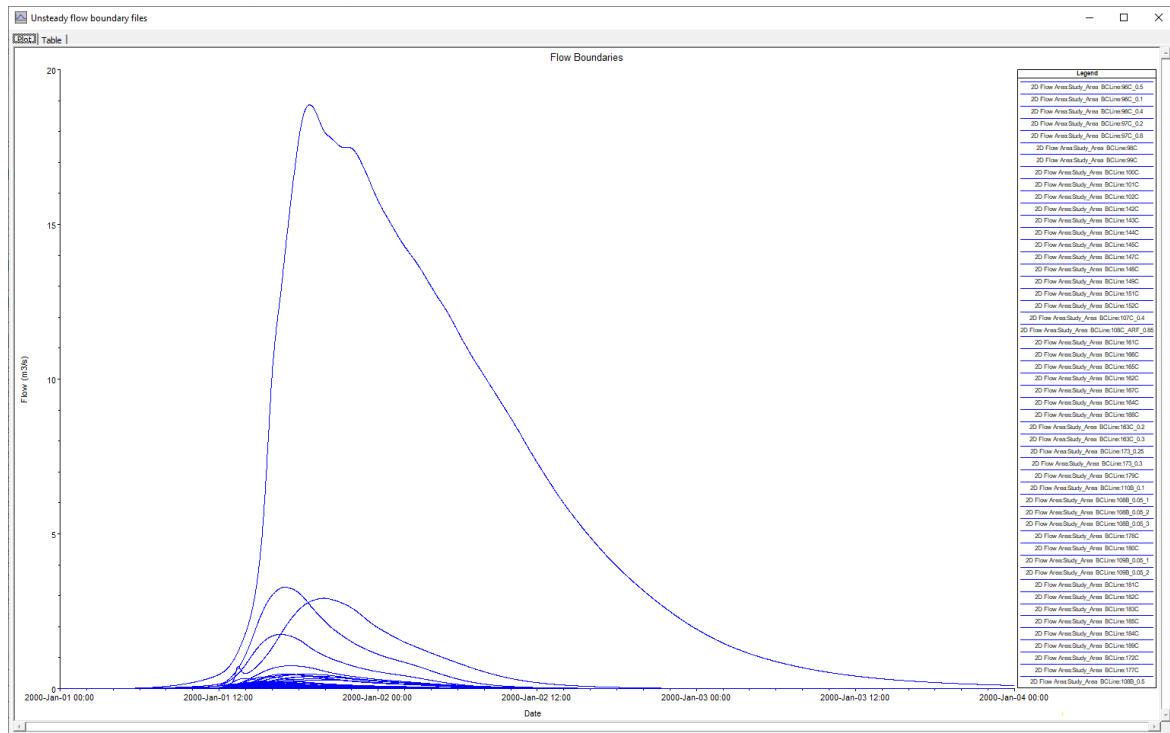


Figure 7.7: Boundary conditions (BC) for return period of 10 years (Hydrographs)

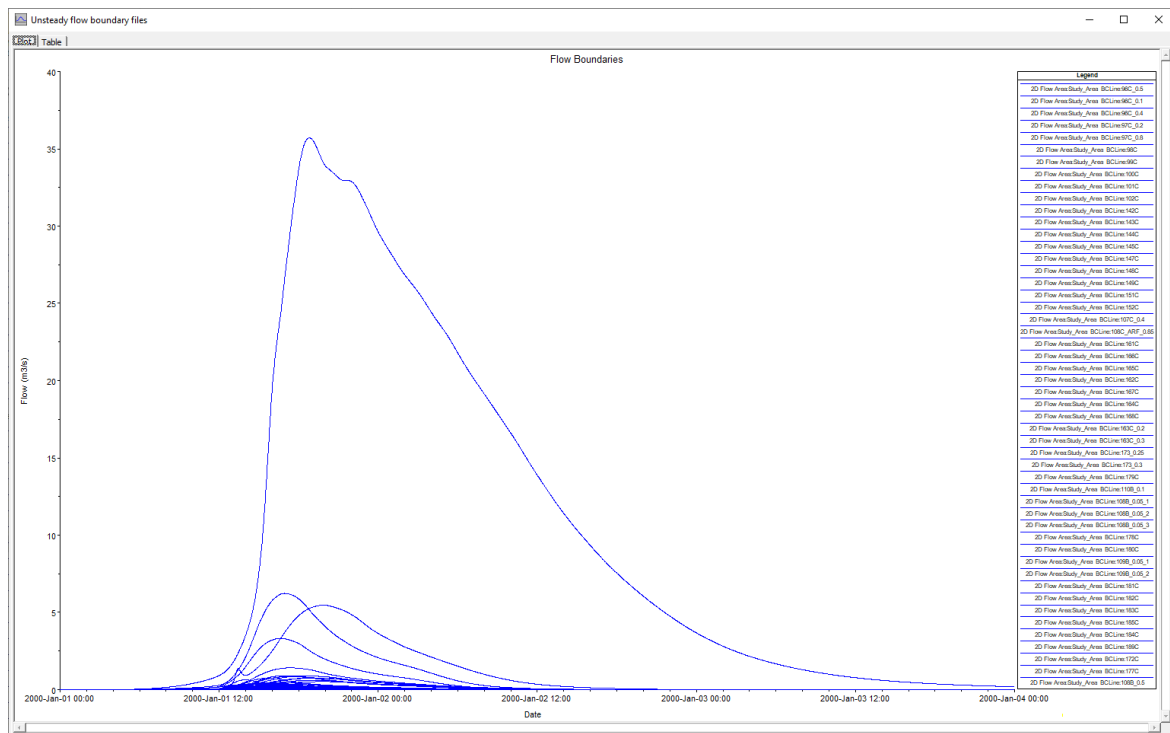
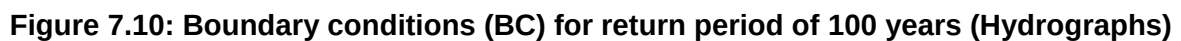


Figure 7.8: Boundary conditions (BC) for return period of 20 years (Hydrographs)



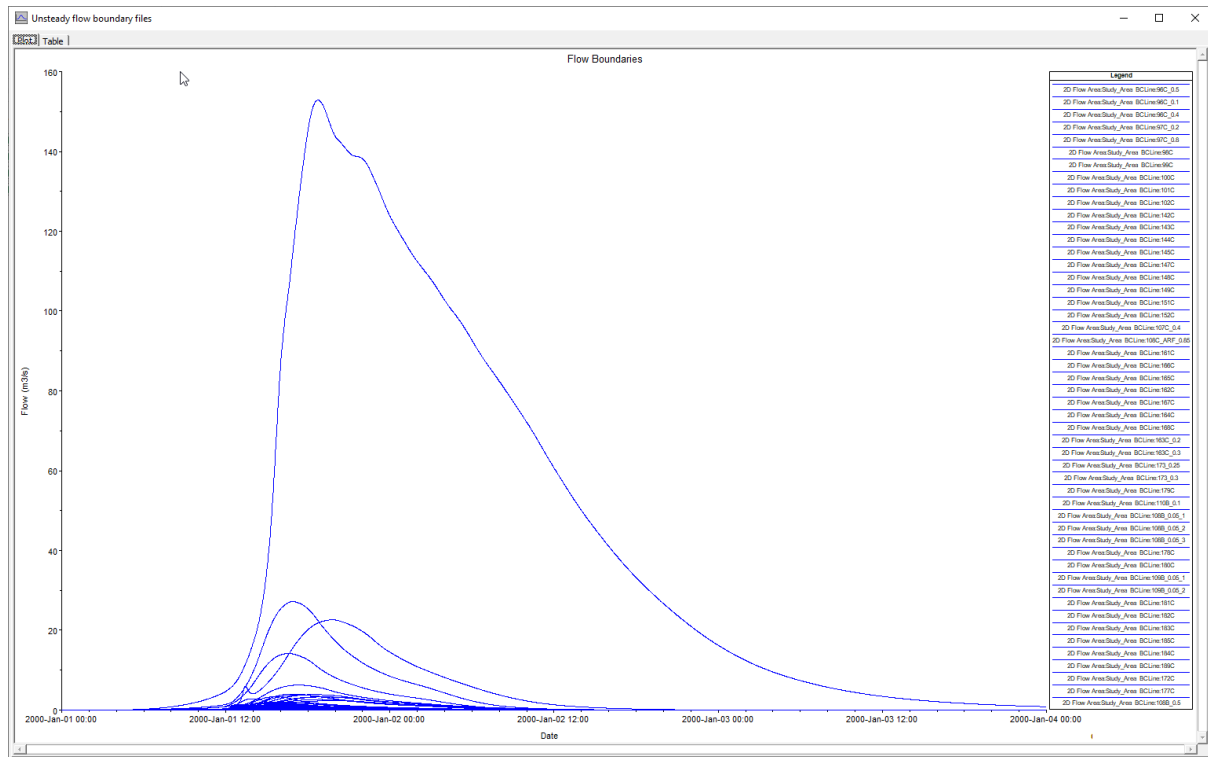


Figure 7.11: Boundary conditions (BC) for return period of 100 years Climate Change (Hydrographs)

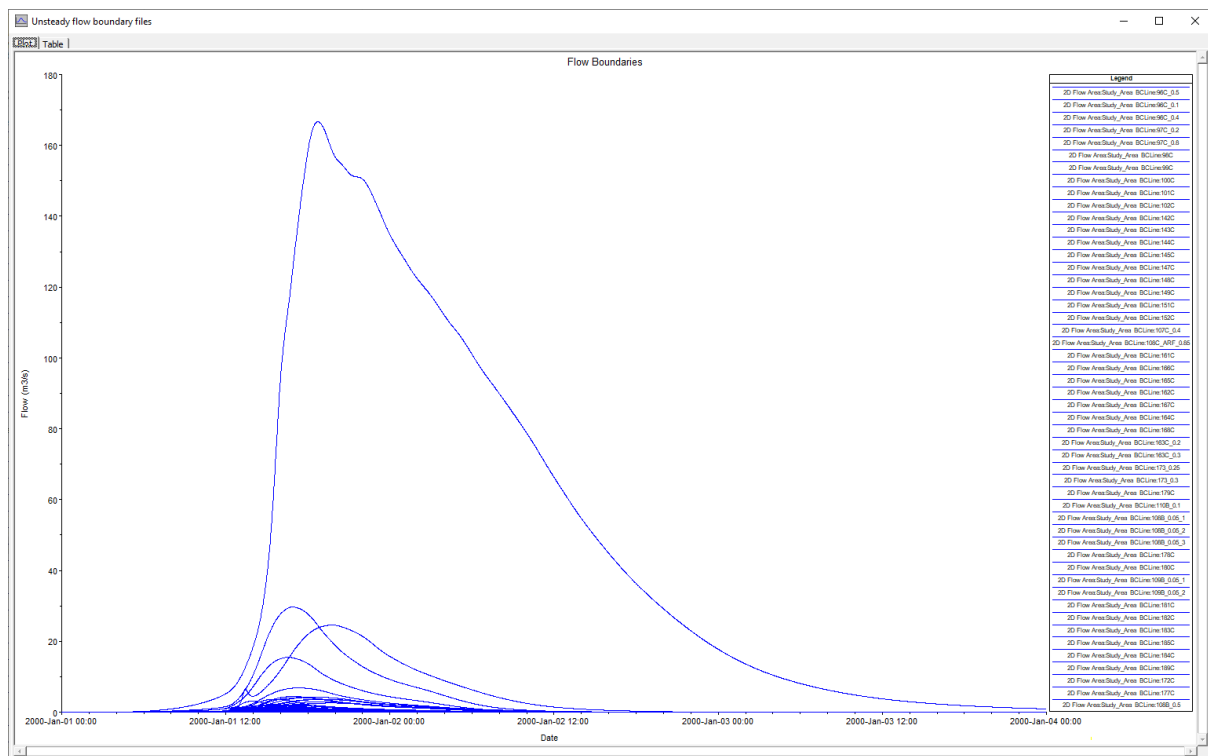


Figure 7.12: Boundary conditions (BC) for return period of 200 years (Hydrographs)

7.3. 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, water depth 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 7.13 shows the run time for each simulation, it ranges from 12 to 15 hrs.

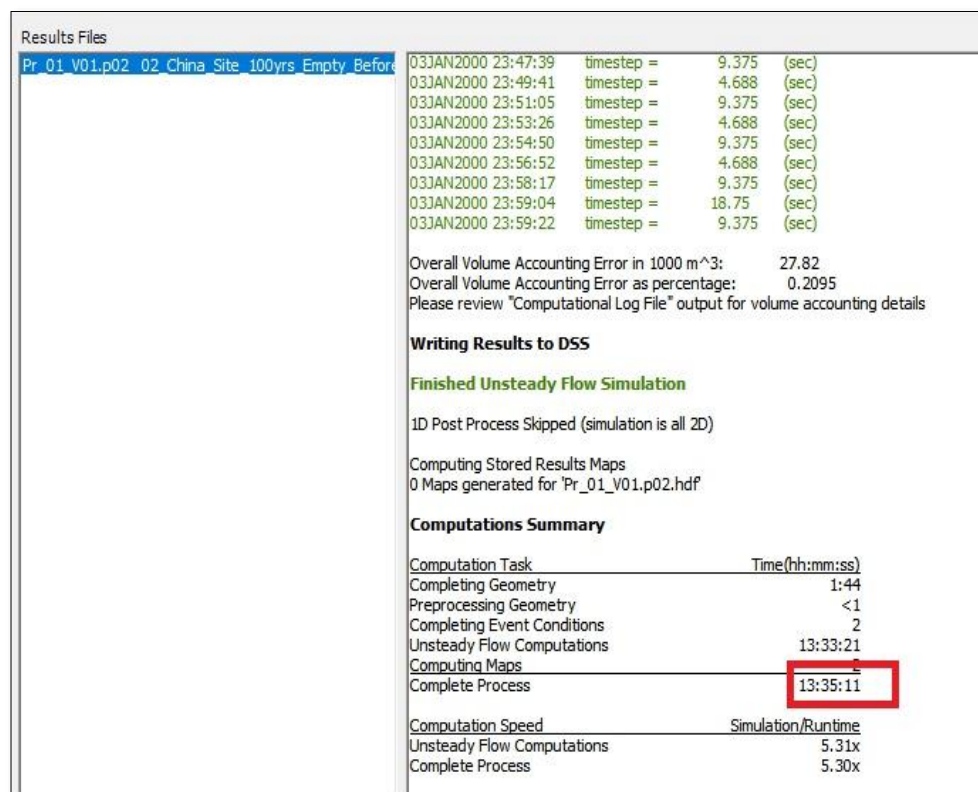


Figure 7.13: Simulation / Run time for each scenario

7.4. 2D Hydraulic Models Outputs

Results of the existing condition simulation are analyzed to examine the effect of the floodplain on structures and internal roads inside the site, assess the risk to them, and propose the necessary protection. Figures 7.14 to 7.21 show the depth maps for the return periods of 2, 5, 10, 20, 50, 100, 100 + CC, 200 years; respectively. On the other hand, Figures 7.22 to 7.29 show the velocity maps for the same return periods; respectively.

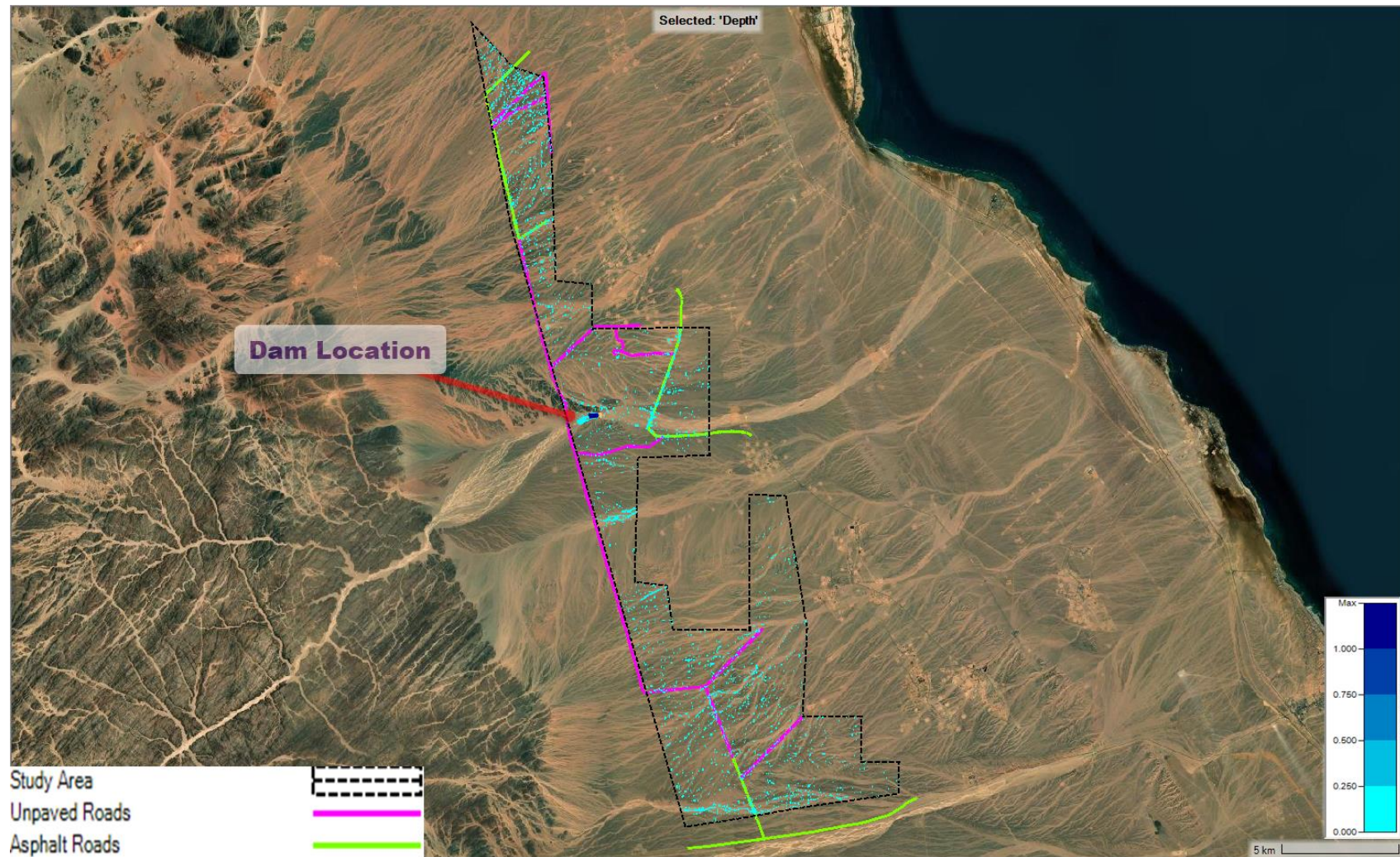


Figure 7.14: Depth map for return period of 2 years

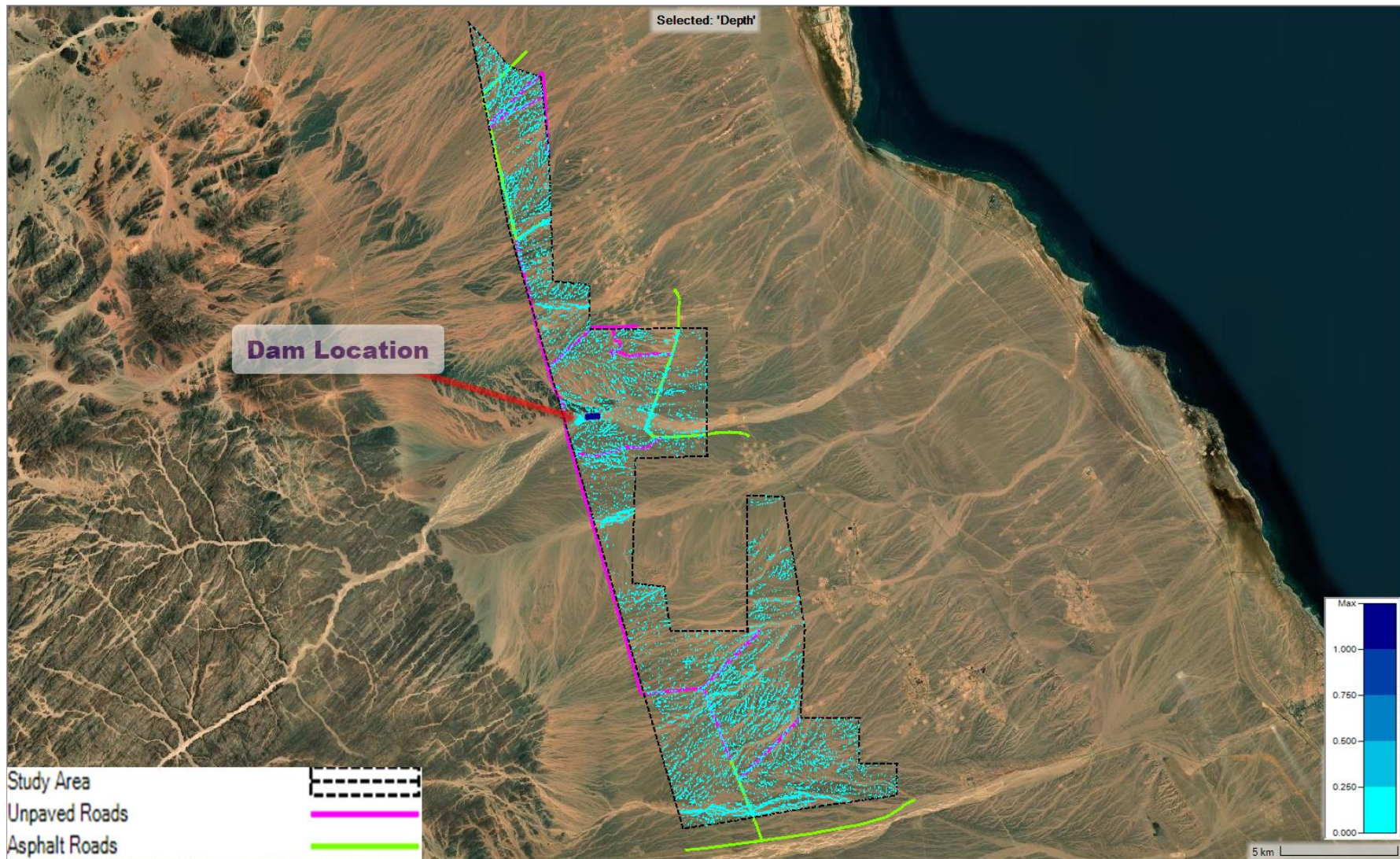


Figure 7.15: Depth map for return period of 5 years

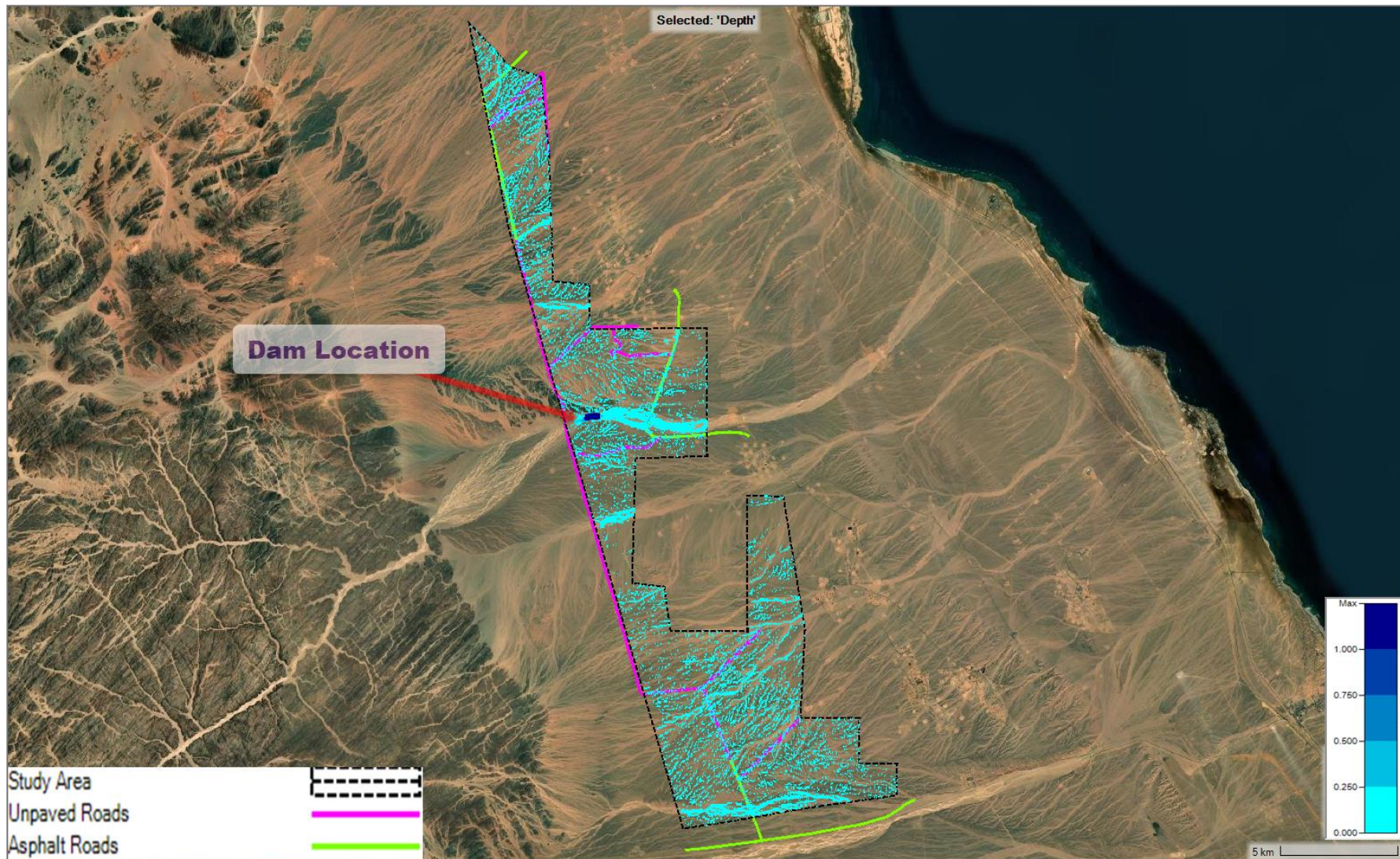


Figure 7.16: Depth map for return period of 10 years

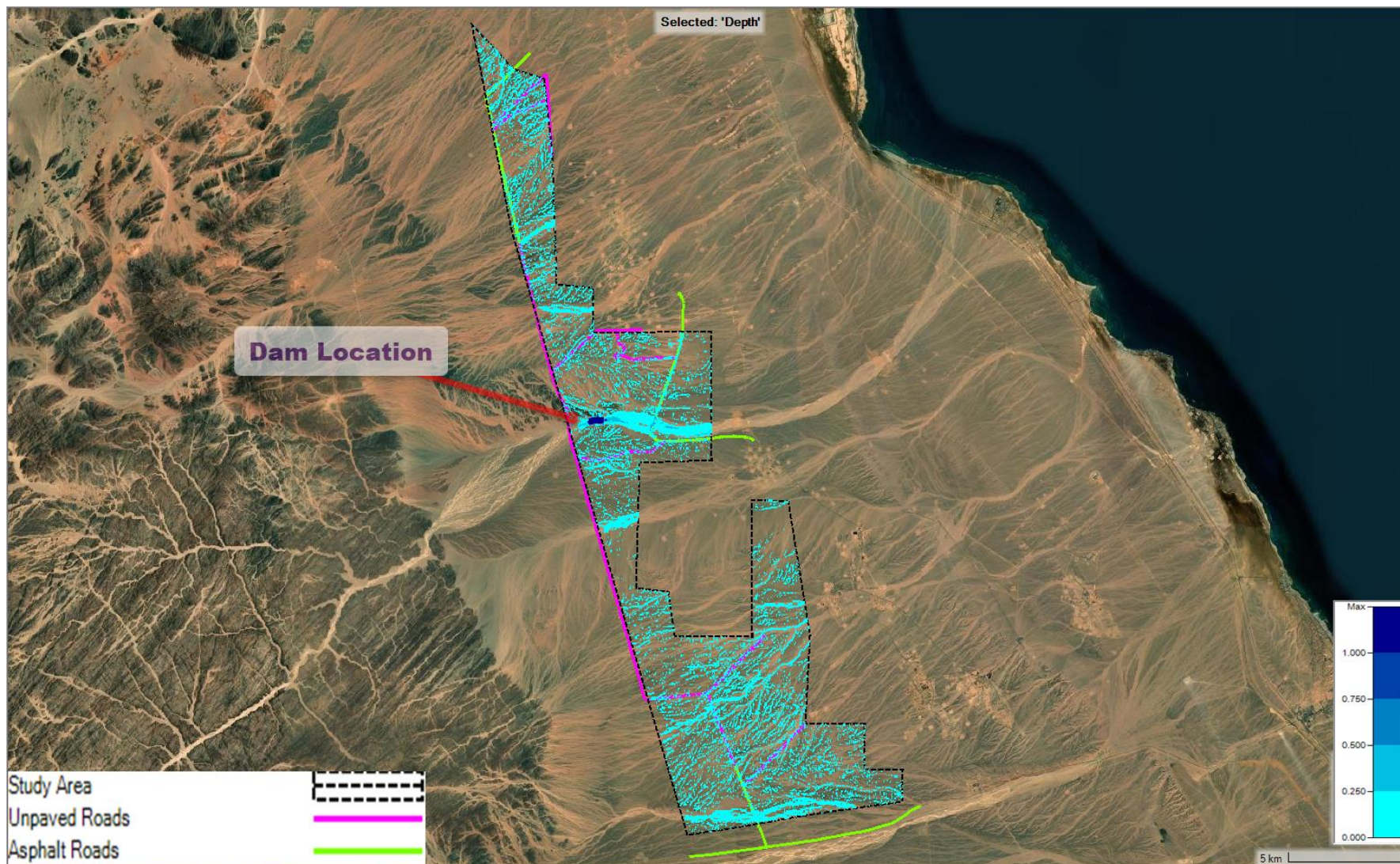


Figure 7.17: Depth map for return period of 20 years

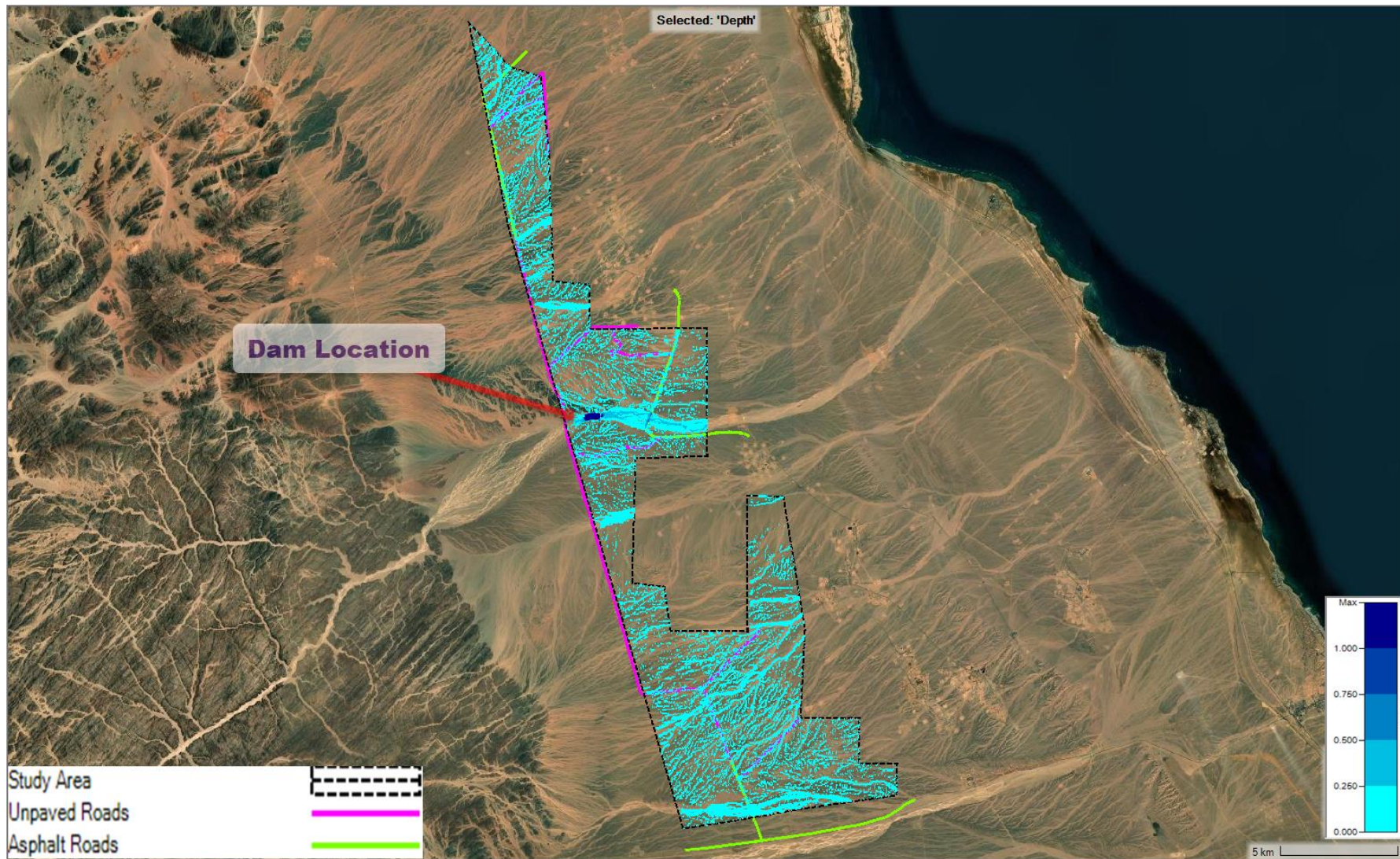


Figure 7.18: Depth map for return period of 50 years

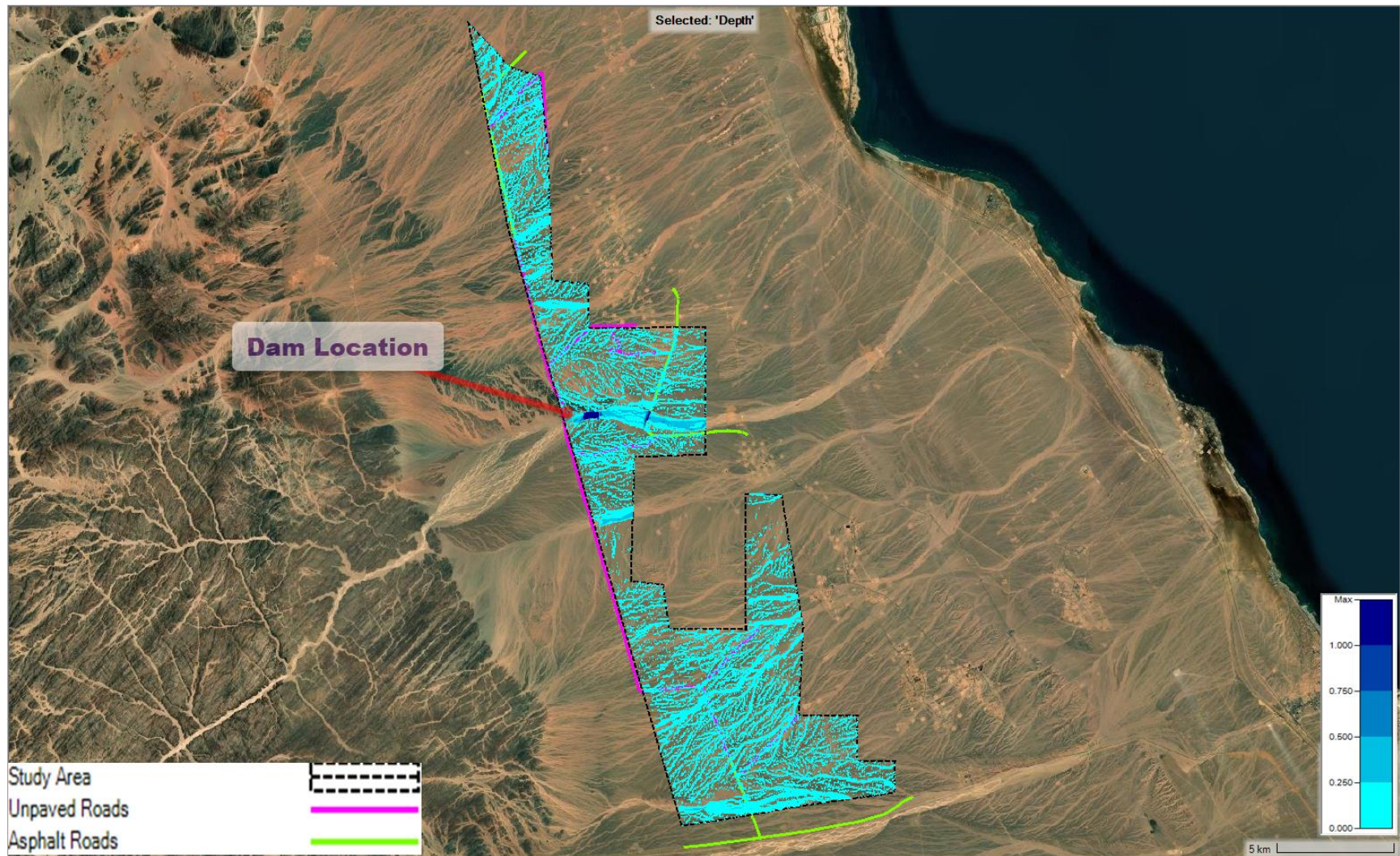


Figure 7.19: Depth map for return period of 100 years

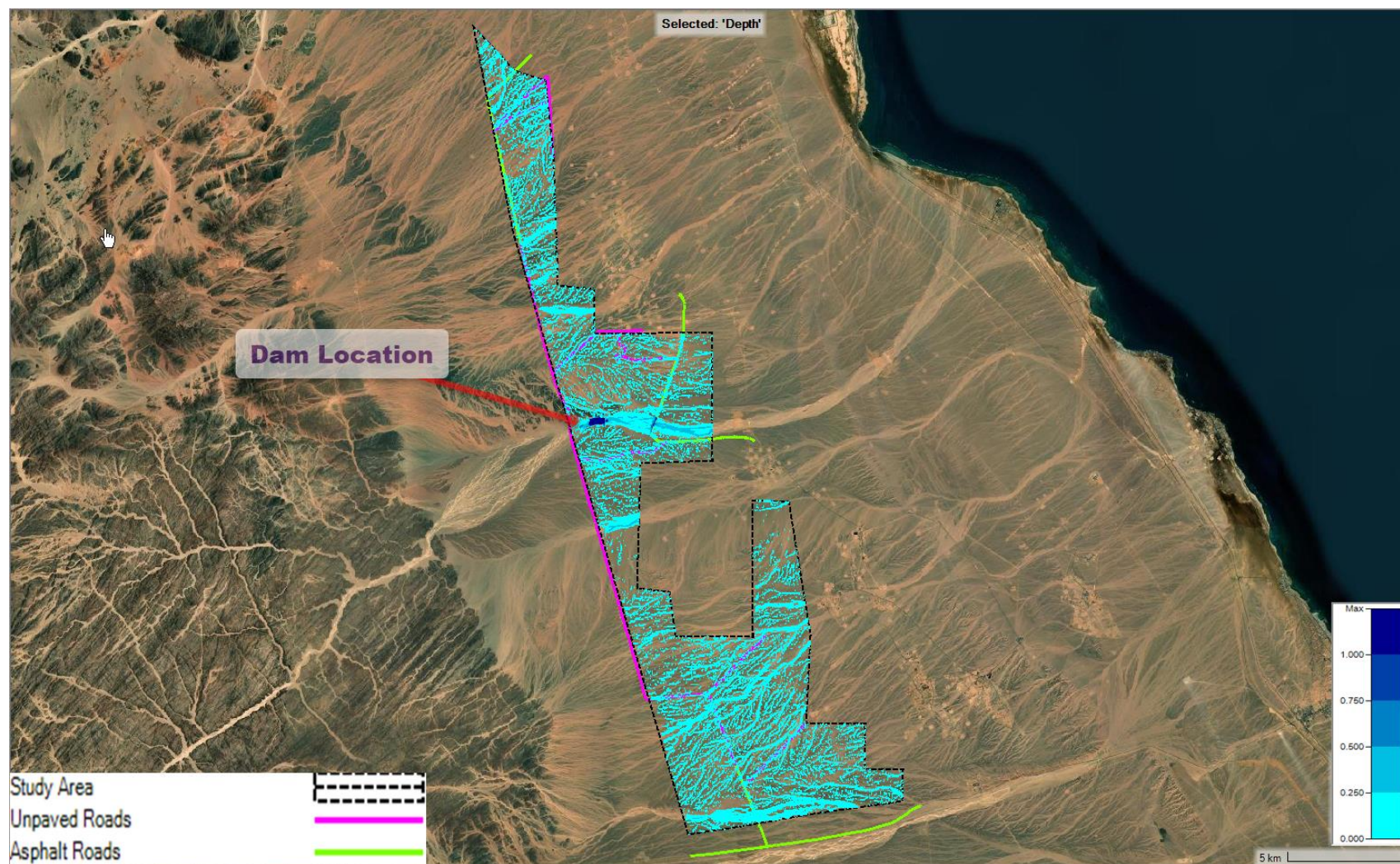


Figure 7.20: Depth map for return period of 100 years taking climate change into consideration

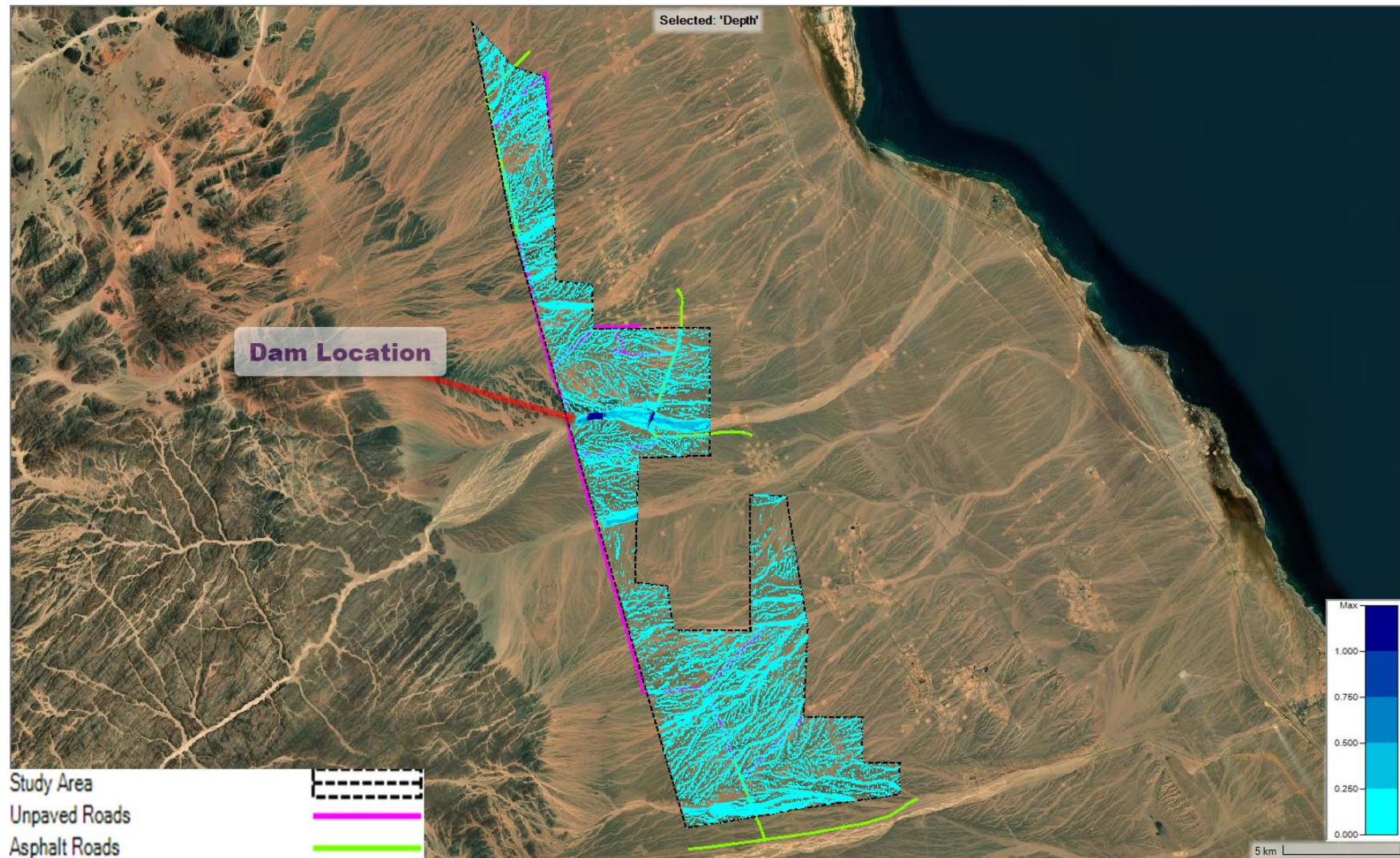


Figure 7.21: Depth map for return period of 200 years

- *Velocity Maps*

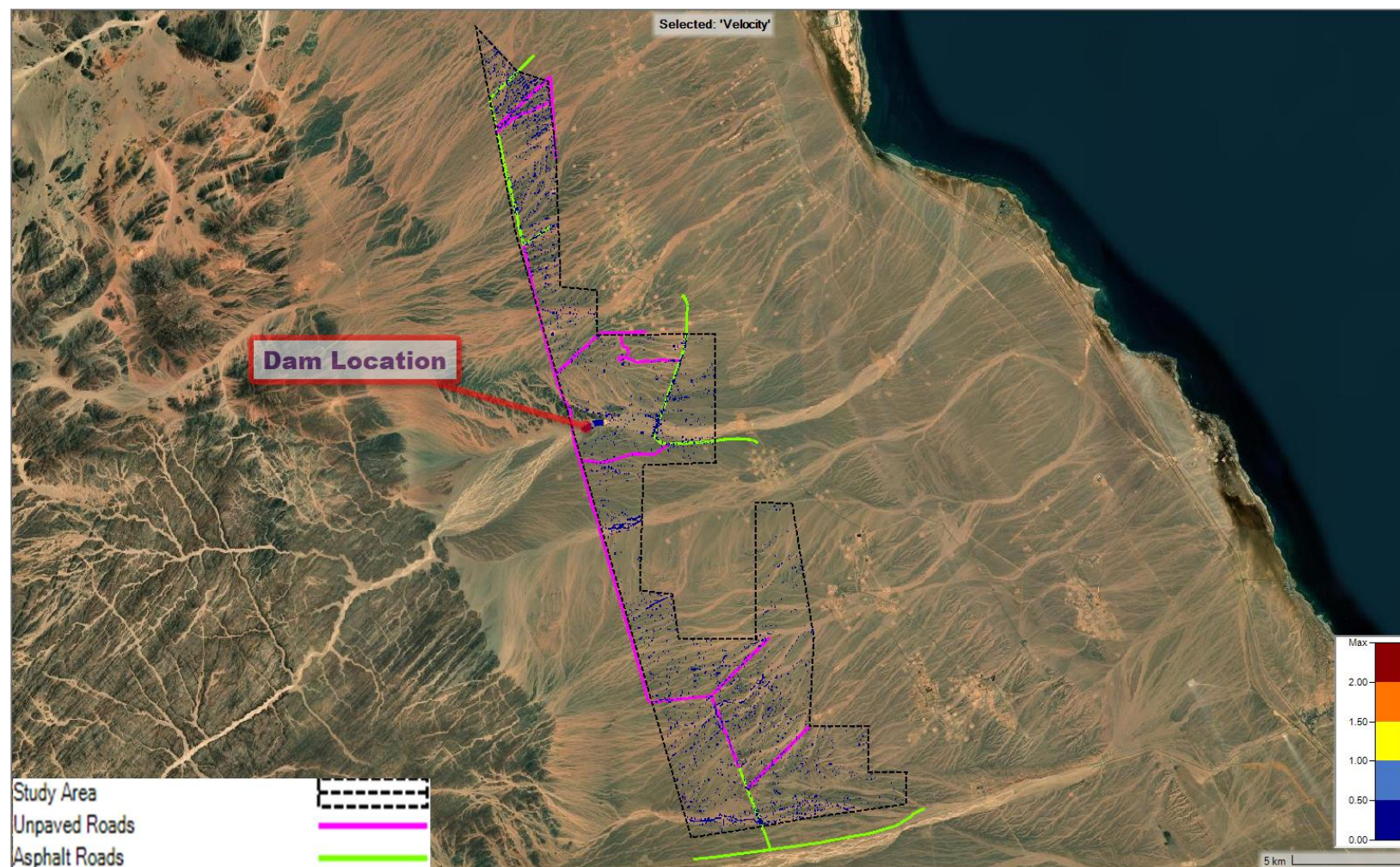


Figure 7.22: Velocity map for return period of 2 years

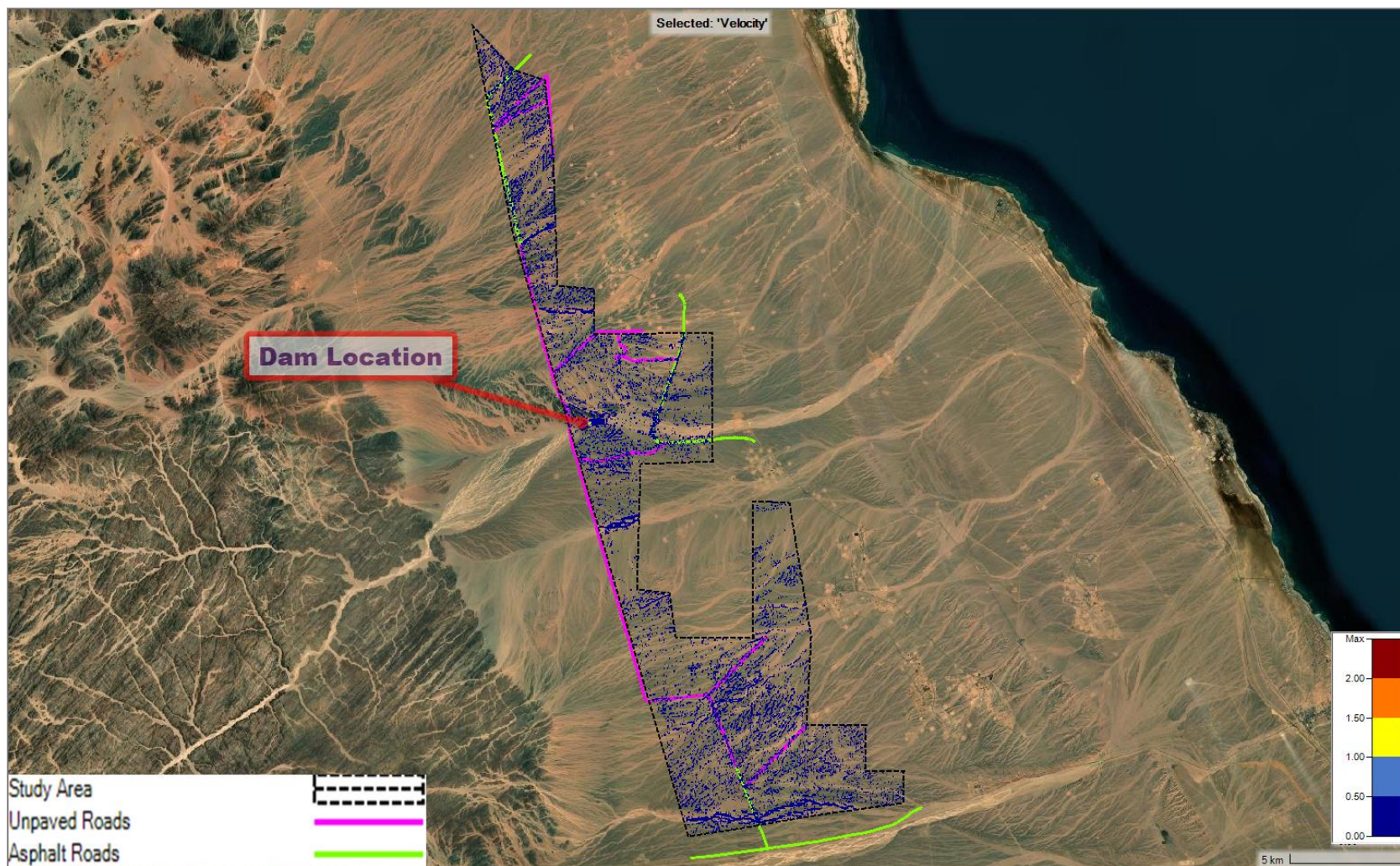


Figure 7.23: Velocity map for return period of 5 years

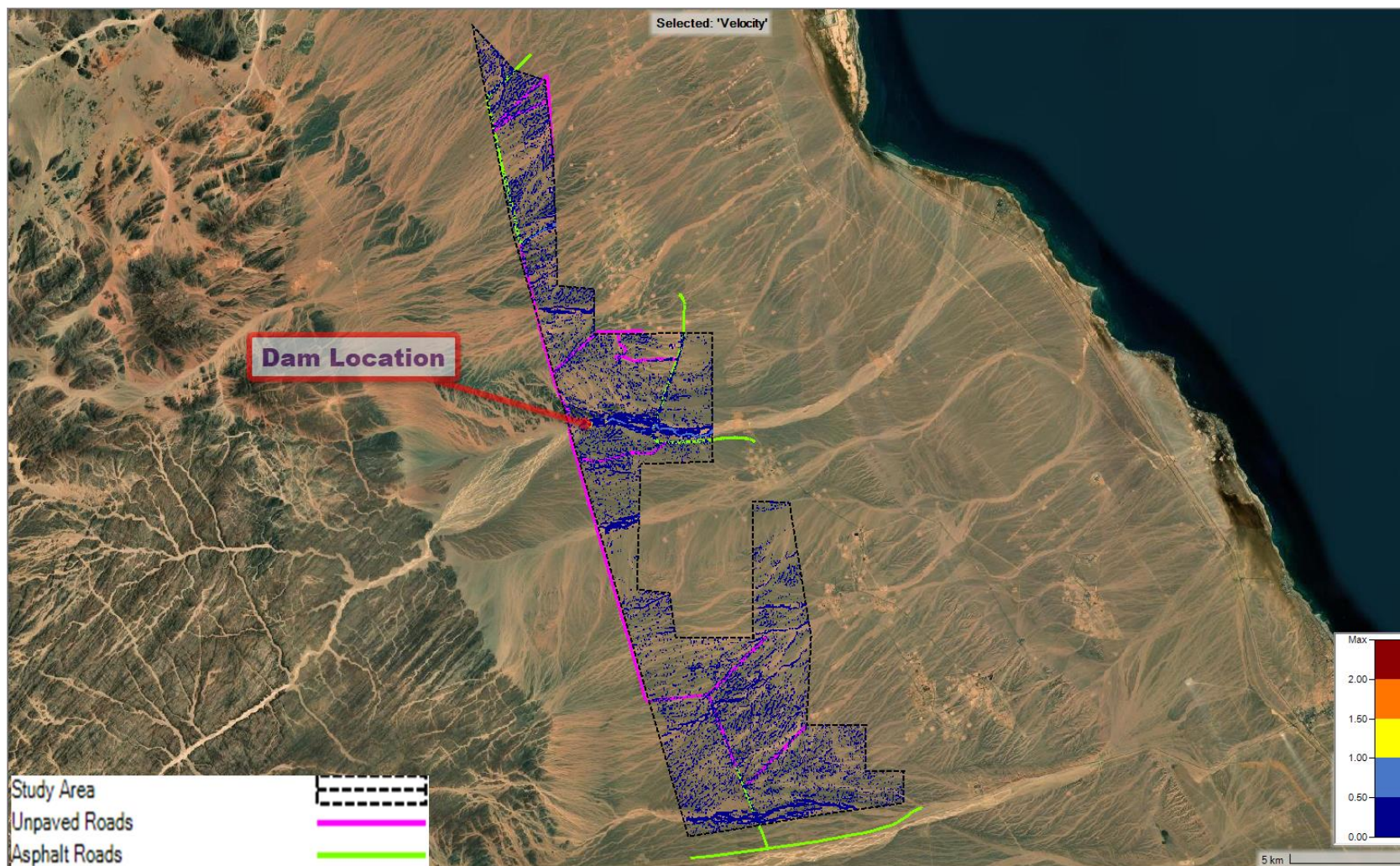


Figure 7.24: Velocity map for return period of 10 years

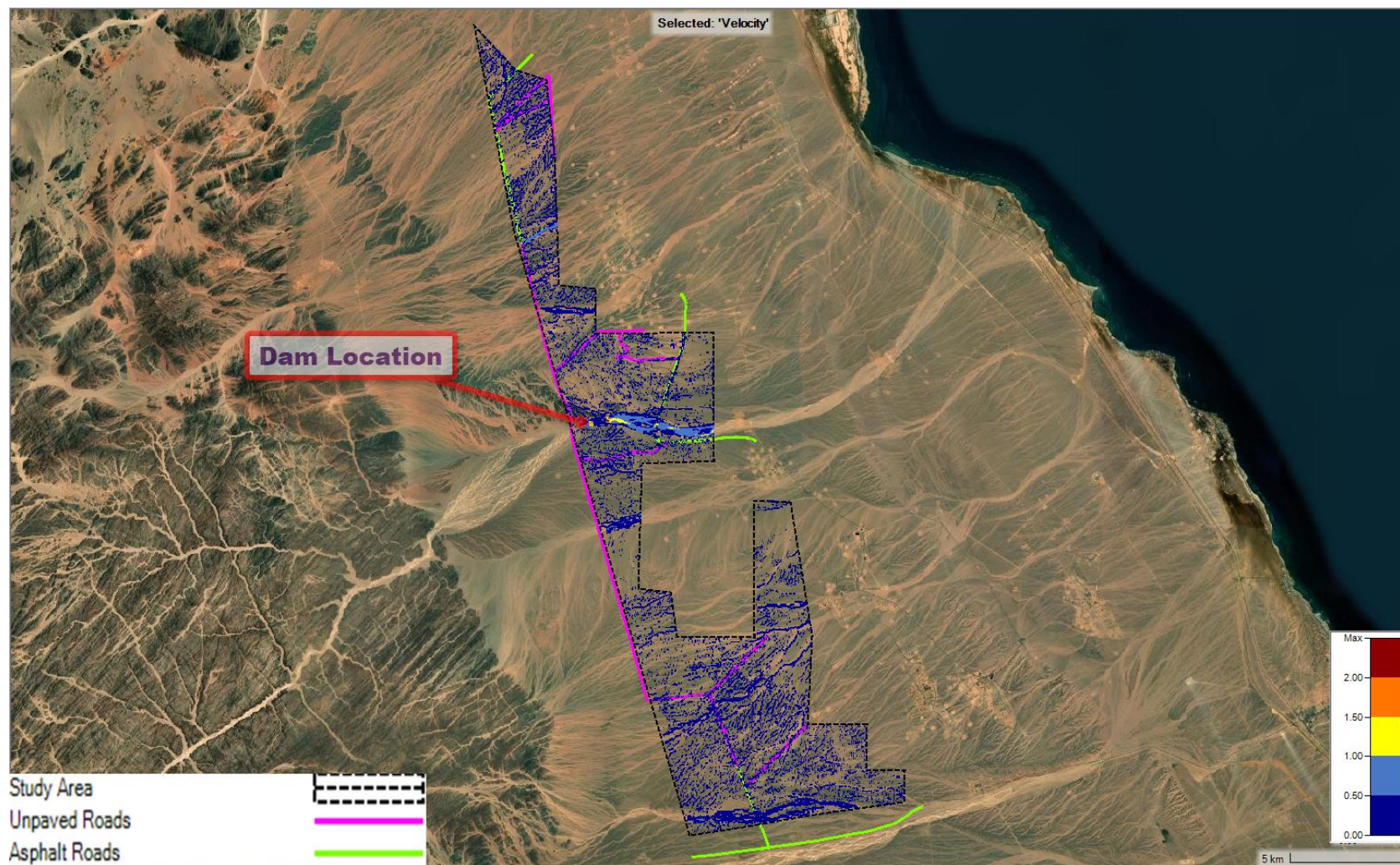


Figure 7.25: Velocity map for return period of 20 years

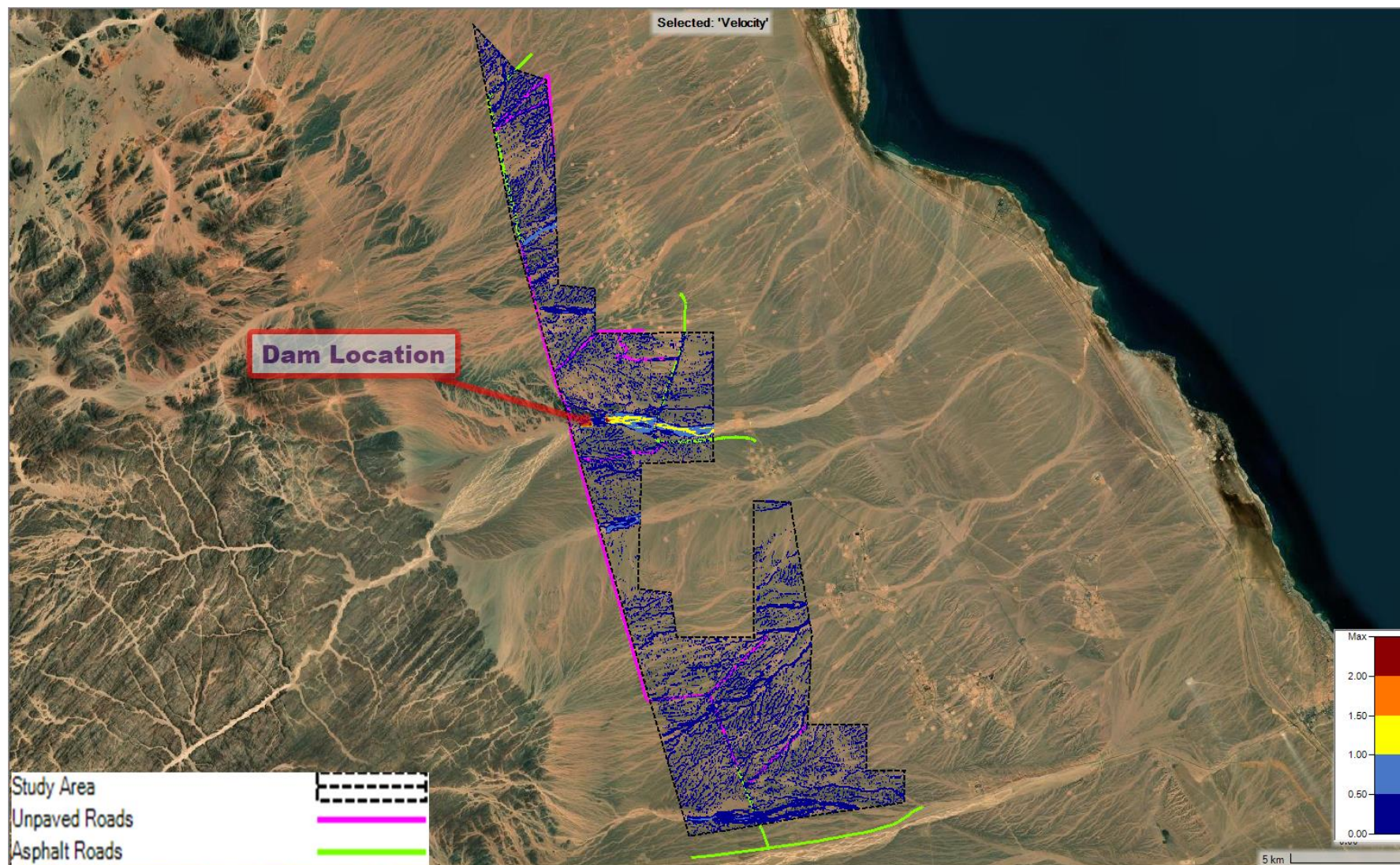


Figure 7.26: Velocity map for return period of 50 years

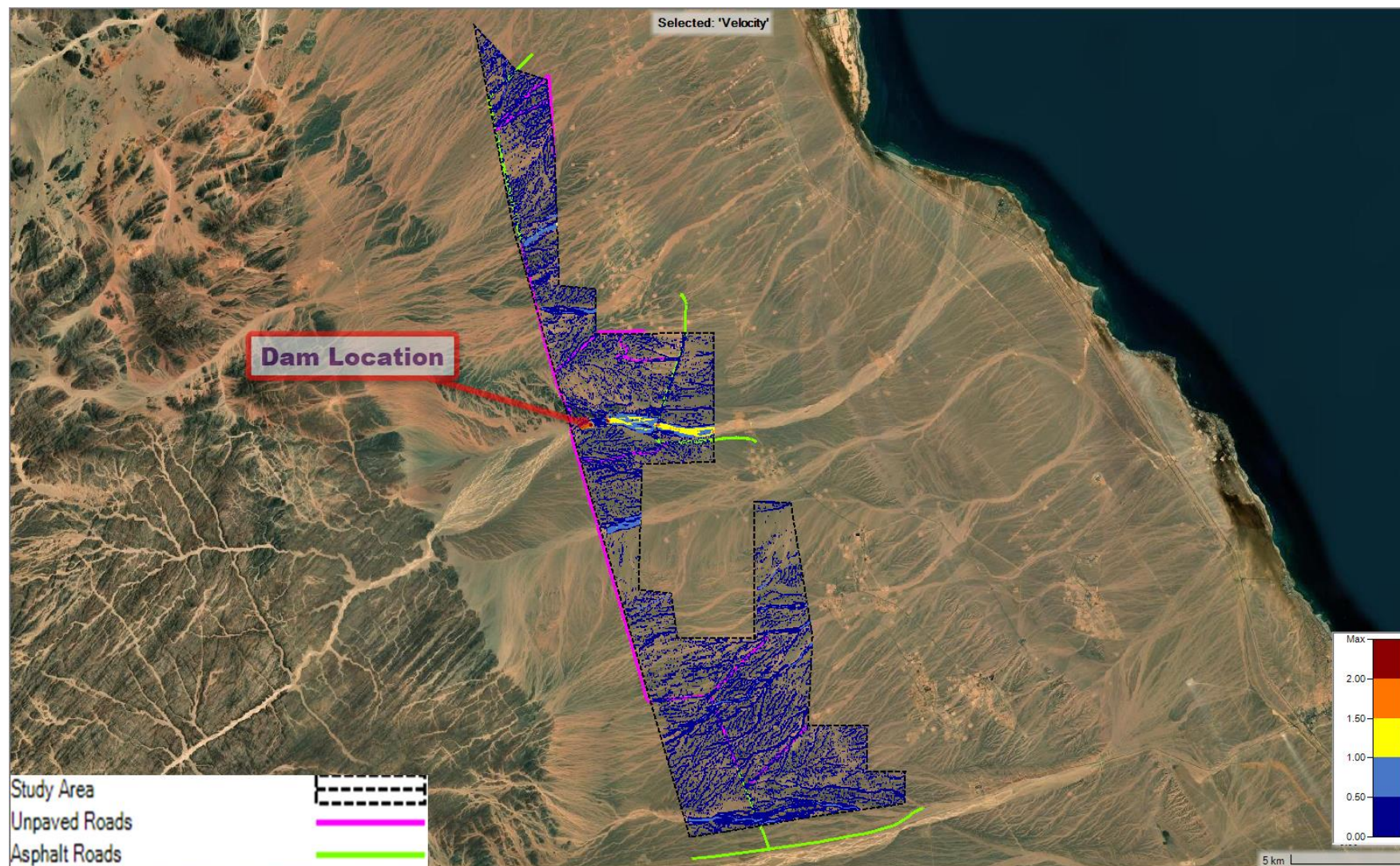


Figure 7.27: Velocity map for return period of 100 years

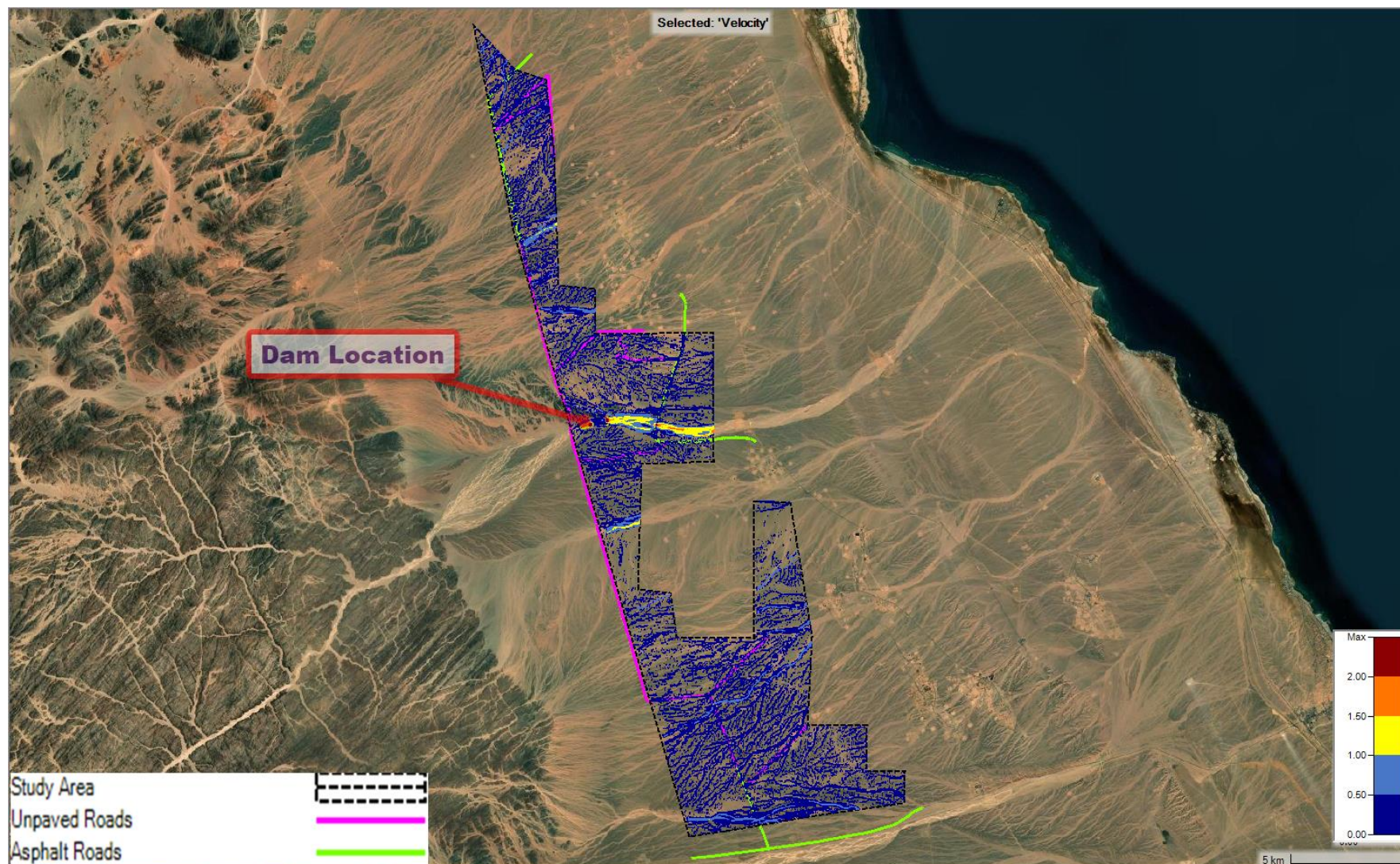


Figure 7.28: Velocity map for return period of 100 years taking climate change into consideration

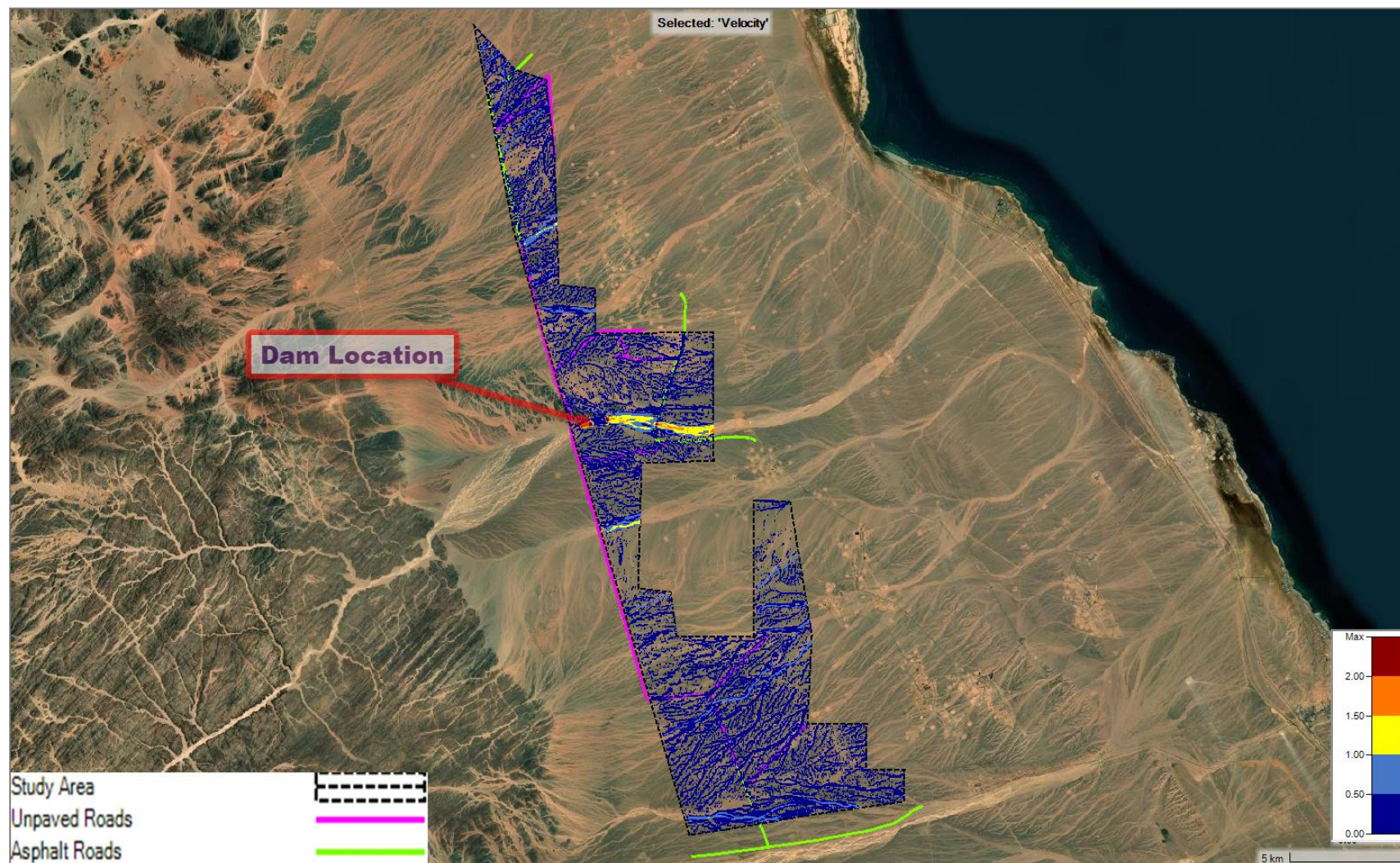


Figure 7.29: Velocity map for return period of 200 years

Figures 7.14 to 7.21 indicate that the flood depth for each return period is as follows:

- For the 2-year return period, flood depth ranges from 0 to 0.04 m.
- For the 5-year return period, flood depth ranges from 0 to 0.05 m.
- For the 10-year return period, flood depth ranges from 0 to 0.20 m.
- For the 20-year return period, flood depth ranges from 0 to 0.35 m.
- For the 50-year return period, flood depth ranges from 0 to 0.50 m.
- For the 100-year return period, flood depth ranges from 0 to 0.60 m.
- For the return period of 100 year + CC, flood depth ranges from 0 to 0.65 m
- For the 200-year return period, flood depth ranges from 0 to 0.75 m.

7.5. Flood Risk Assessment

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:

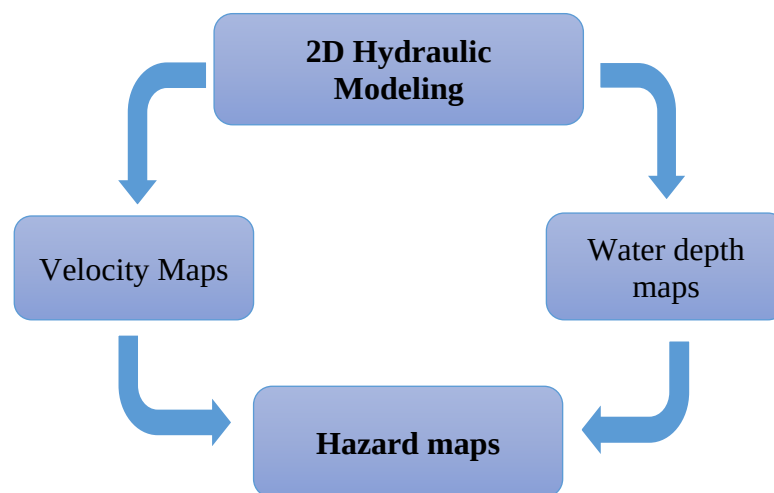


Figure 7.30: Methodology used to derive flood risk maps

- 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:

$$HR = D * (V + 0.5) + DF \quad (7-1)$$

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 7.2: . Then the classification of hazards is concluded as shown in Table 7.3, while Figures 7.31 to 7.38 show the hazard maps for return periods from 2 to 200 years.

Table 7.2: 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 7.3: 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

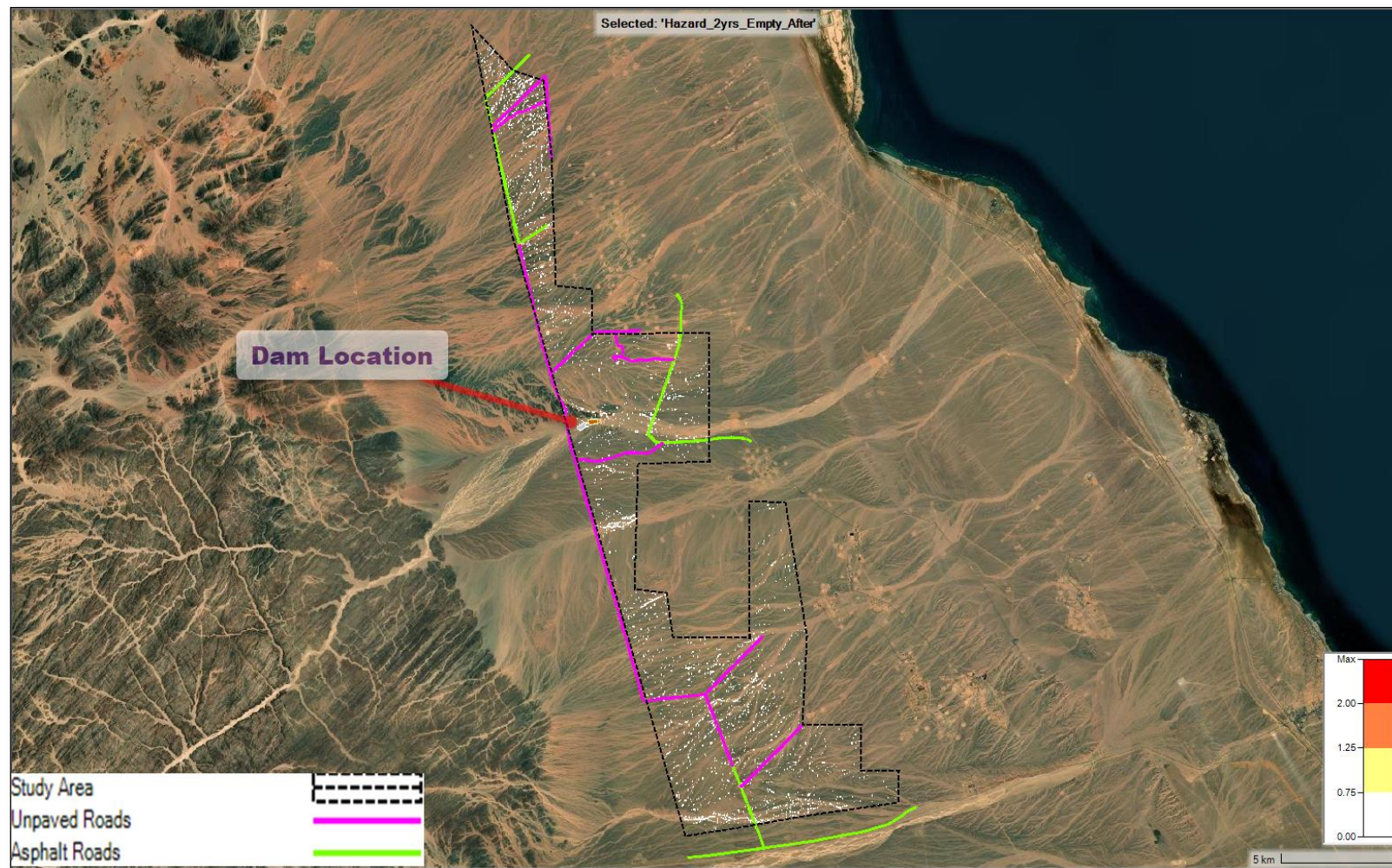


Figure 7.31: Hazard map for return period of 2 years

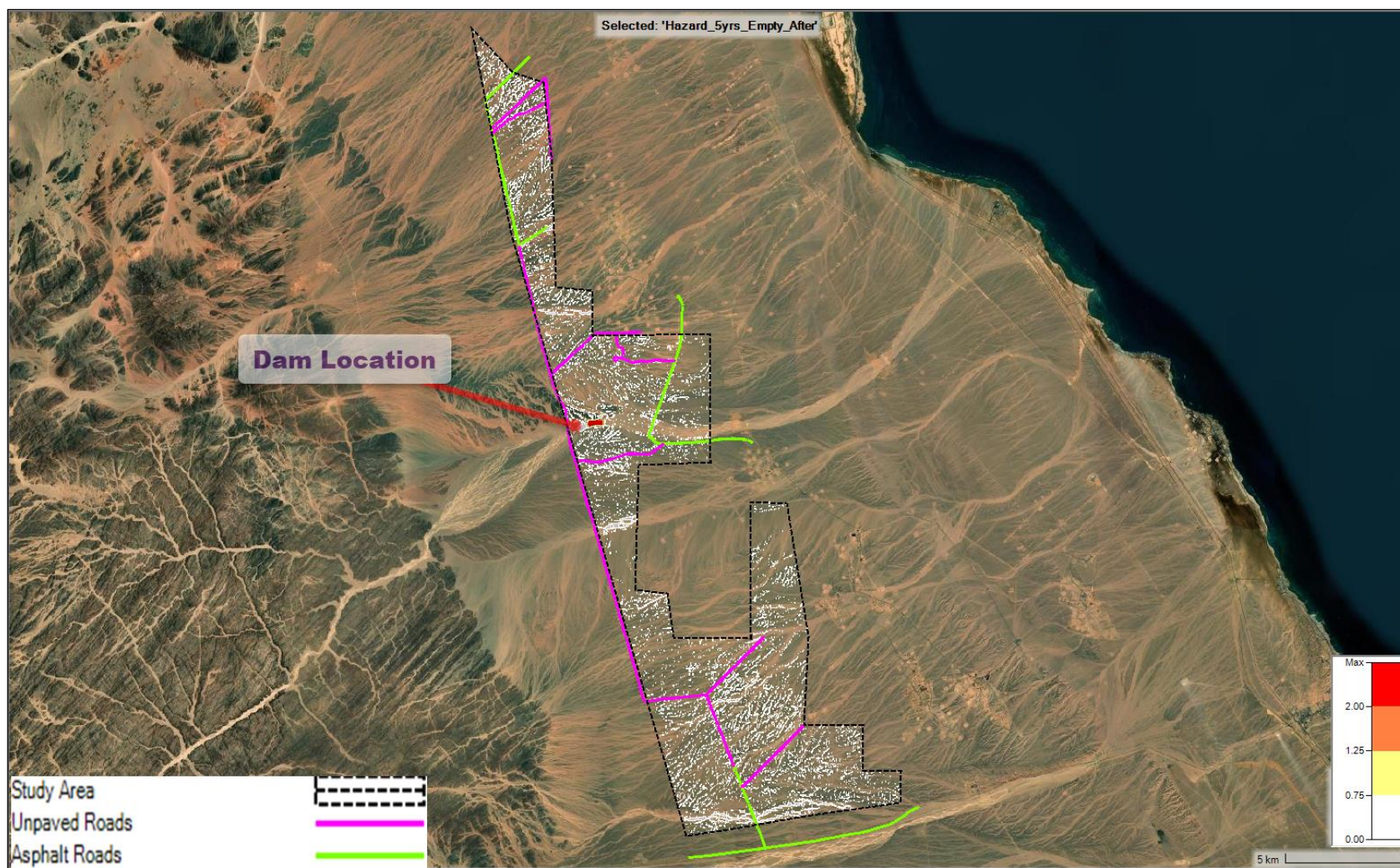


Figure 7.32: Hazard map for return period of 5 years

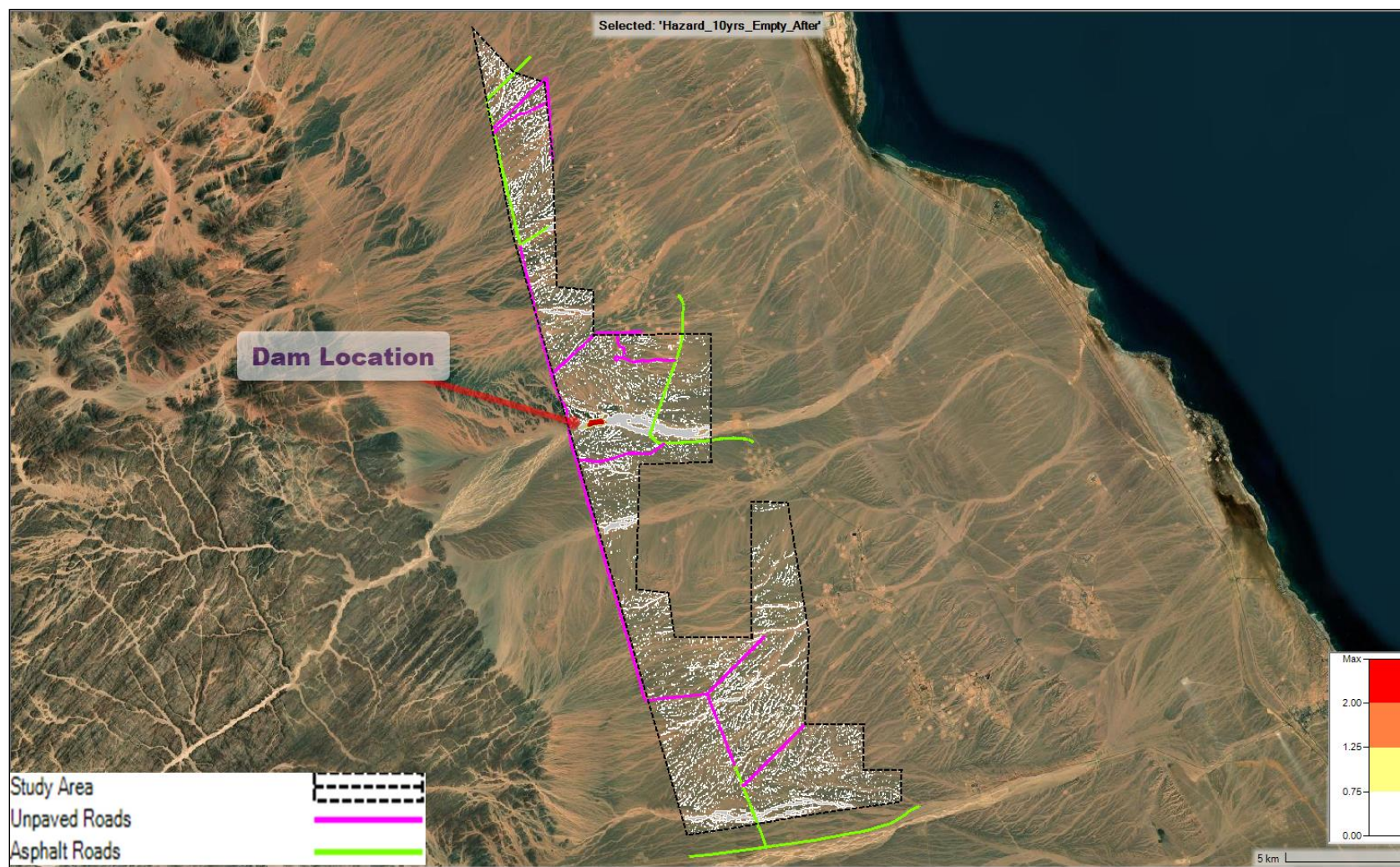


Figure 7.33: Hazard map for return period of 10 years

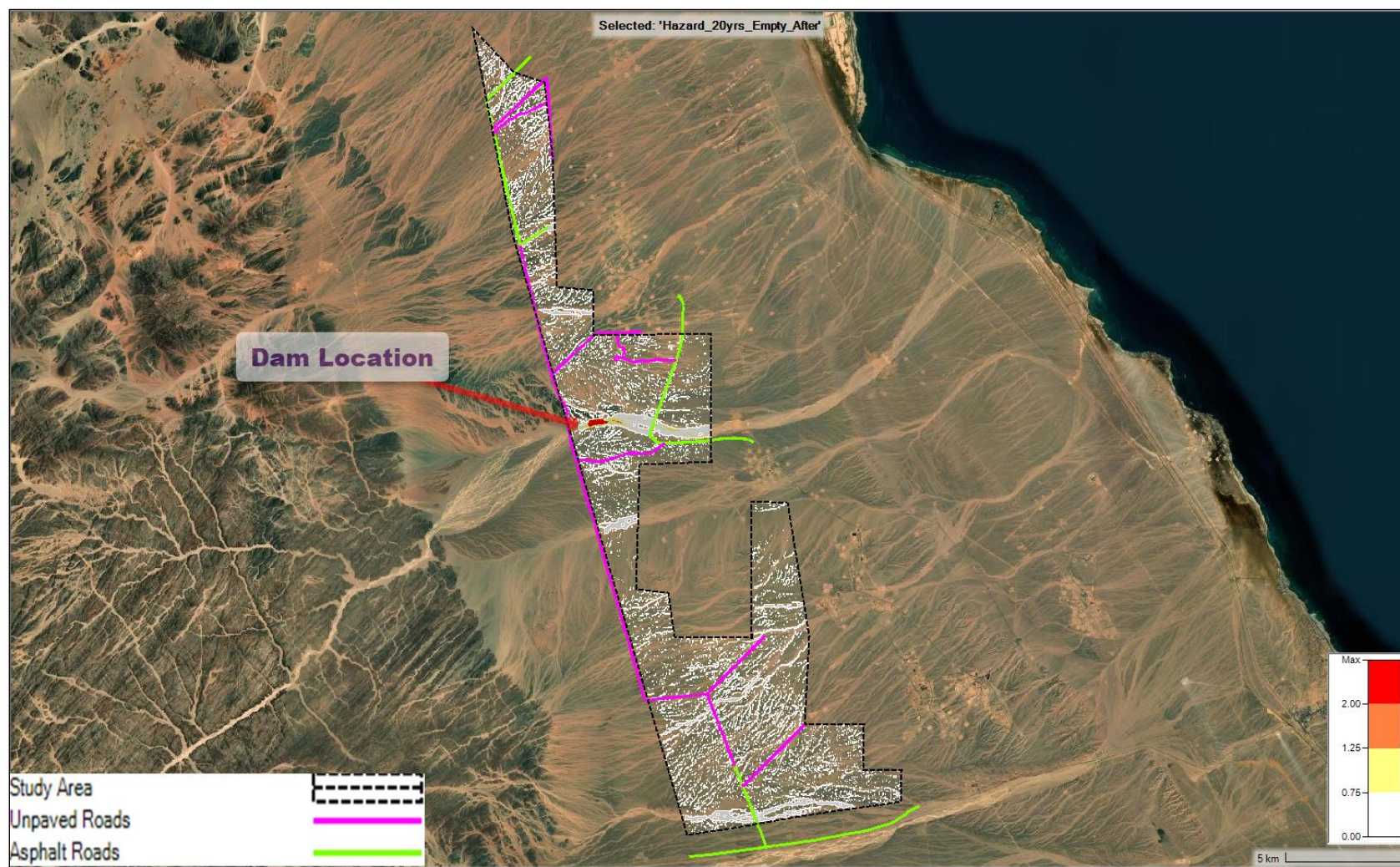


Figure 7.34: Hazard map for return period of 20 years

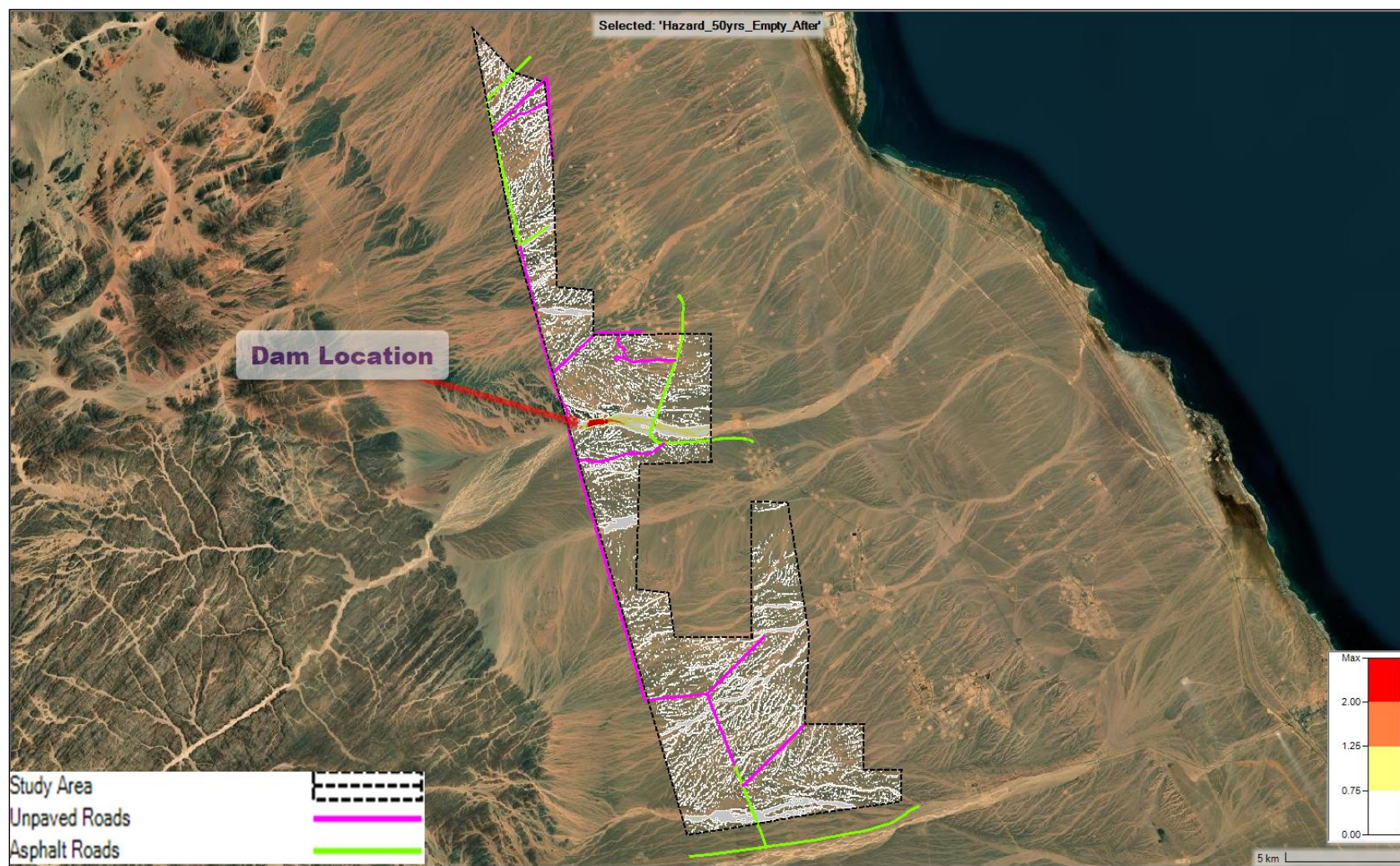


Figure 7.35: Hazard map for return period of 50 years

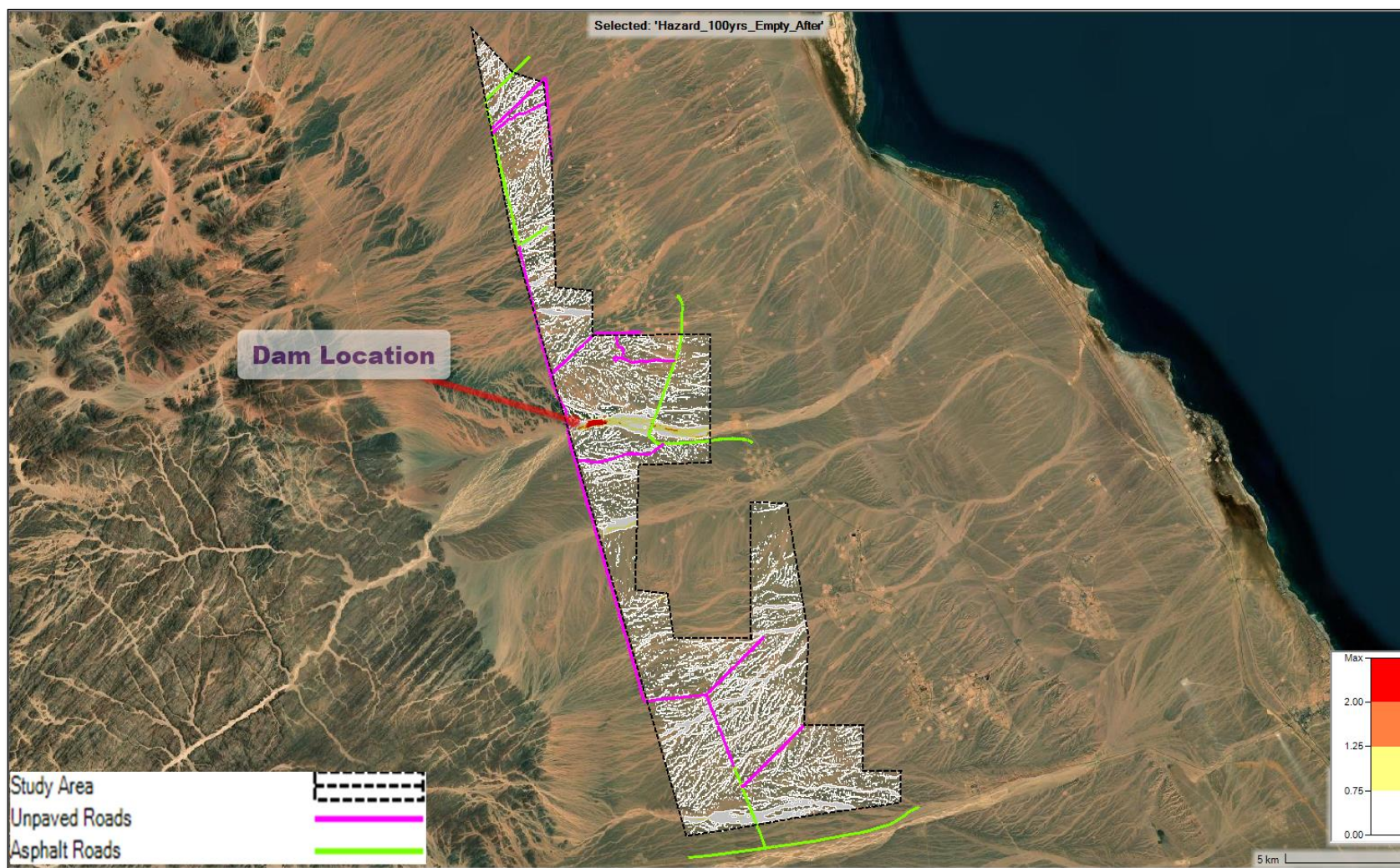


Figure 7.36: Hazard map for return period of 100 years

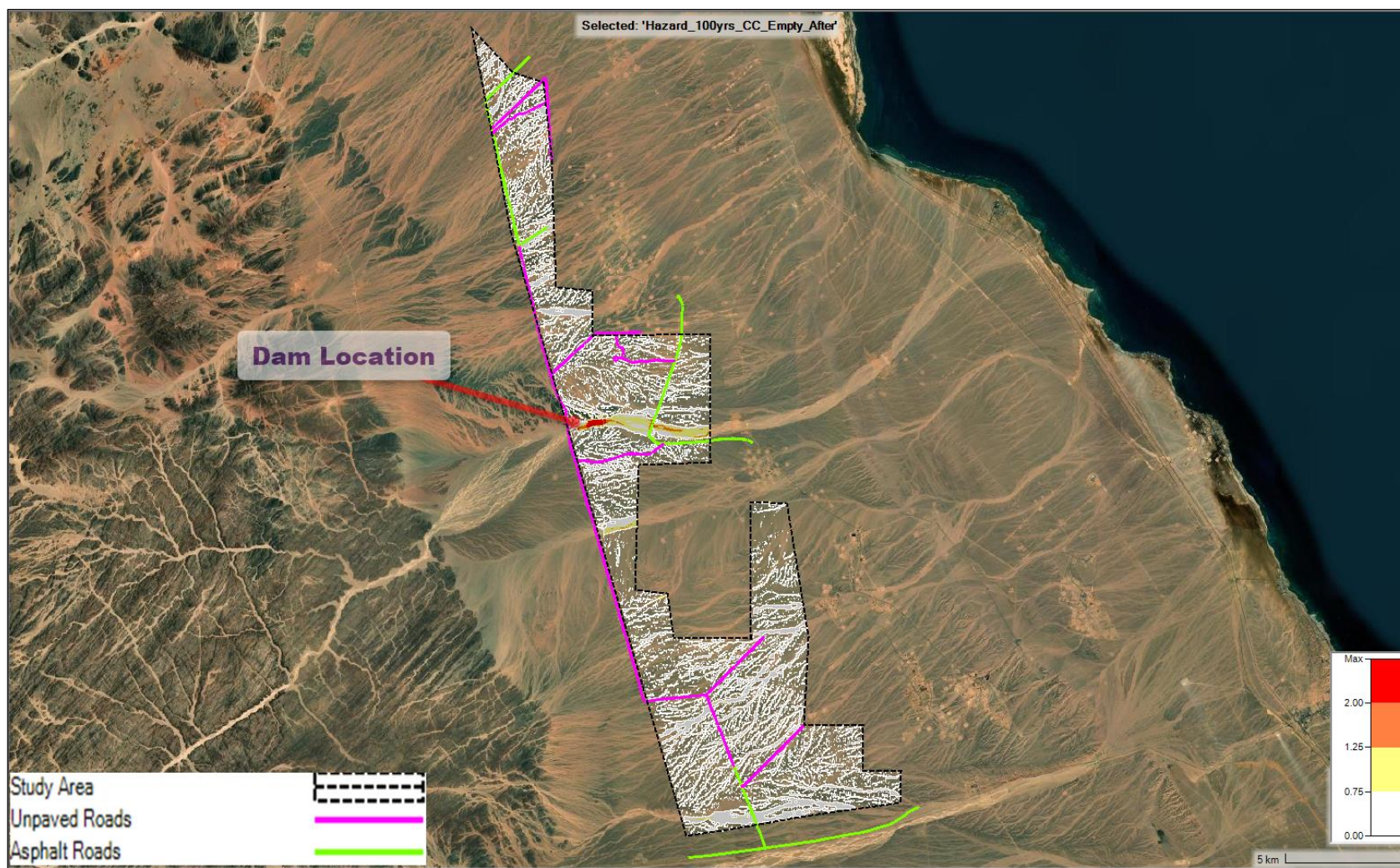


Figure 7.37: Hazard map for return period of 100 years taking climate change into consideration

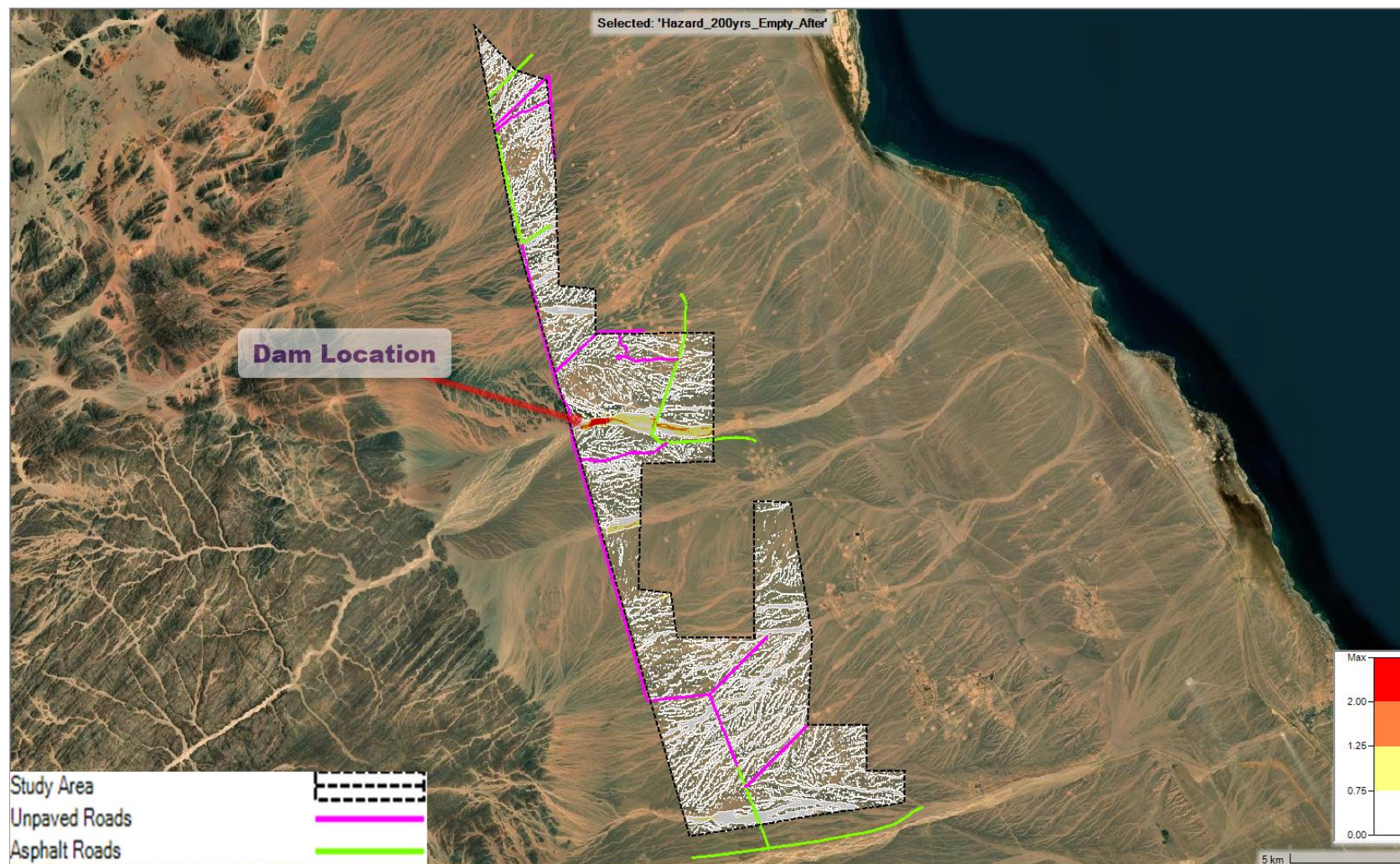


Figure 7.38: Hazard map for return period of 200 years

Figures 7.31 to 7.38 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.
- The flood hazard for the 20-year return period is mostly low.
- The flood hazard for return period 50 is mostly low, with a few small points downstream of medium hazard.
- The flood hazard for the 100-year return period is mostly low, in addition to medium hazard and spotted areas of high hazard,
- The flood hazard map for the 100-year return period, taking climate change into consideration, is mostly low, in addition to medium and high hazards.
- The flood hazard for the 200-year return period is mostly low, in addition to medium and high hazards.

8. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

- The hydraulic model is carried out for return periods of 2 to 200 years and for a return period of 100 years taking climate change into consideration.
- Existing dam (Dam 01) is studied in the hydraulic calculations and it is also included in the hydraulic model.
- 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, while Figure 8.3 shows the hazard map after excluding the areas of low hazards. Therefore, it is recommended to use these maps 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 besides tower foundations. The details of the proposed grouted riprap protection around wind towers are shown in Figure 8.4.
- The locations of internal asphalt roads are included in the hydraulic 2D model to simulate the effect of the Wadis on them.

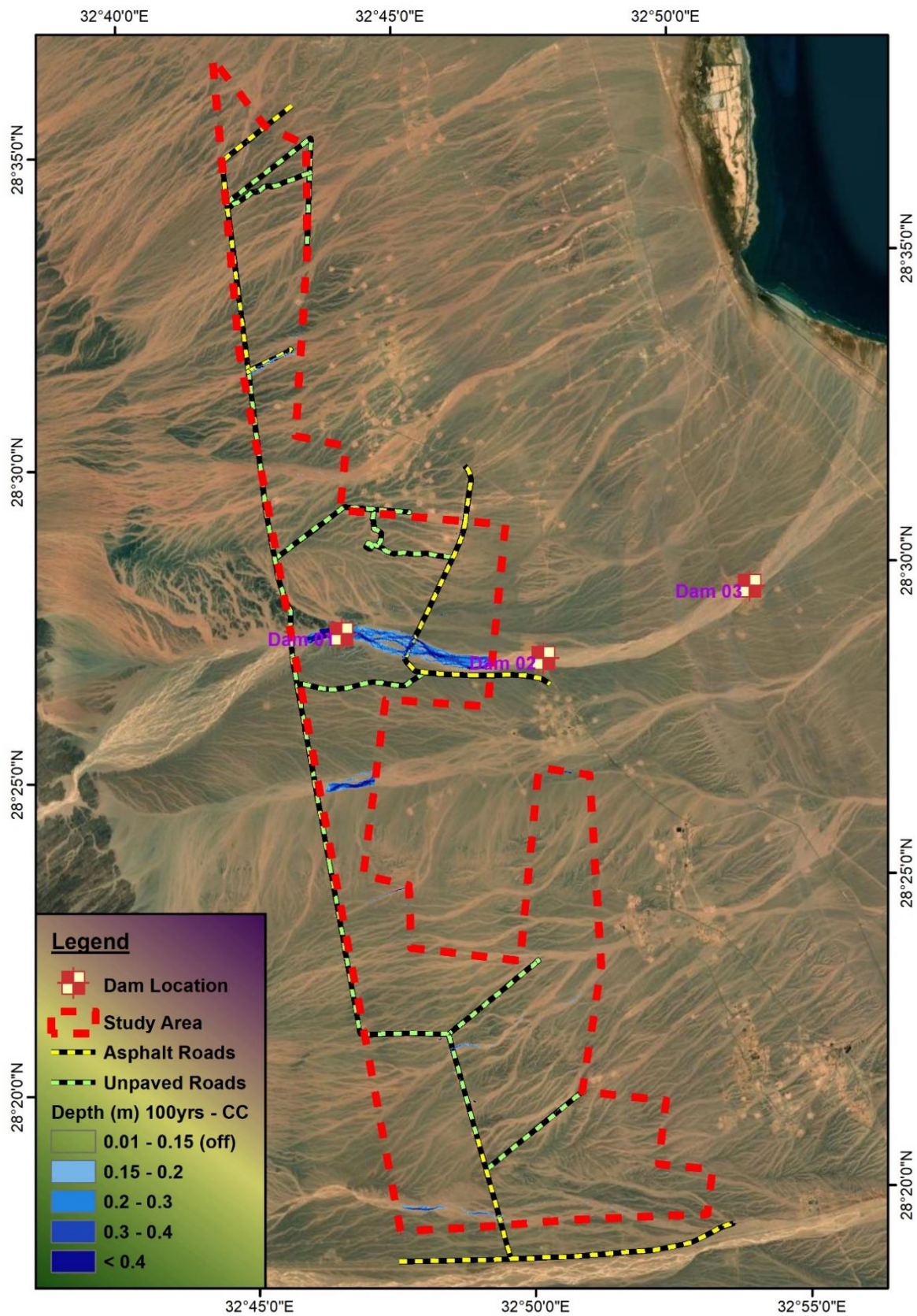


Figure 8.1: Depth map for return period of 100 years taking climate change into consideration and excluding flood depths below 0.15m

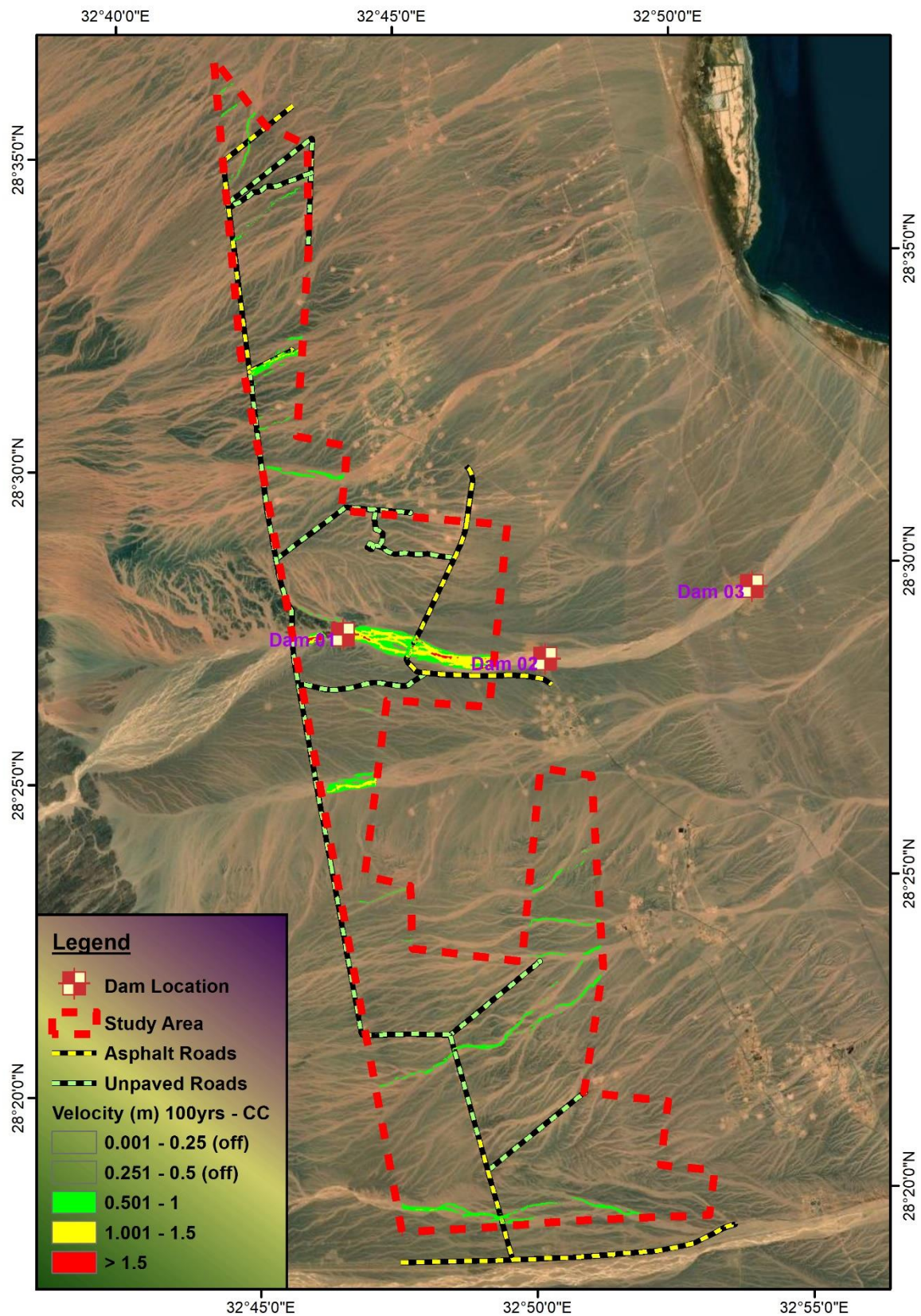


Figure 8.2: Velocity map for return period of 100 years taking climate change into consideration and excluding velocities below 0.5 m/s

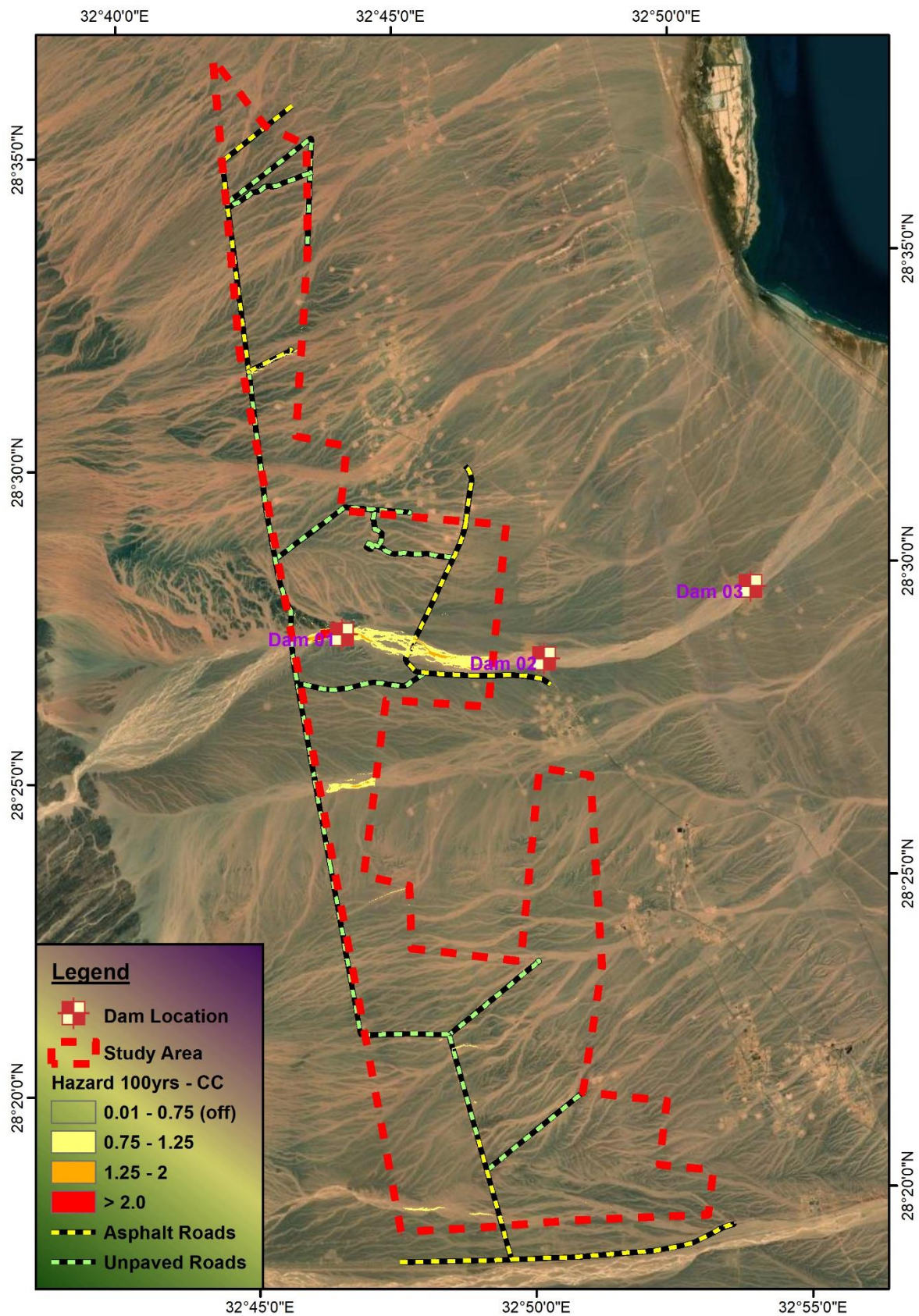


Figure 8.3: Hazard map for return period of 100 years taking climate change into consideration and excluding low hazard areas

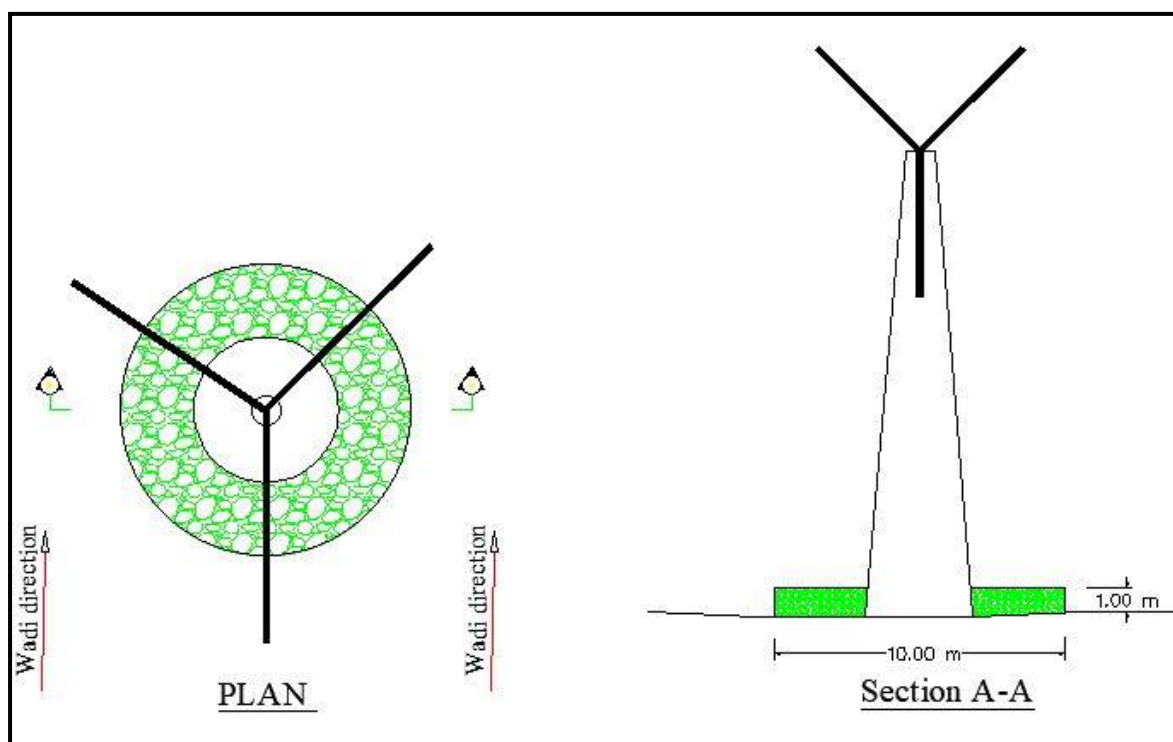


Figure 8.4 : Proposed grouted riprap protection around wind towers

- Four Irish Crossings are proposed at the intersections between internal asphalt roads and main streams to protect the internal roads from flash floods.
- One of the asphalt roads is intersected by Wadi Hawashi. Therefore, a new culvert is proposed with a diversion channel upstream the culvert to force the water to flow towards the culvert without road overtopping.

Table 8.1 shows the data of the proposed Irish crossings and Table 8.2 shows the data of the proposed culvert, Figure 8.5 shows the whole proposed Protection Measures locations on satellite image while Figure 8.6 shows the culvert analysis report.

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
Irish Crossing 3	472439	3156281	1154
Irish Crossing 4	482424	3131861	449

Table 8.2: Proposed culvert data

No.	Easting (m)	Northing (m)	Length (m)	No. of vents	Width (m)	Height (m)
Culvert 1	478035	3148630	25	23	2.0	1.5

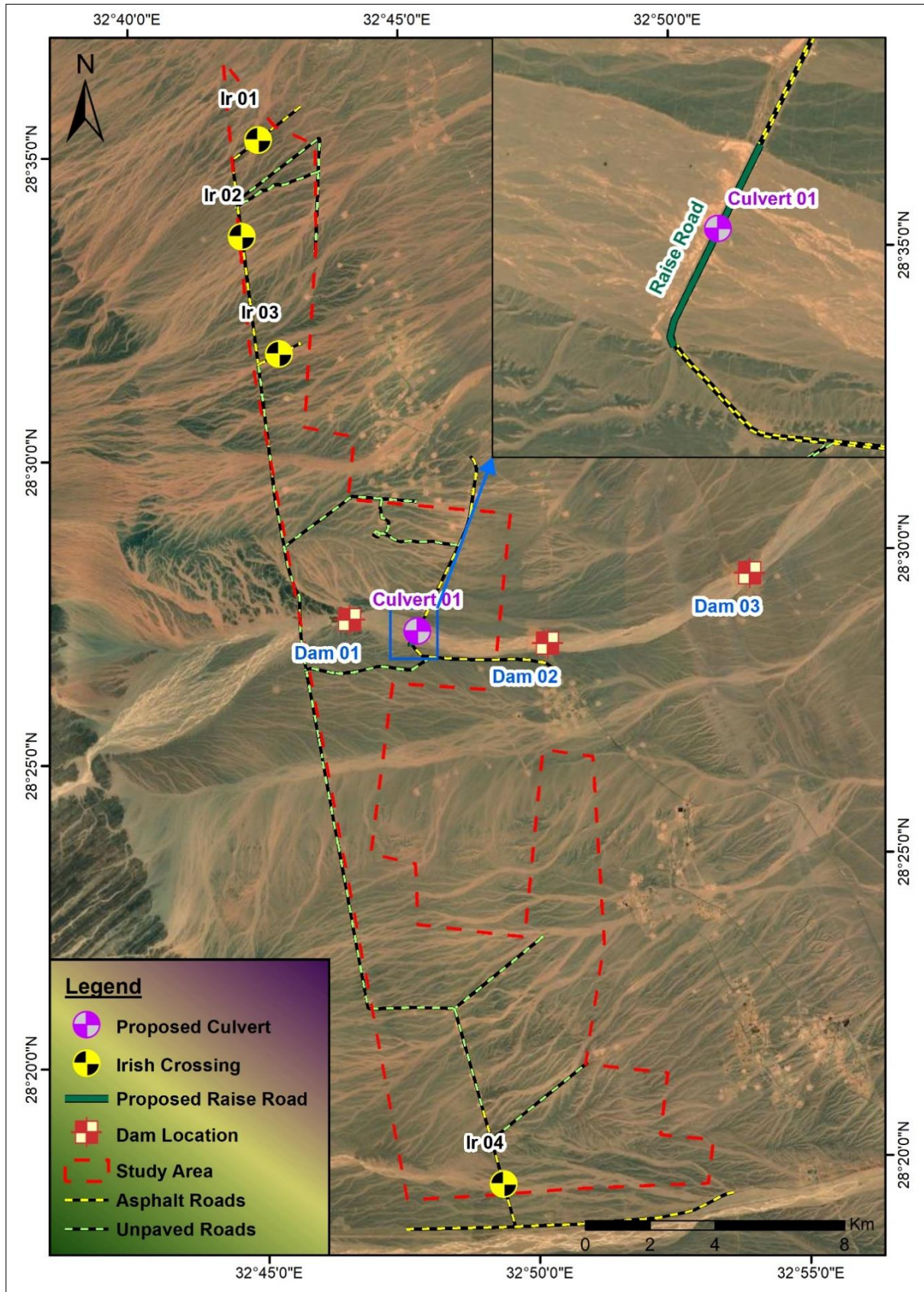


Figure 8.5: Locations of proposed protection measures on satellite image

Culvert Analysis Report Culvert-1			
Culvert Summary			
Computed Headwater Elevation	242.32 m	Discharge	152.3000 m ³ /s
Inlet Control HW Elev.	242.13 m	Tailwater Elevation	N/A m
Outlet Control HW Elev.	242.32 m	Control Type	Entrance Control
Headwater Depth/Height	1.21		
Grades			
Upstream Invert	240.50 m	Downstream Invert	240.33 m
Length	25.00 m	Constructed Slope	0.007000 m/m
Hydraulic Profile			
Profile	S2	Depth, Downstream	0.90 m
Slope Type	Steep	Normal Depth	0.86 m
Flow Regime	Supercritical	Critical Depth	1.04 m
Velocity Downstream	3.69 m/s	Critical Slope	0.004229 m/m
Section			
Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	2.00 m
Section Size	2000*1500	Rise	1.50 m
Number Sections	23		
Outlet Control Properties			
Outlet Control HW Elev.	242.32 m	Upstream Velocity Head	0.52 m
Ke	0.50	Entrance Loss	0.26 m
Inlet Control Properties			
Inlet Control HW Elev.	242.13 m	Flow Control	Unsubmerged
Inlet Type	18.4° wingwall flares - offset	Area Full	69.0 m ²
K	0.49300	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	3
C	0.02270	Equation Form	2
Y	0.89700		

Figure 8.6: Culvert analysis report

Figure 8.7 to Figure 8.10 show the locations of the Irish crossings on a depth map, a velocity map, and a hazard map for a return period of 100 years + CC, respectively. Then the details of the Irish crossing are given in Figure 8.7.

Figure 8.11 to 8.14 show the locations of the proposed culvert for the asphalt road at the intersection with Wadi Hawashi on satellite image, a depth map, a velocity map and a hazard map for a return period of 100 years + CC, respectively.

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).

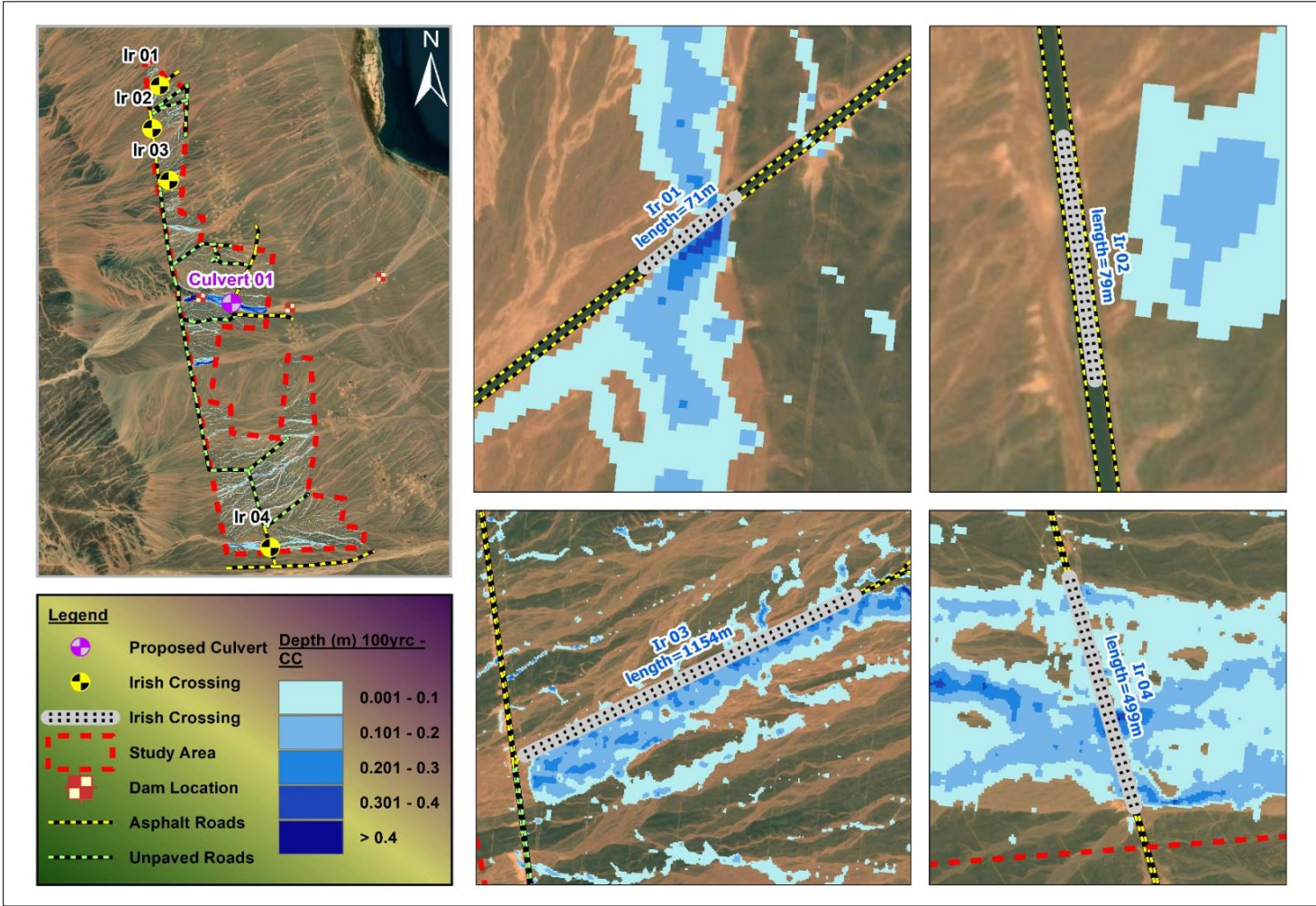


Figure 8.7: Proposed Irish crossings locations on Depth Map for return period 100 years + CC.

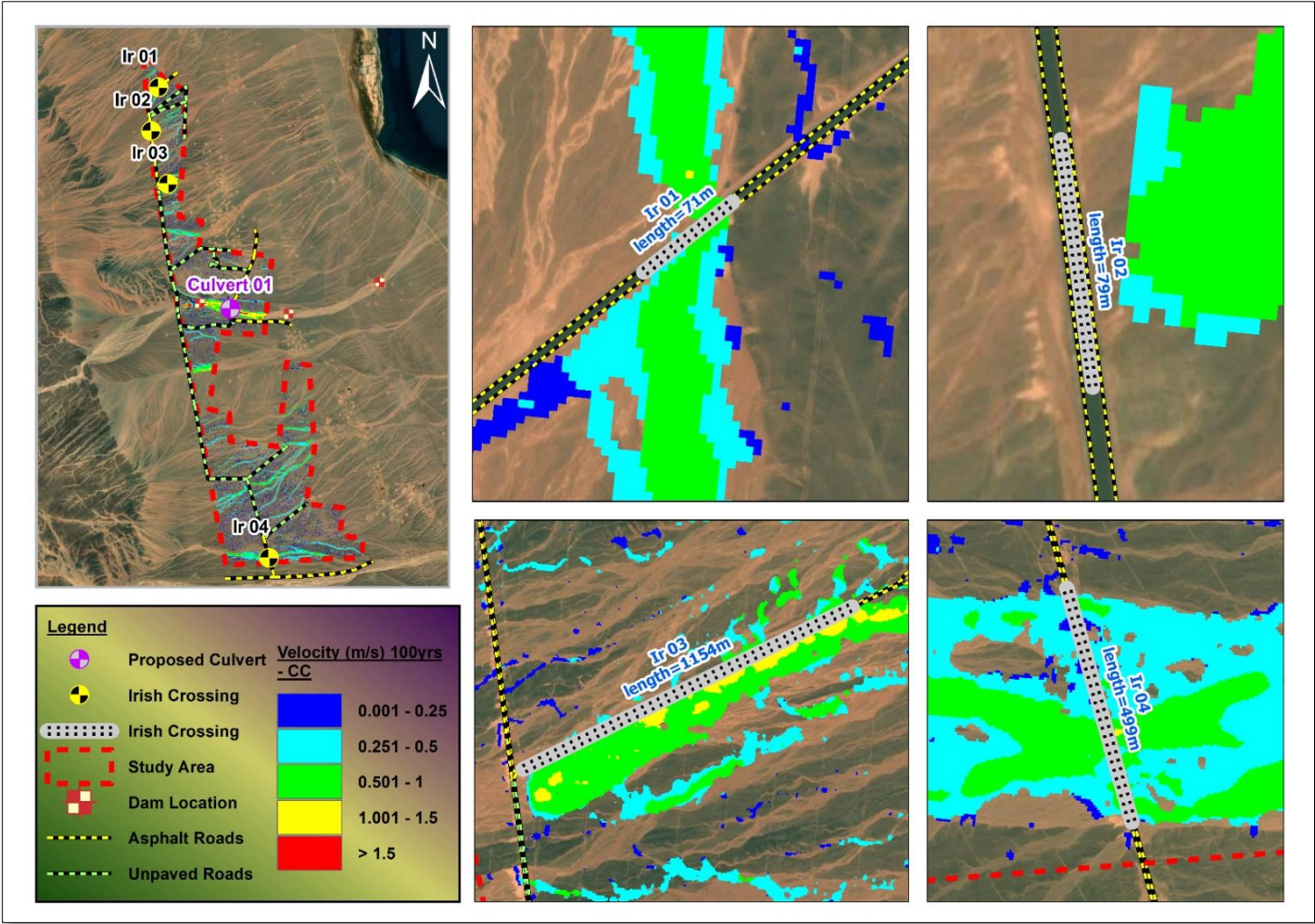


Figure 8.8: Proposed Irish crossings locations on Velocity Map for return period 100 years + CC

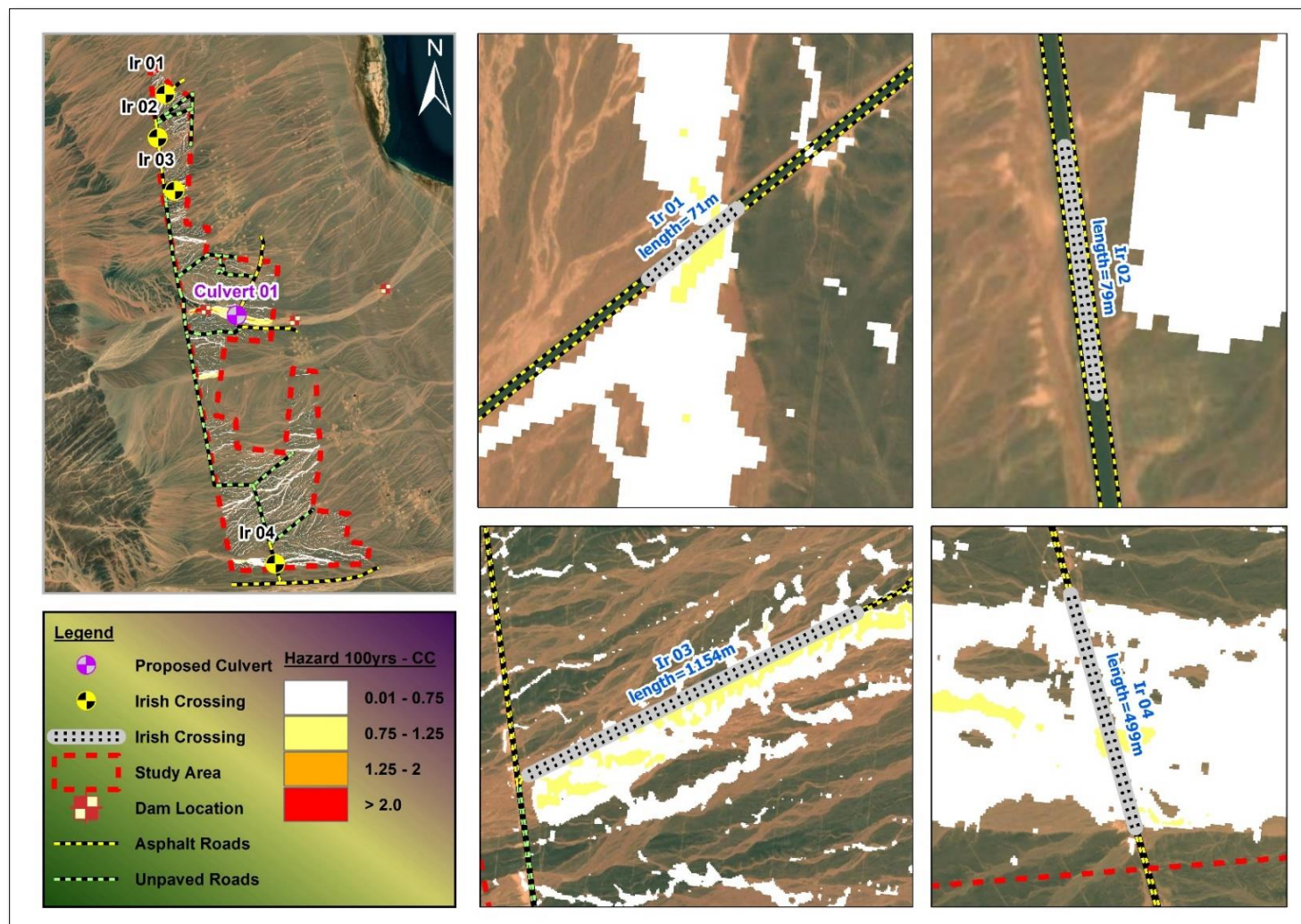


Figure 8.9: Proposed Irish crossings locations on Hazard Map for return period 100 years + CC

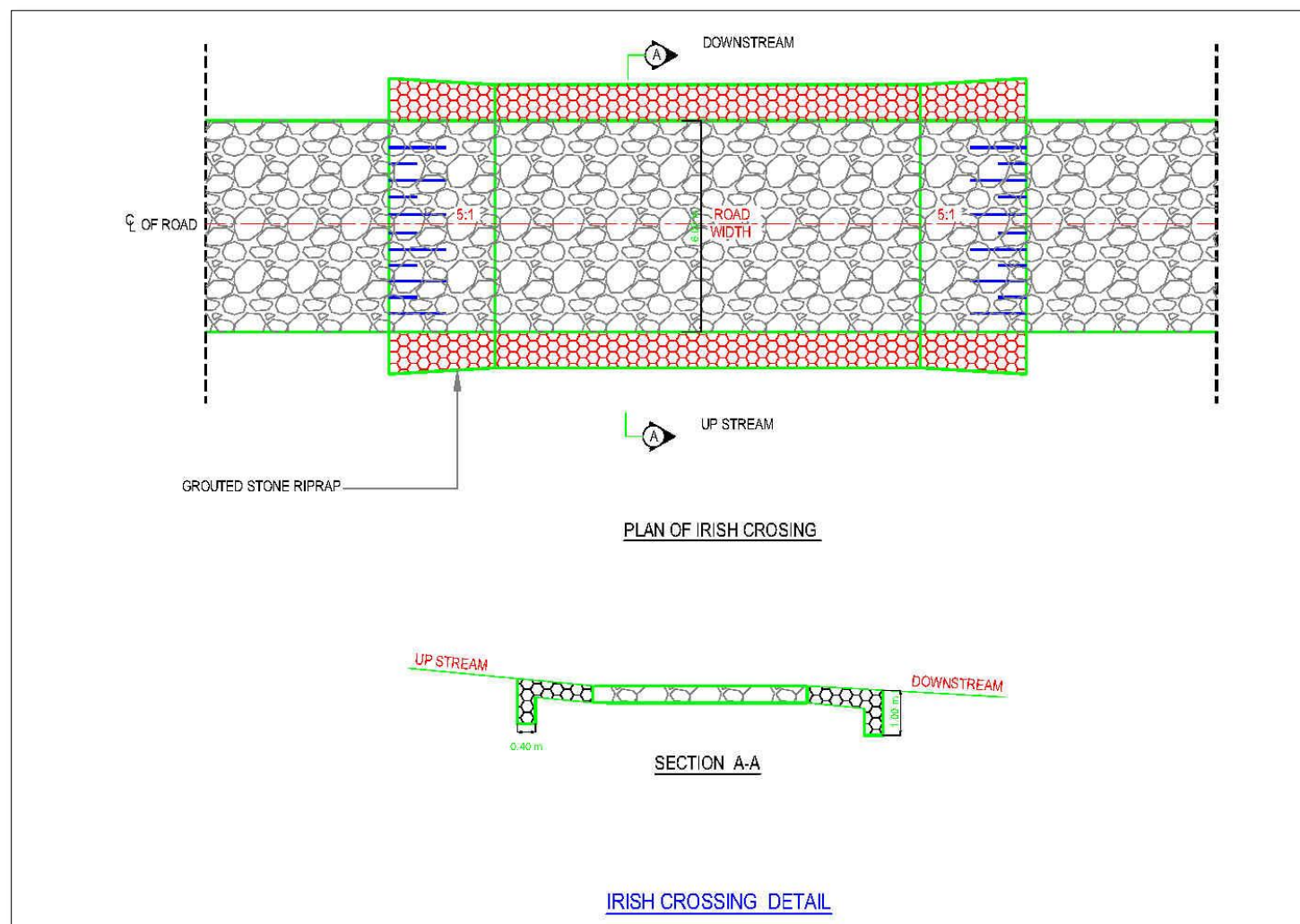


Figure 8.10: Proposed Irish crossing Details

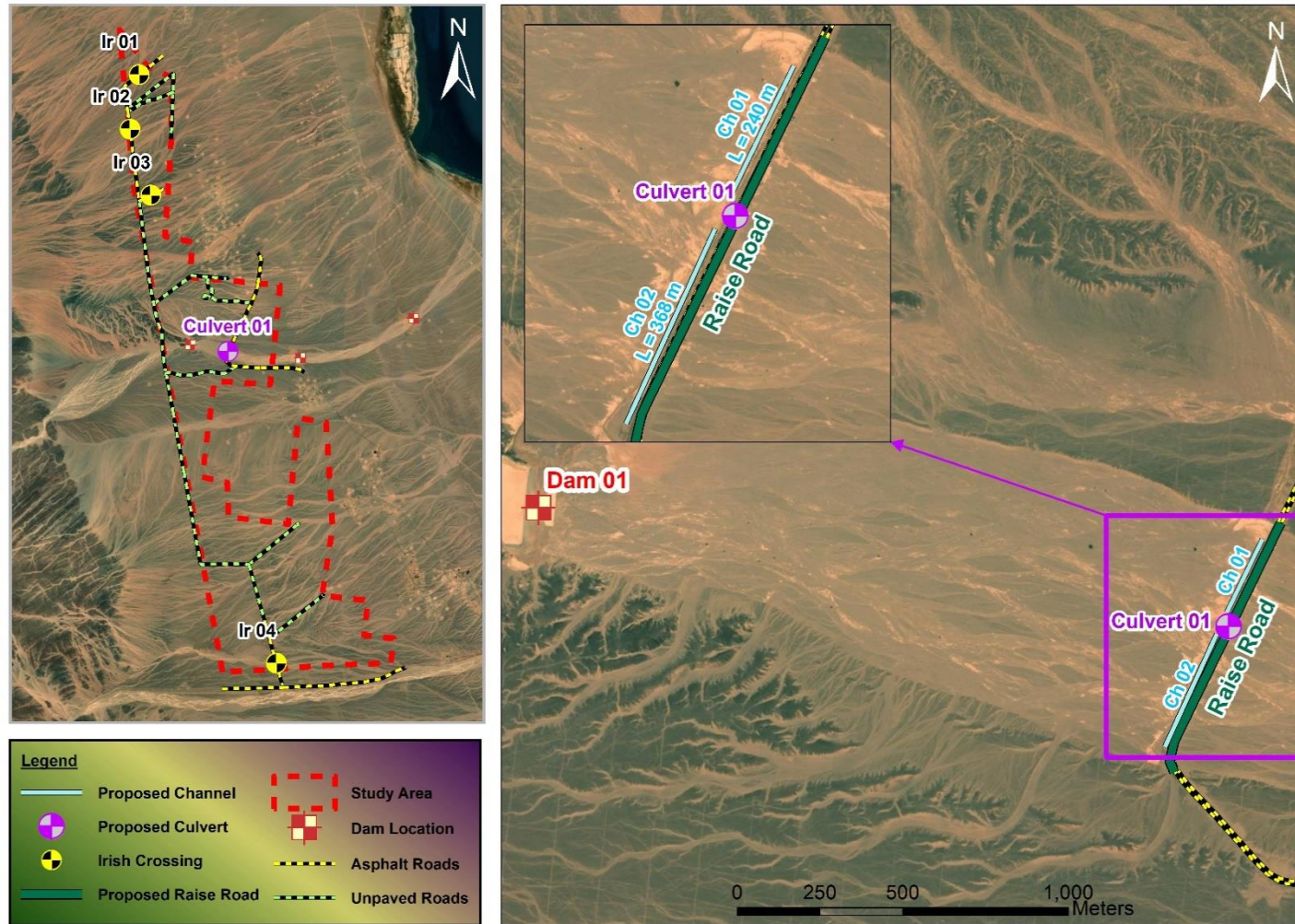


Figure 8.11: Proposed Protection Measures locations for the asphalt road at the intersection with Wadi Hawashi on satellite image.

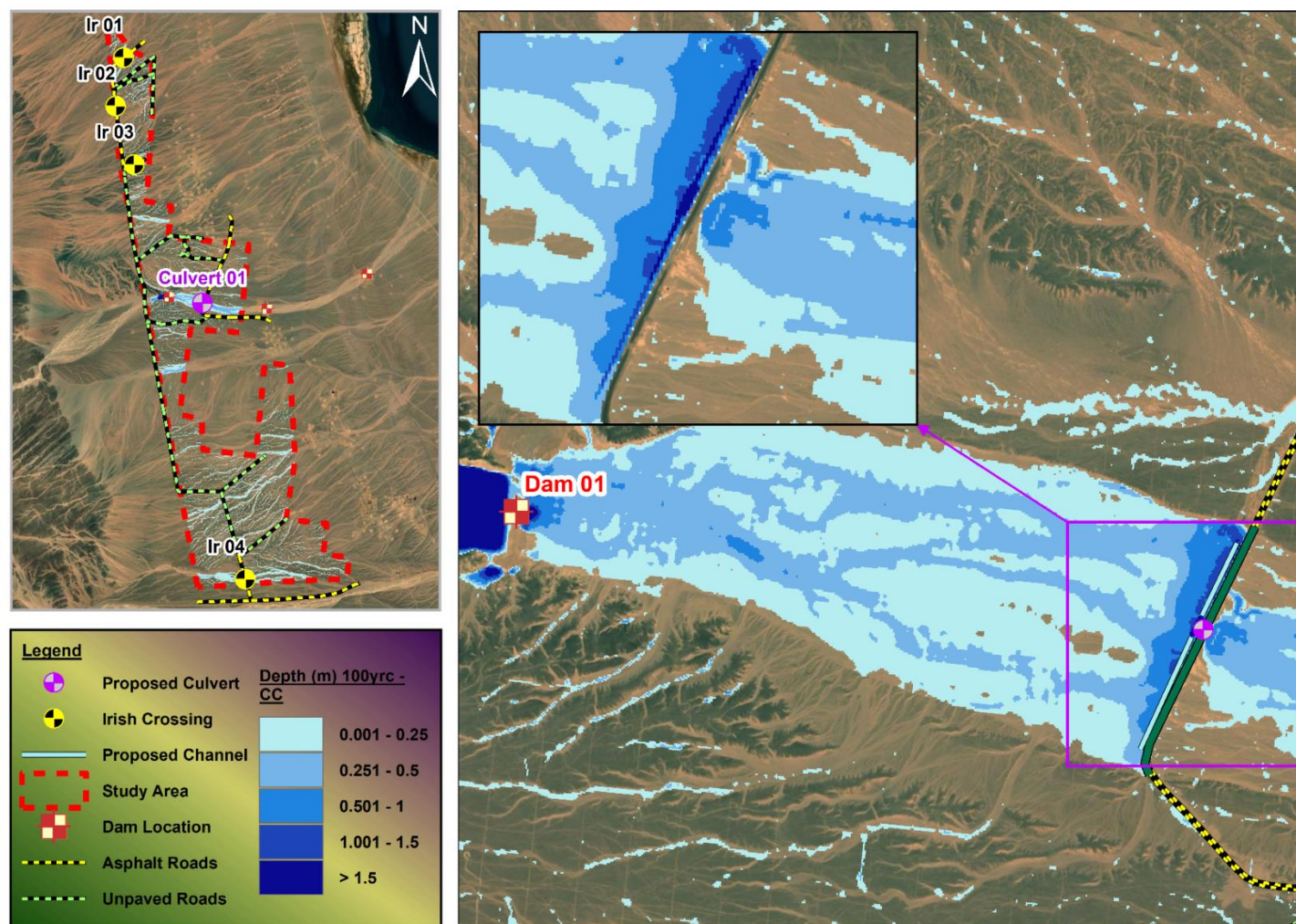


Figure 8.12: Proposed Culvert and Channel on Depth Map for return period 100 years + CC

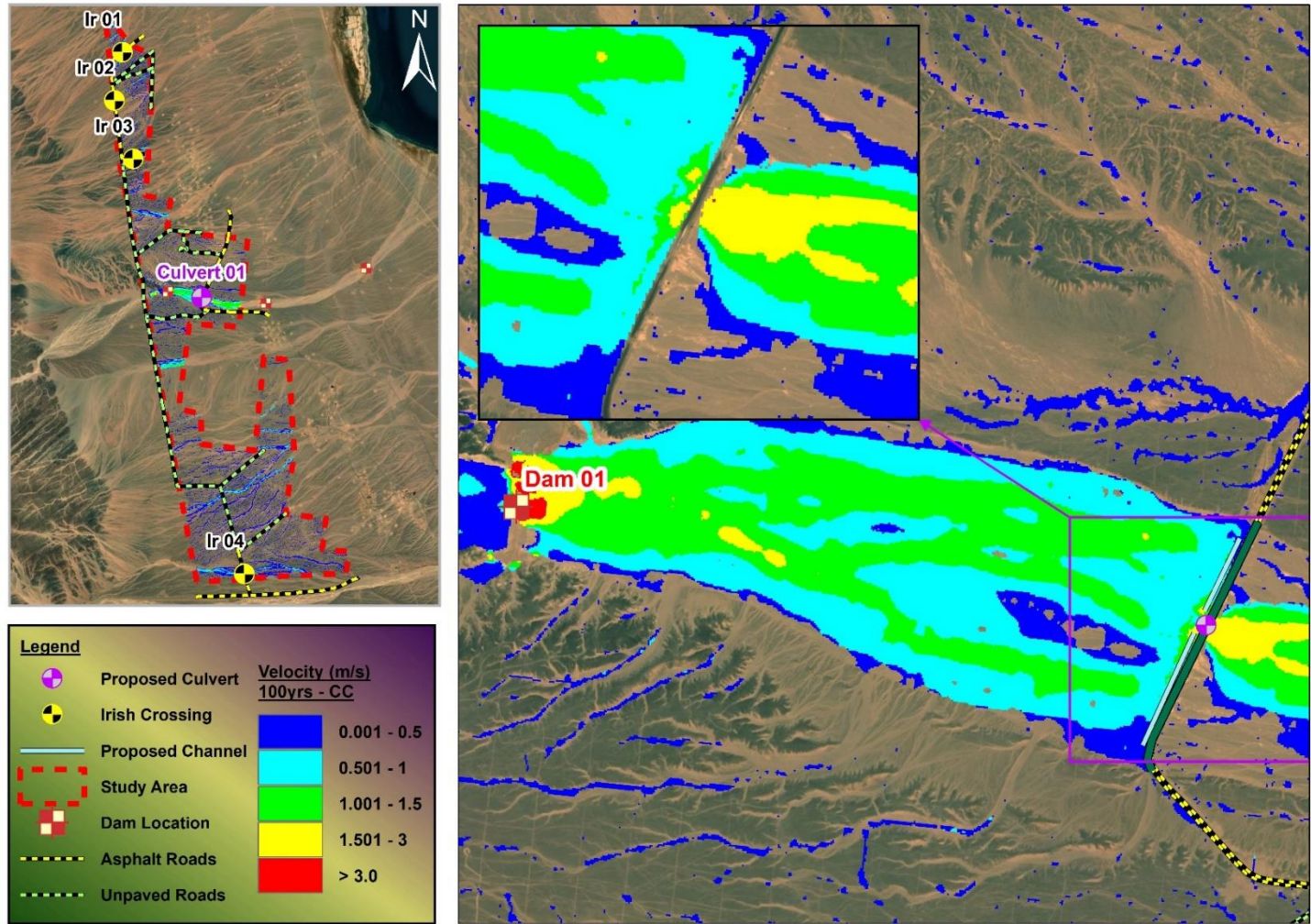


Figure 8.13: Proposed Culvert and Channel on Velocity Map for return period 100 years + CC

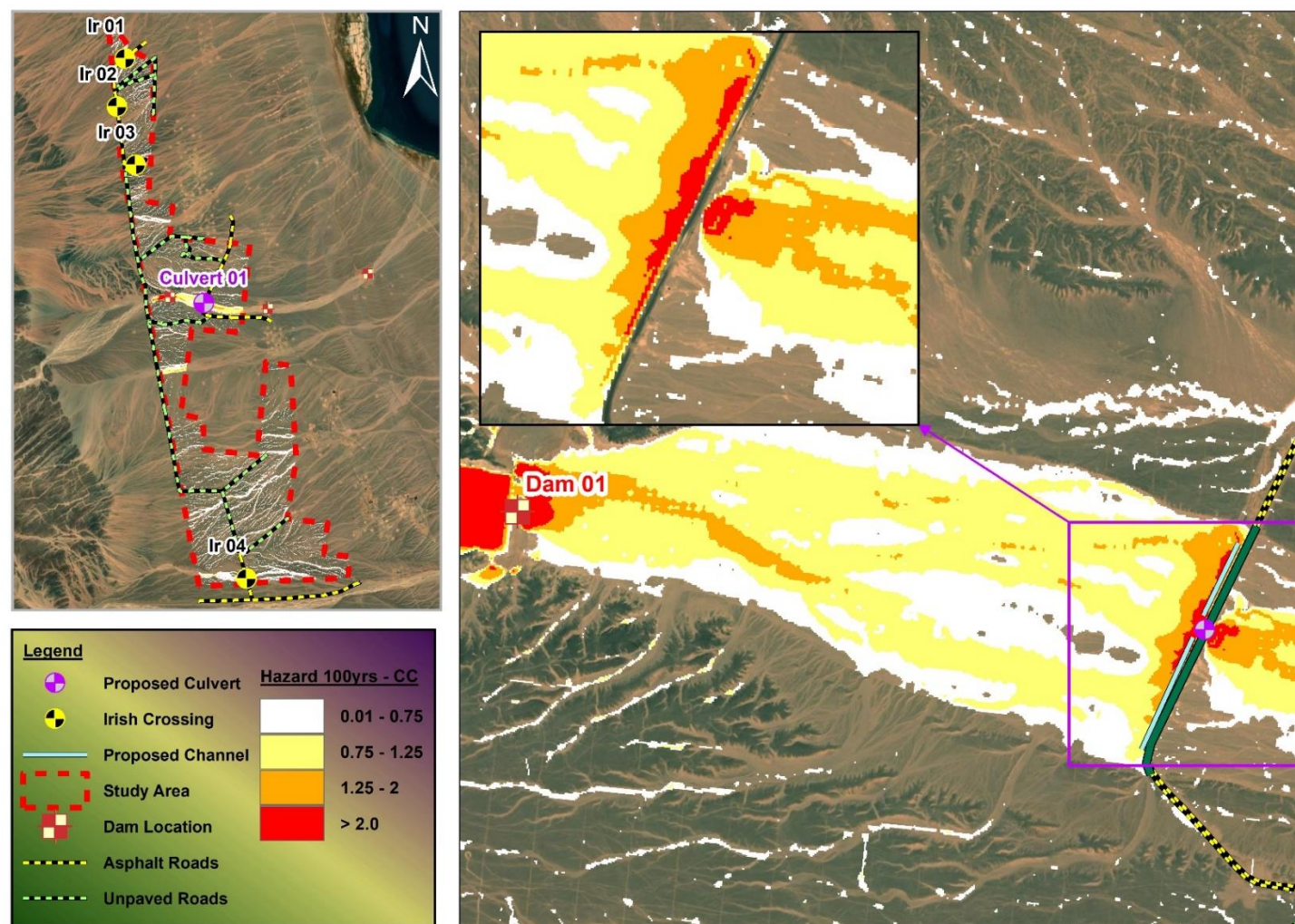


Figure 8.14: Proposed Culvert and Channel on Hazard Map for return period 100 years + CC

Appendix A

HYDROGRAPHS & HYDRAULIC MODEL OUTPUTS

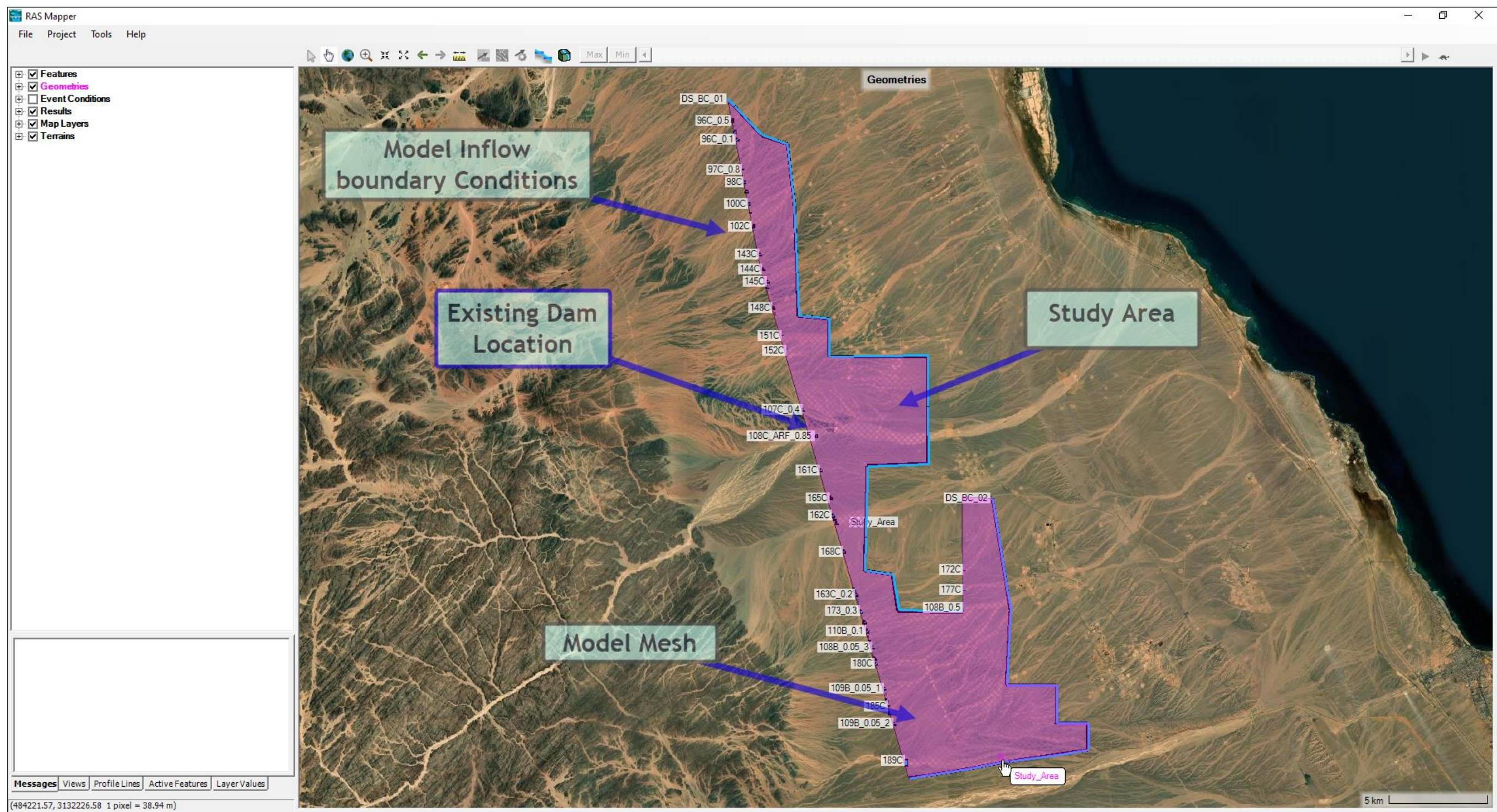


Figure A.1: Site boundary and hydraulic model boundary conditions (BC)

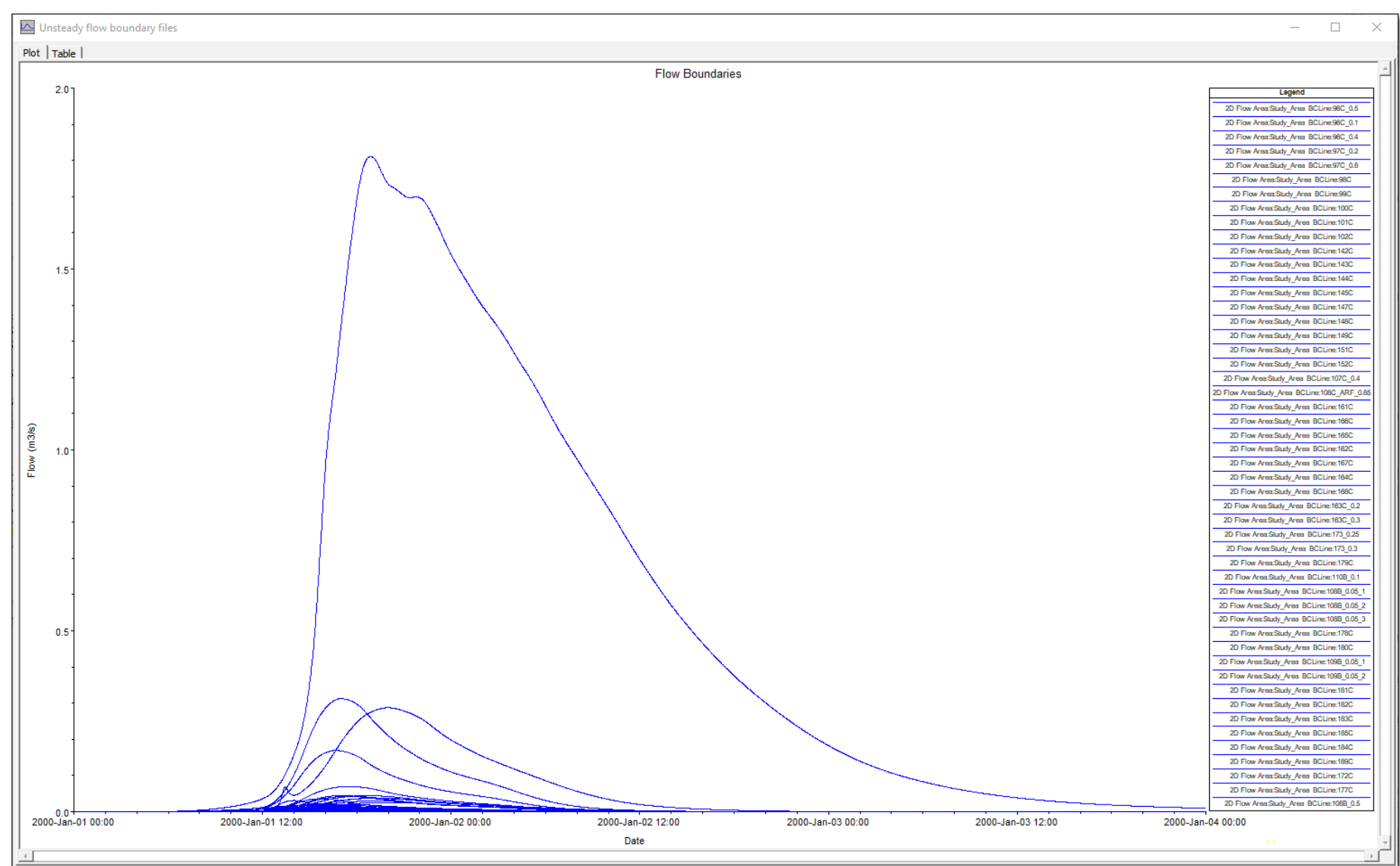


Figure A.2: Boundary conditions (BC) for return period of 2 years (Hydrographs)

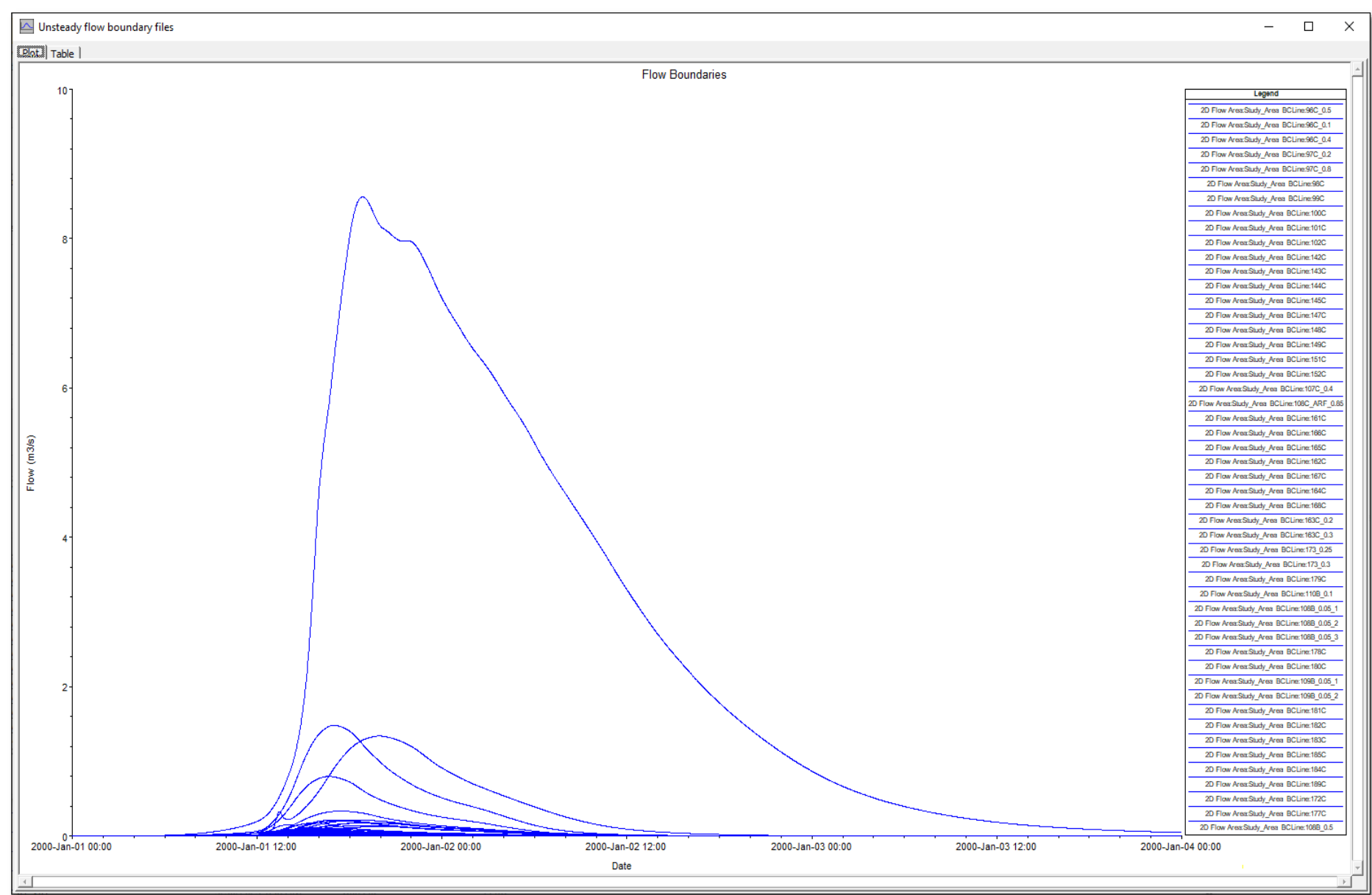


Figure A.3: Boundary conditions (BC) for return period of 5 years (Hydrographs)

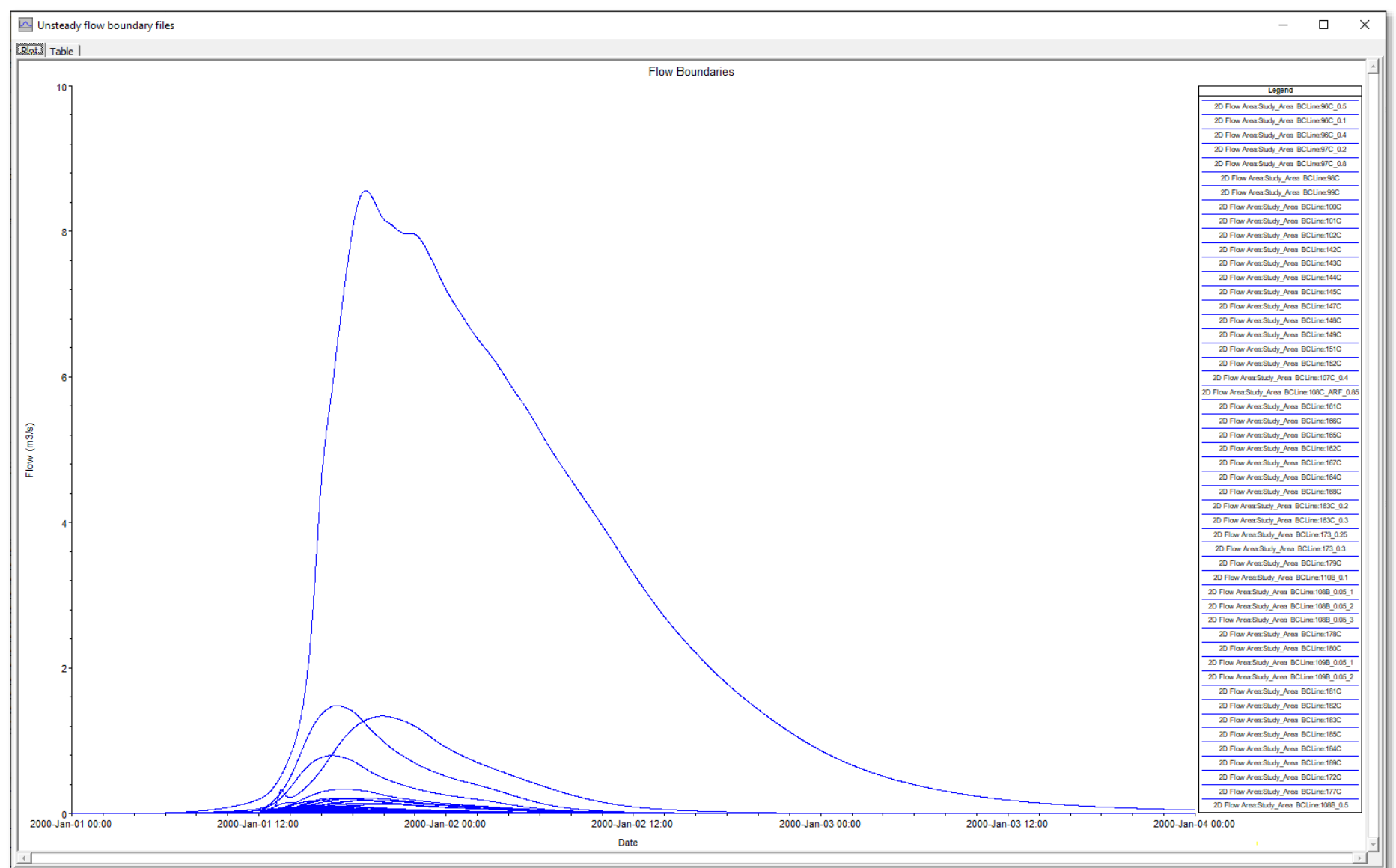


Figure A.4: Boundary conditions (BC) for return period of 10 years (Hydrographs)

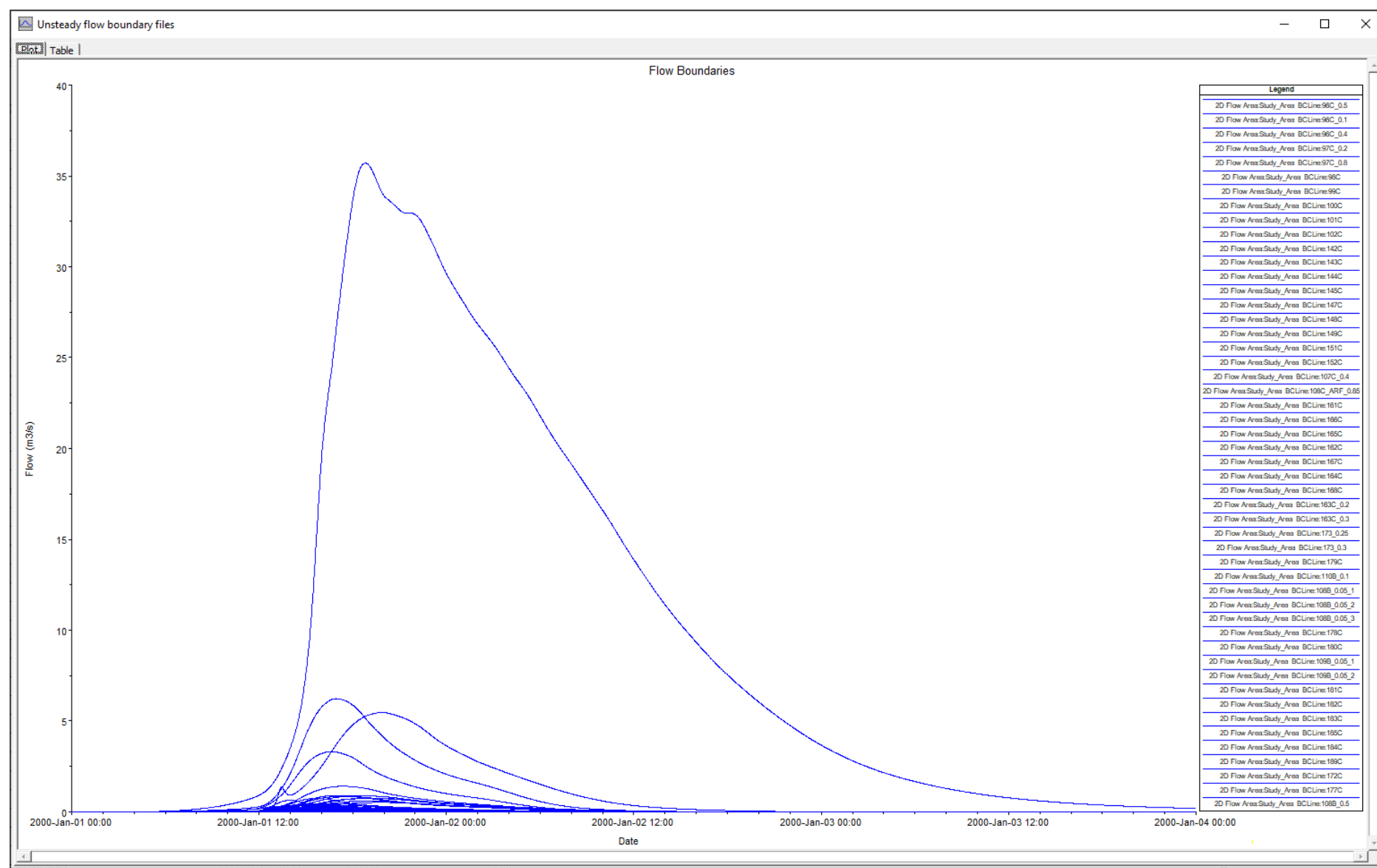


Figure A.5: Boundary conditions (BC) for return period of 20 years (Hydrographs)

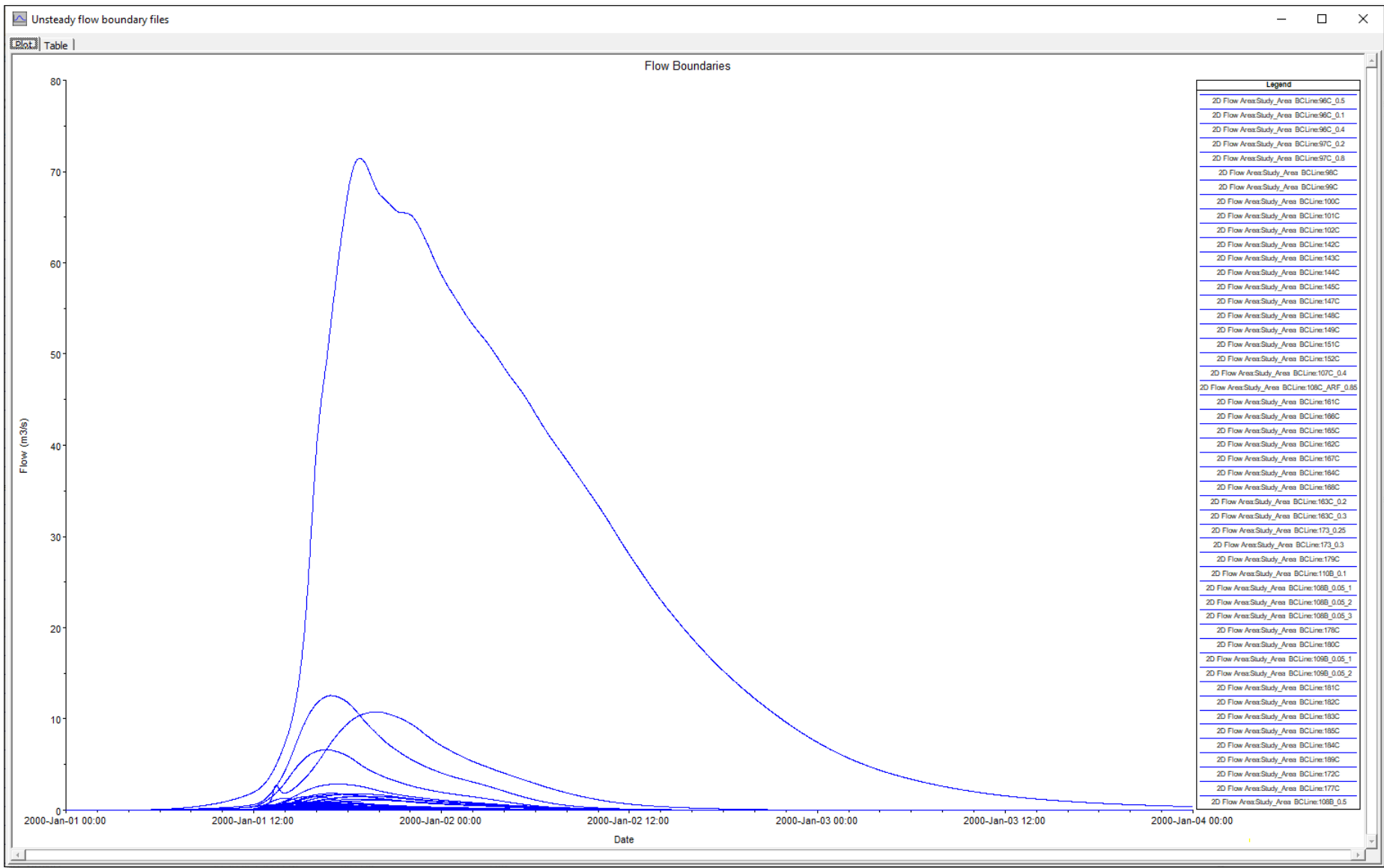


Figure A.6: Boundary conditions (BC) for return period of 50 years (Hydrographs)

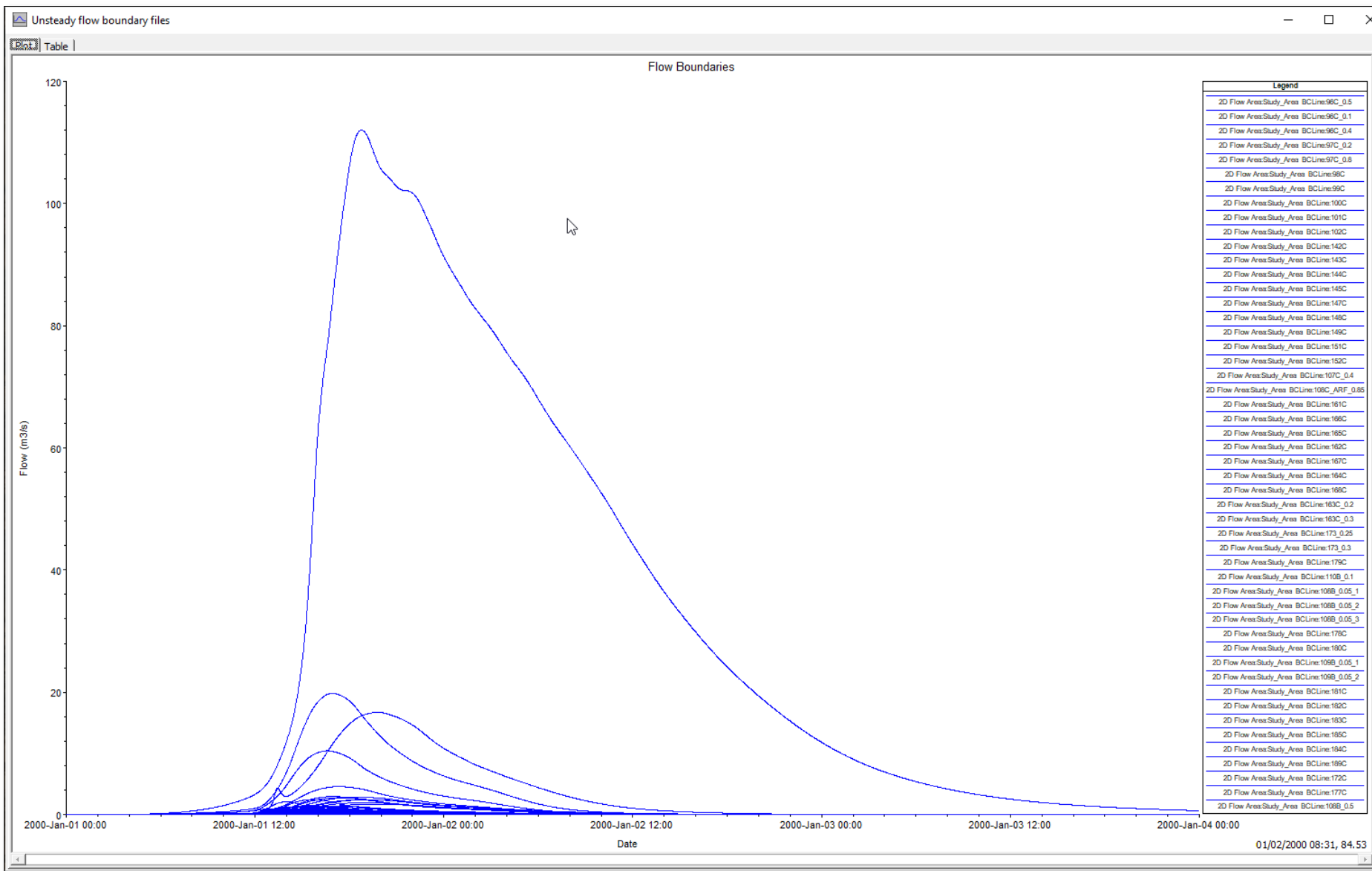


Figure A.7: Boundary conditions (BC) for return period of 100 years (Hydrographs)

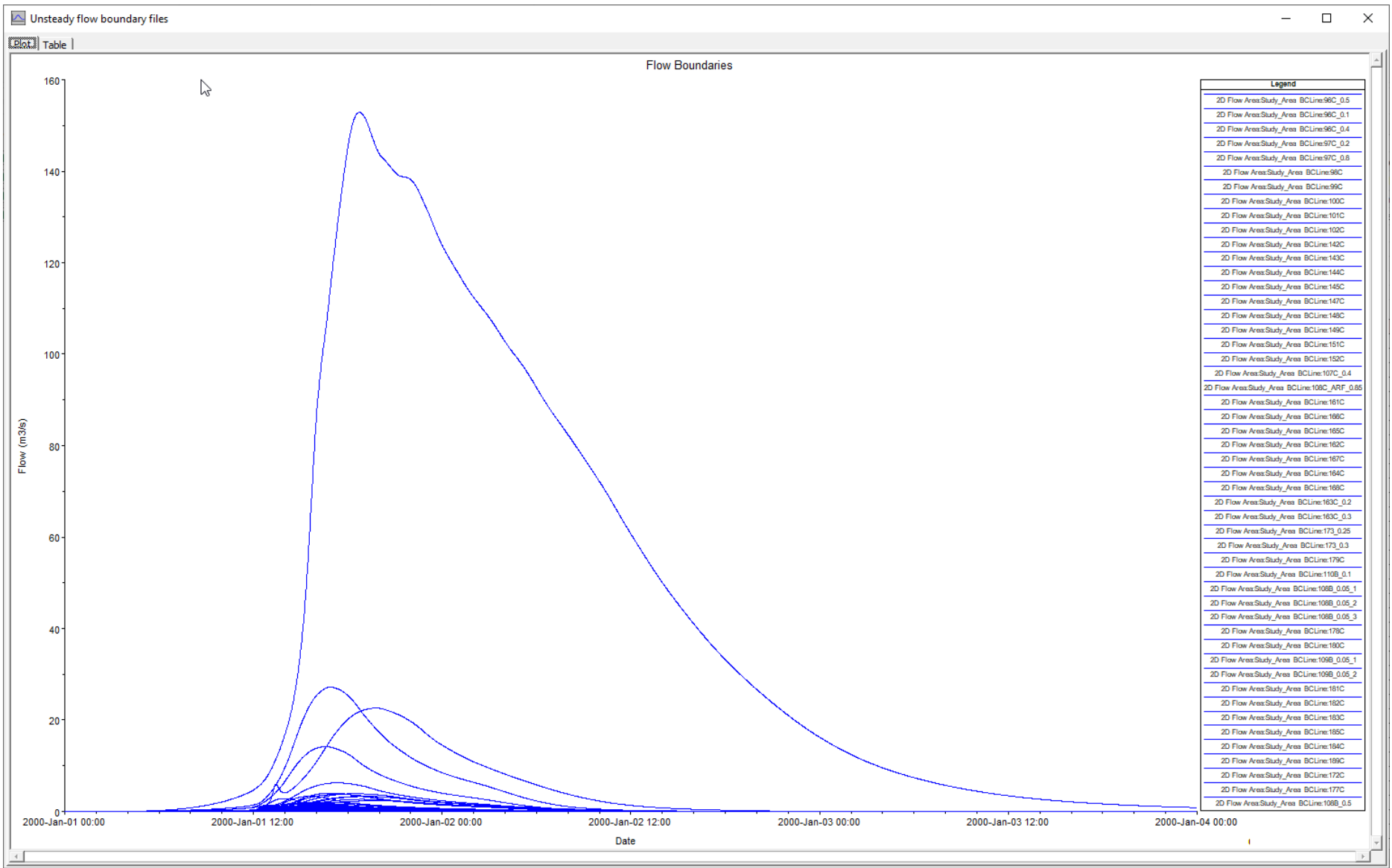


Figure A.8: Boundary conditions (BC) for return period of 100 years + climate change (Hydrographs)

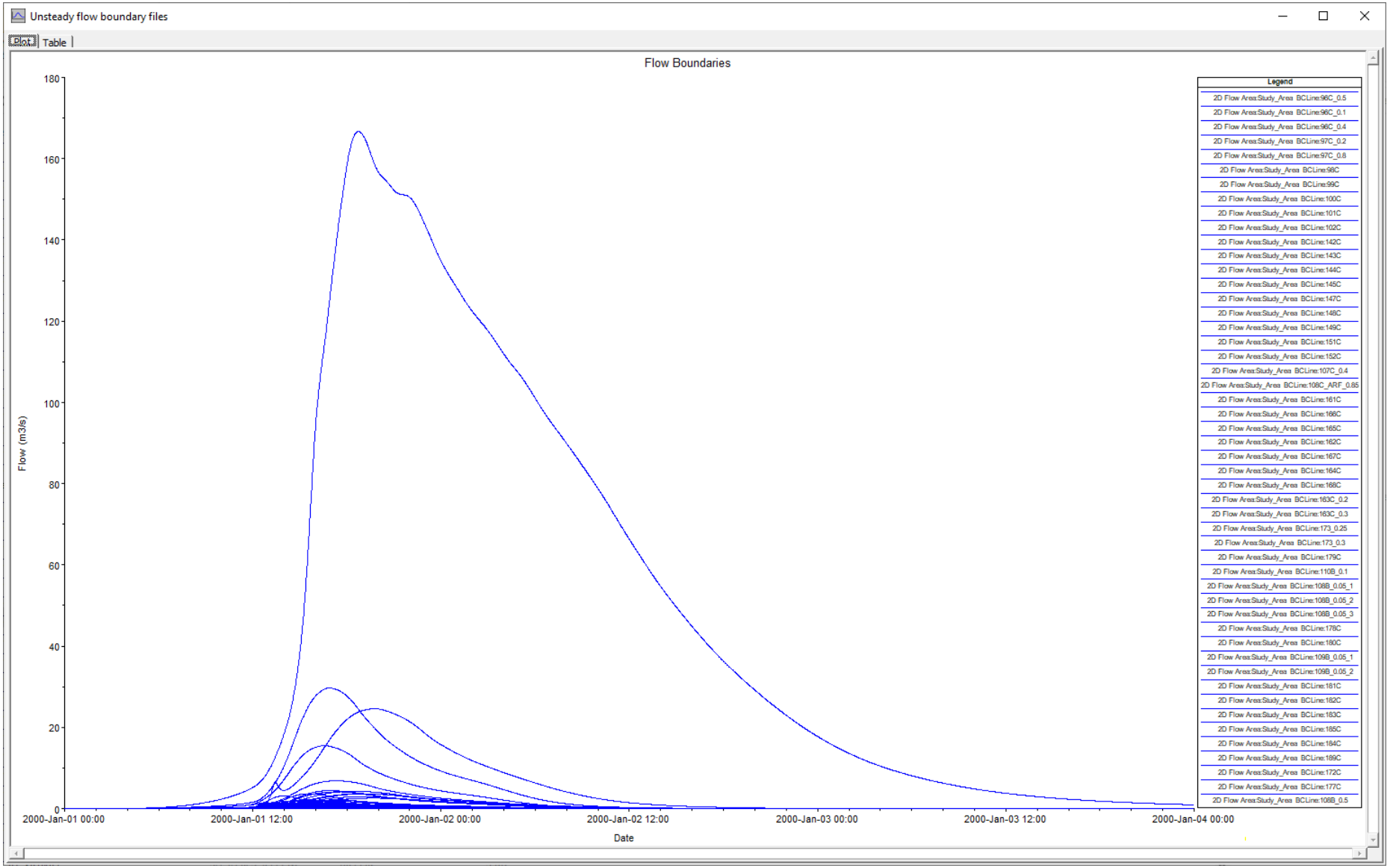


Figure A.9: Boundary conditions (BC) for return period of 200 years (Hydrographs)

- Flood Extent & Depth Maps

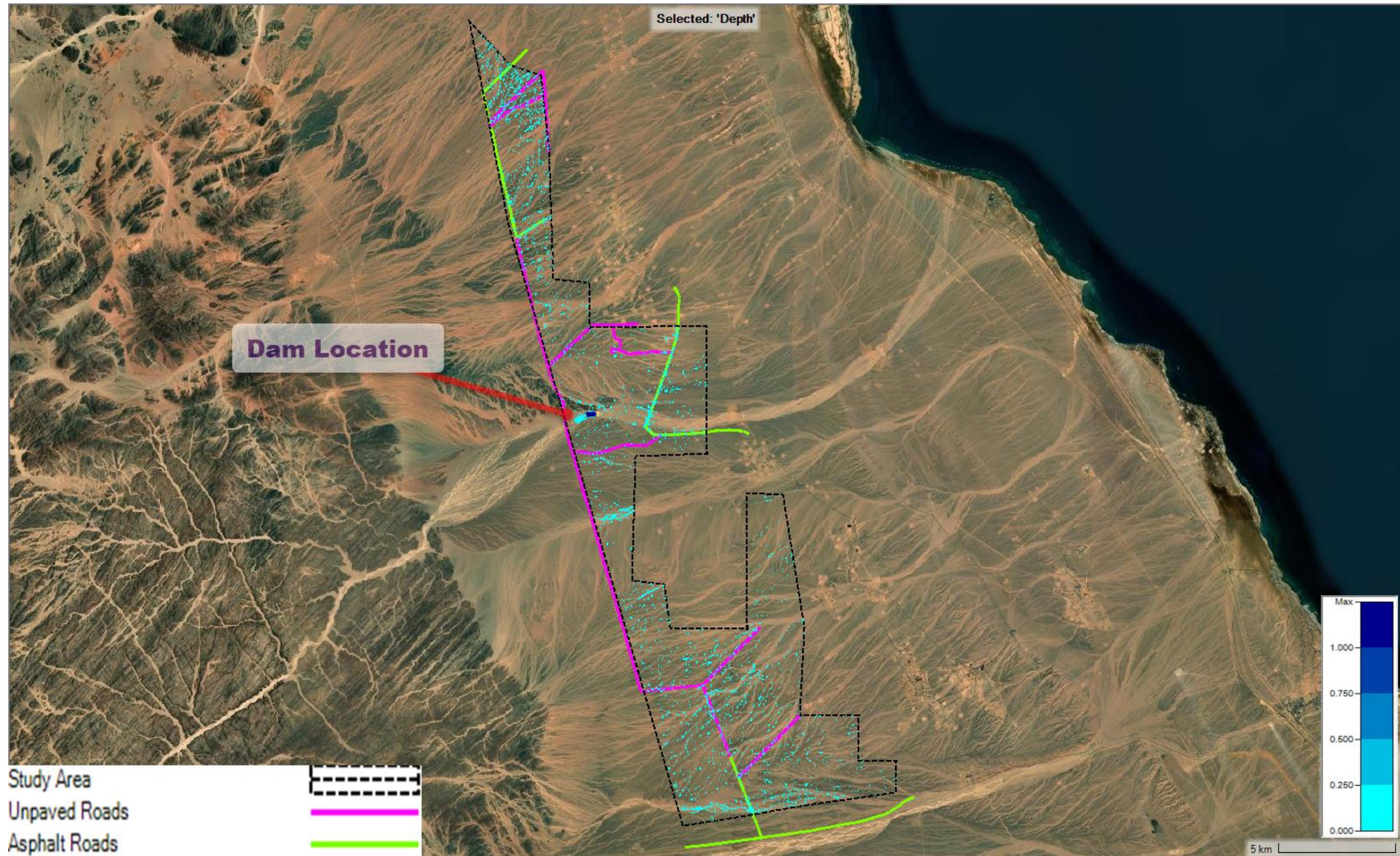


Figure A.10: Depth Map for return period of 2 years

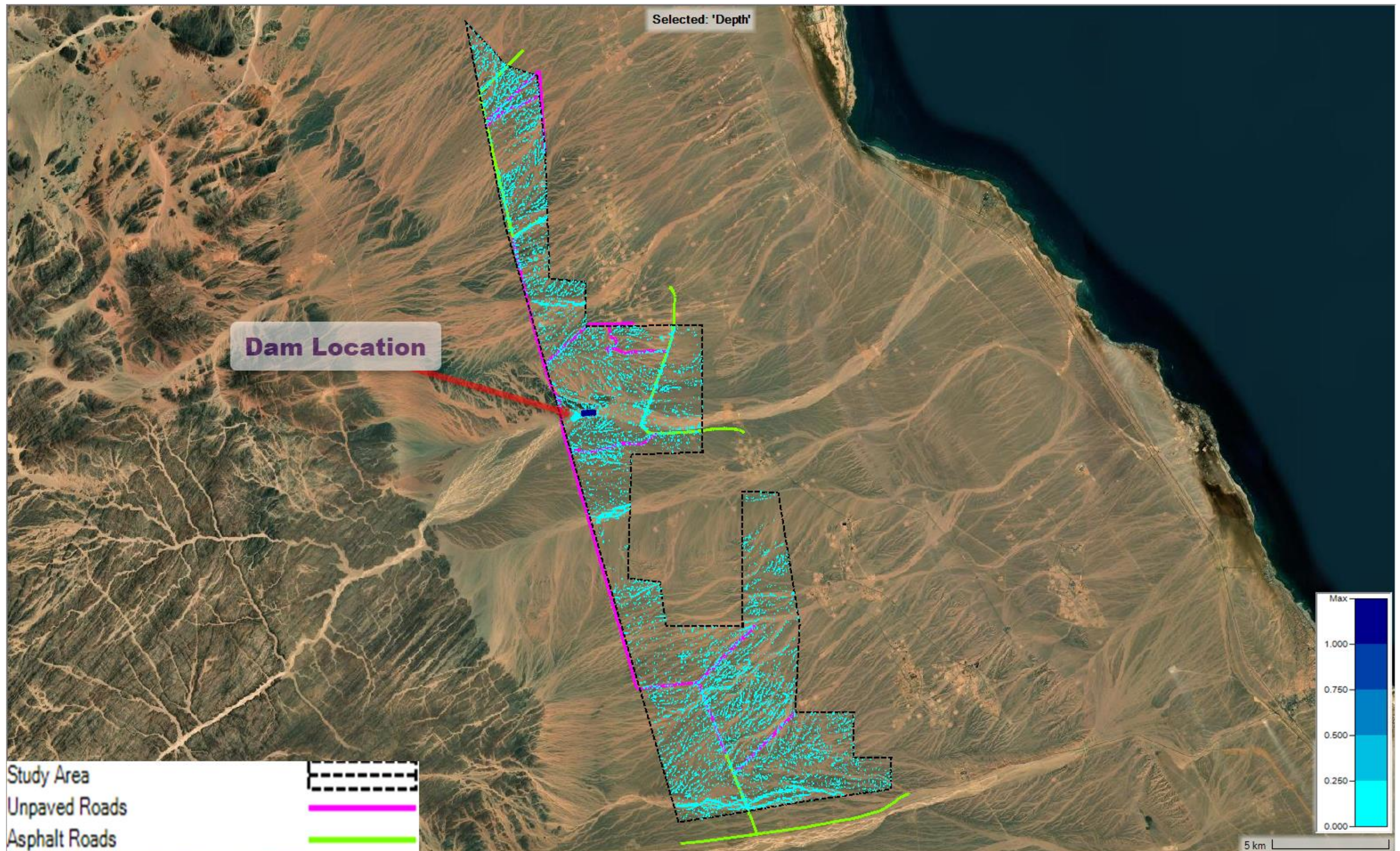


Figure A.11: Depth Map for return period of 5 years

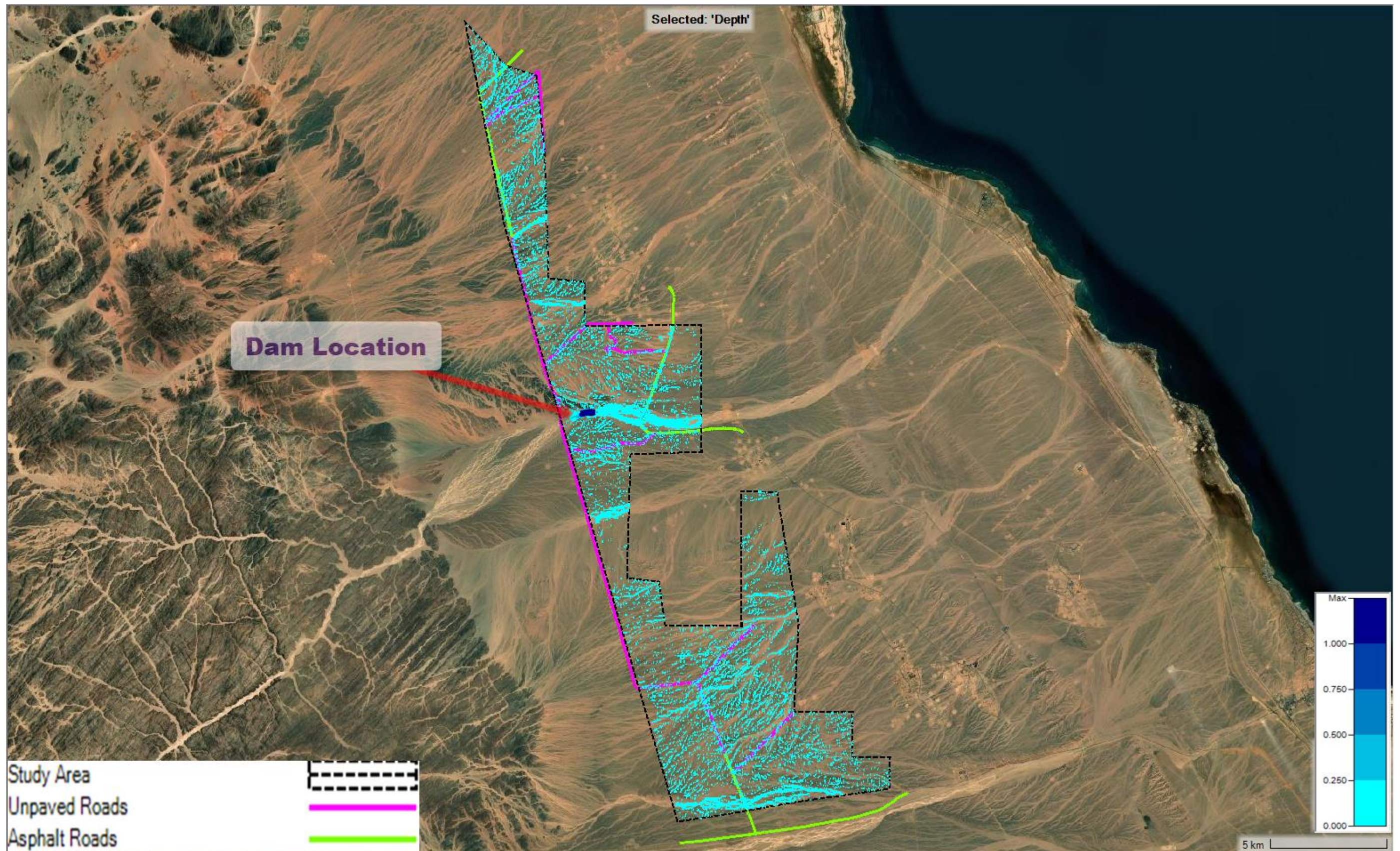


Figure A.12: Depth Map for return period of 10 years

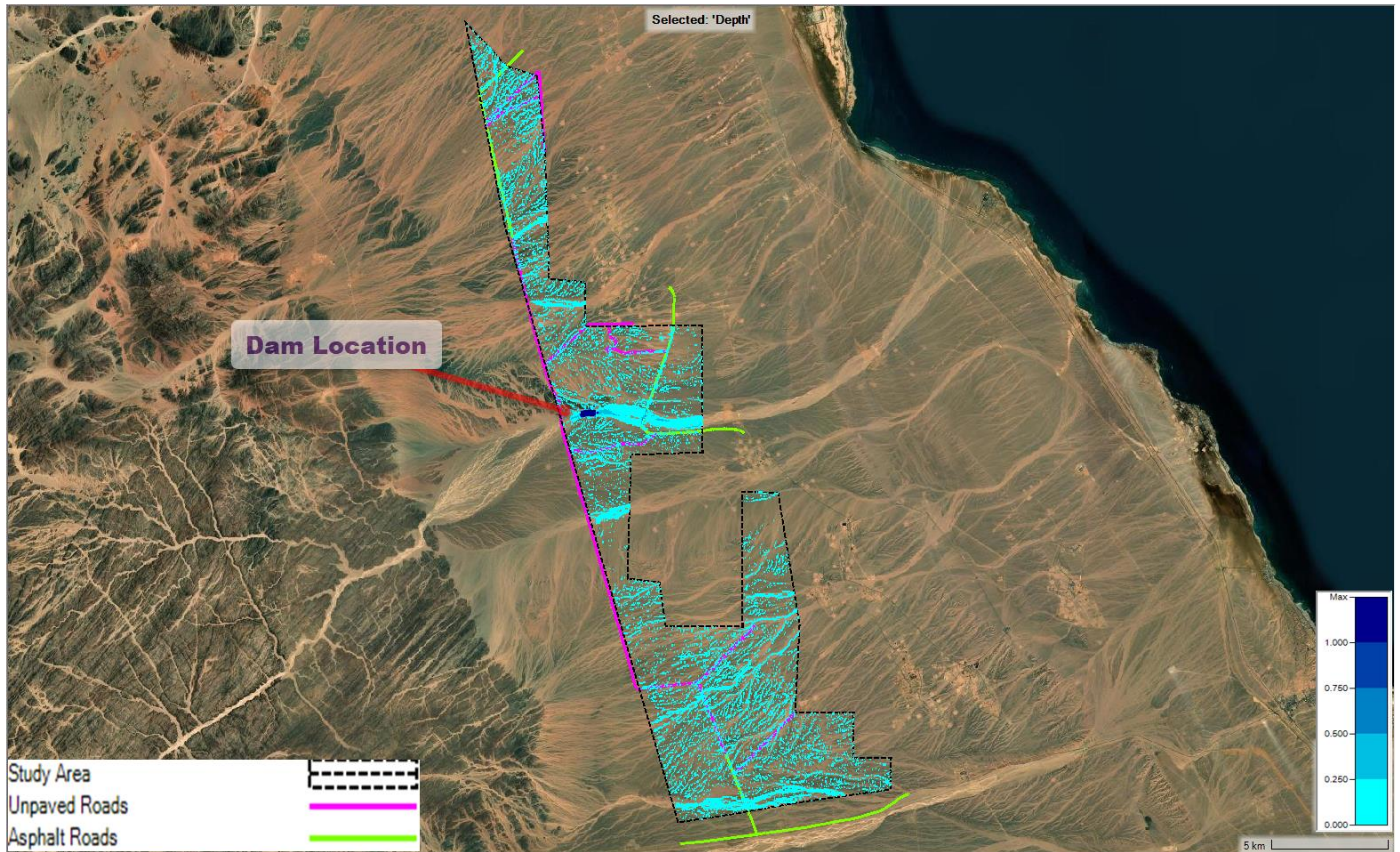


Figure A.13: Depth Map for return period of 20 years

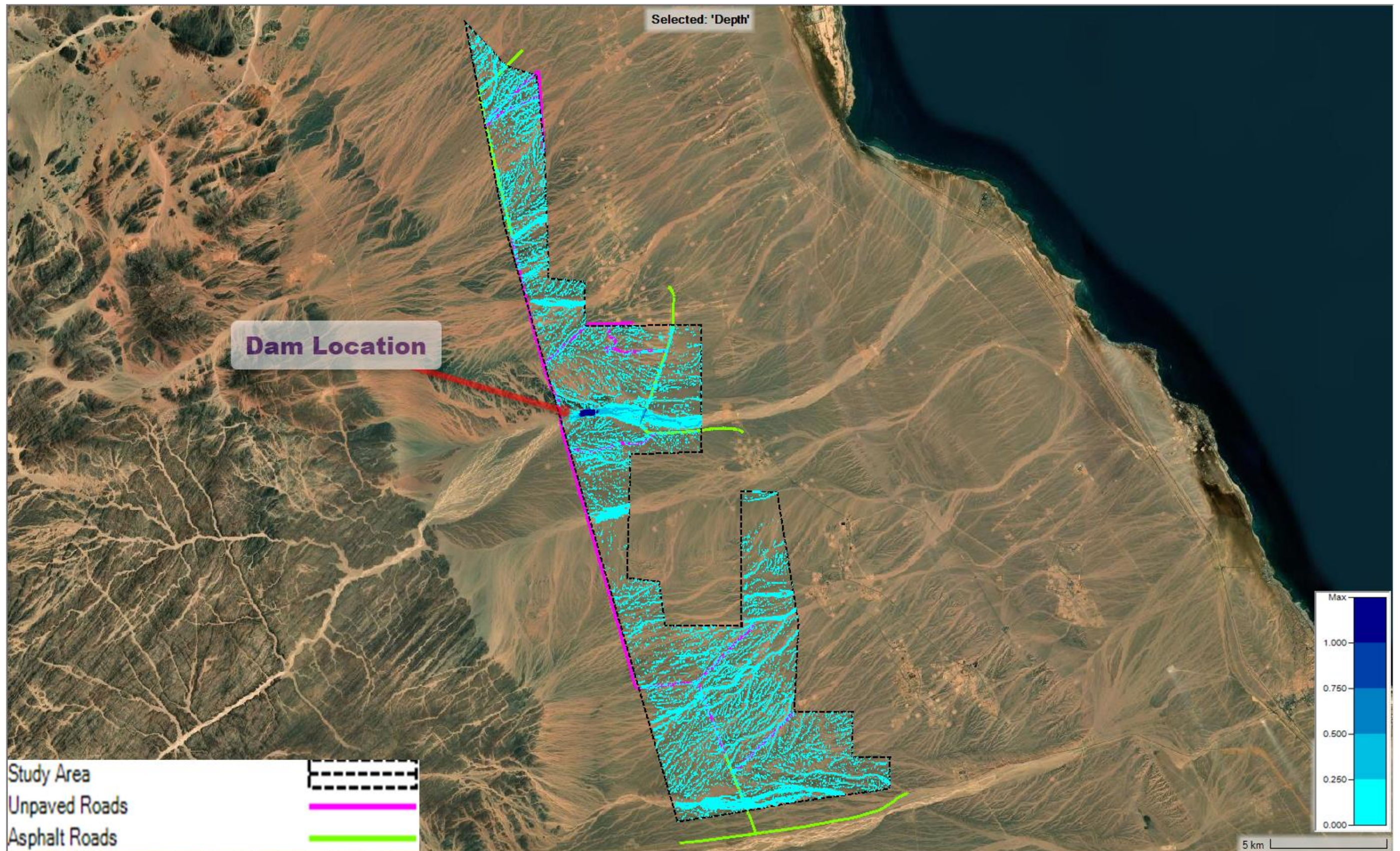


Figure A.14: Depth Map for return period of 50 years

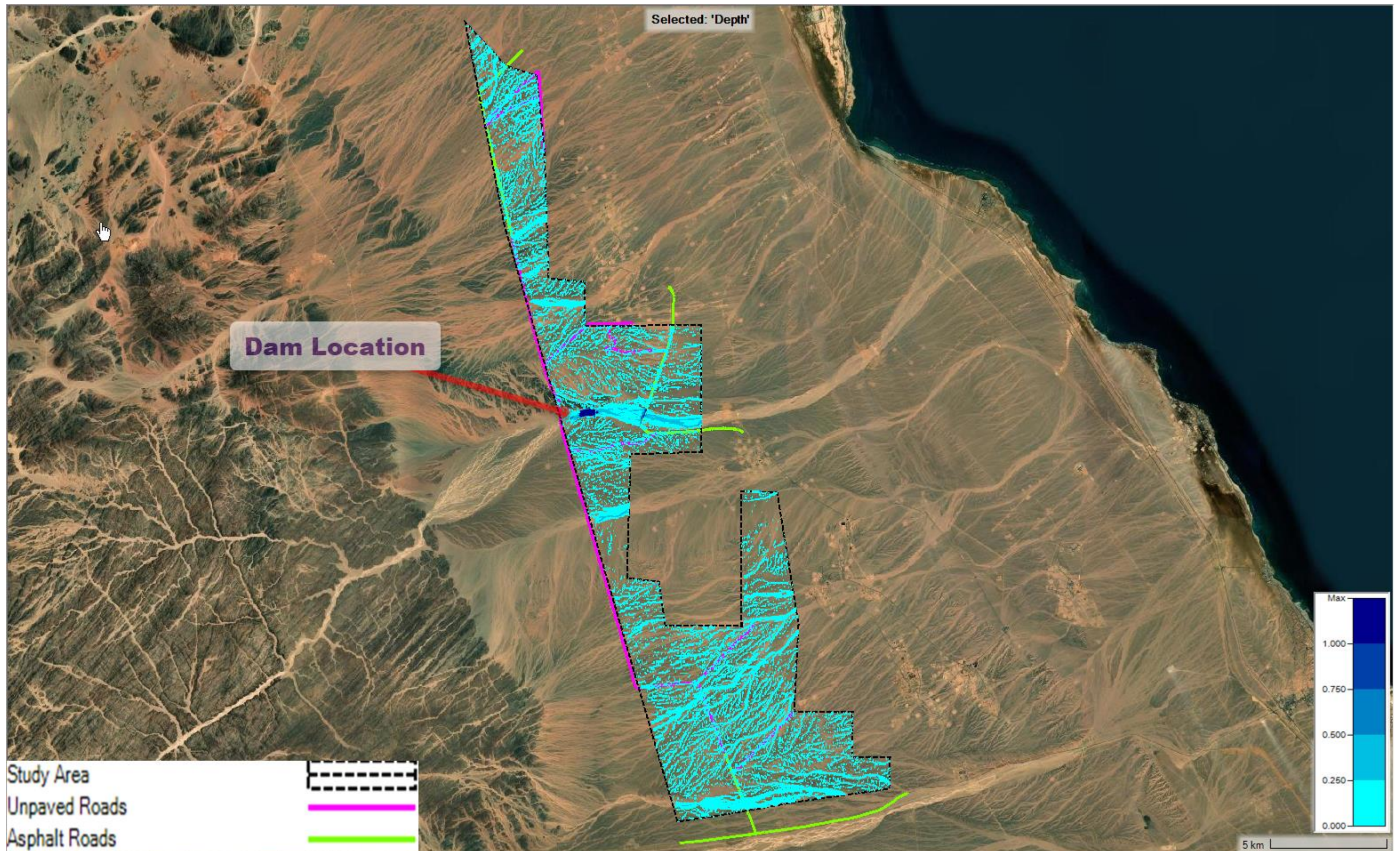


Figure A.15 : Wind tower locations on Depth Map for return period of 100 years

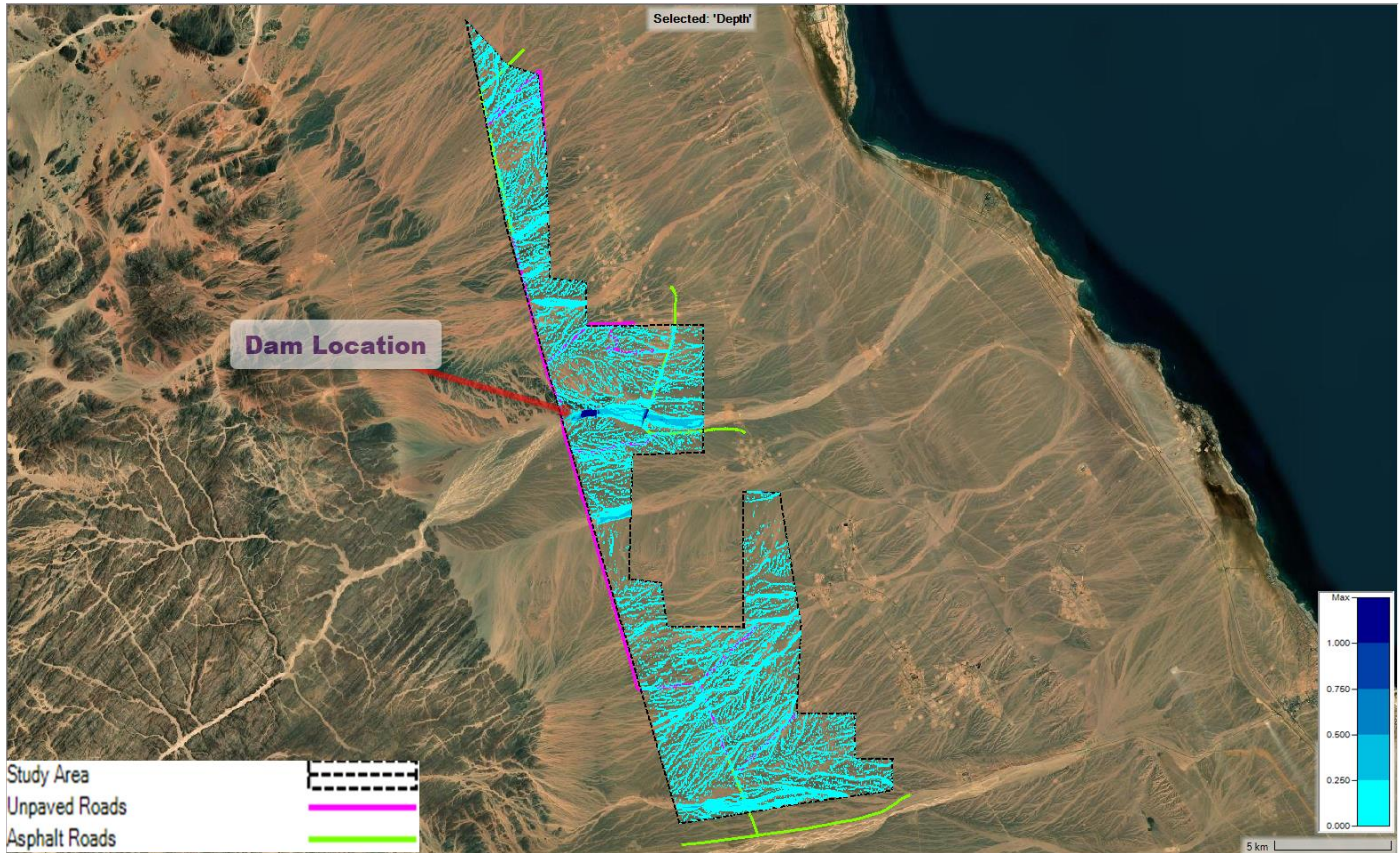


Figure A.16: Depth Map for return period of 100 years taking climate change into consideration

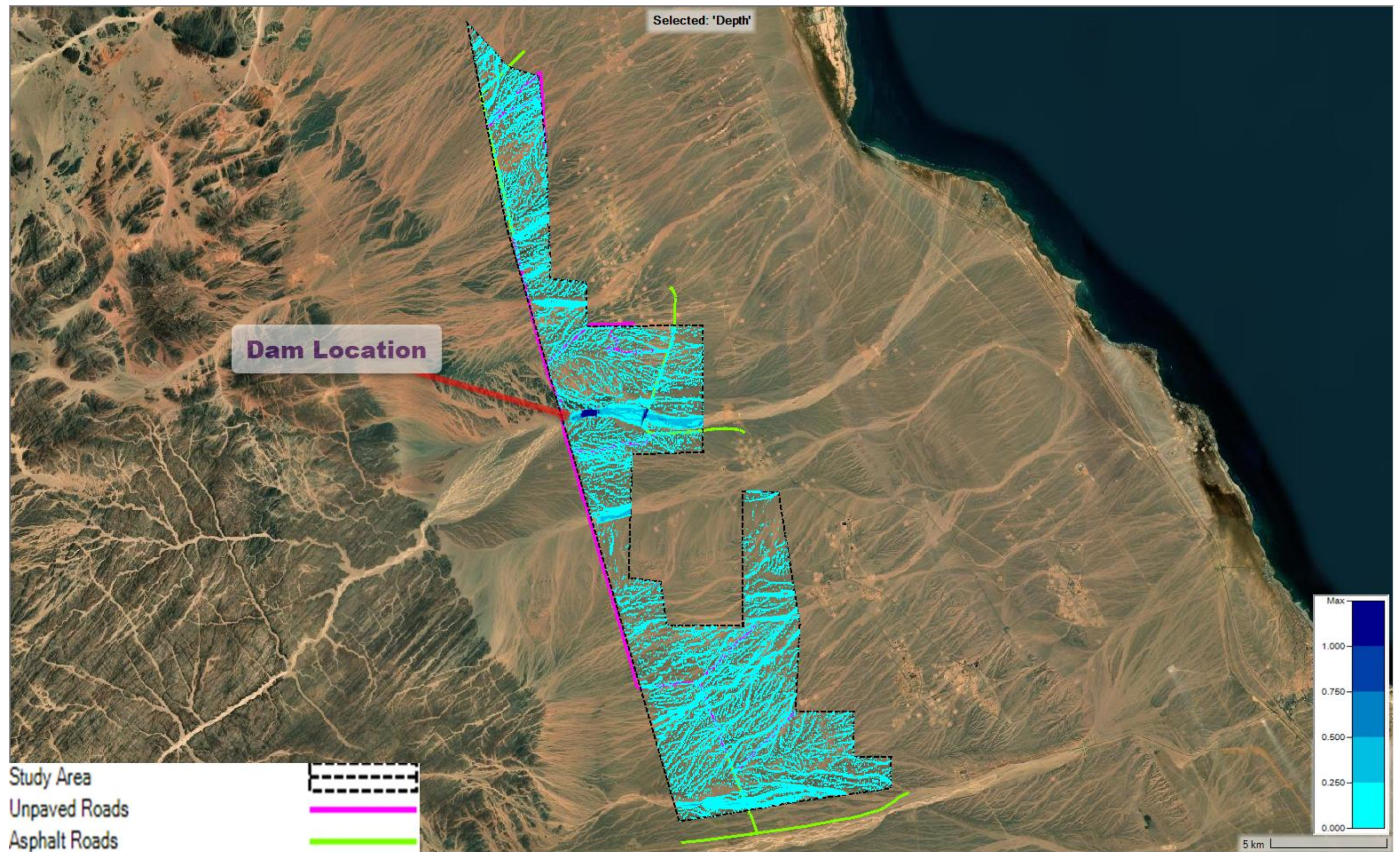


Figure A.17: Depth Map for return period of 200 years

• Velocity Maps

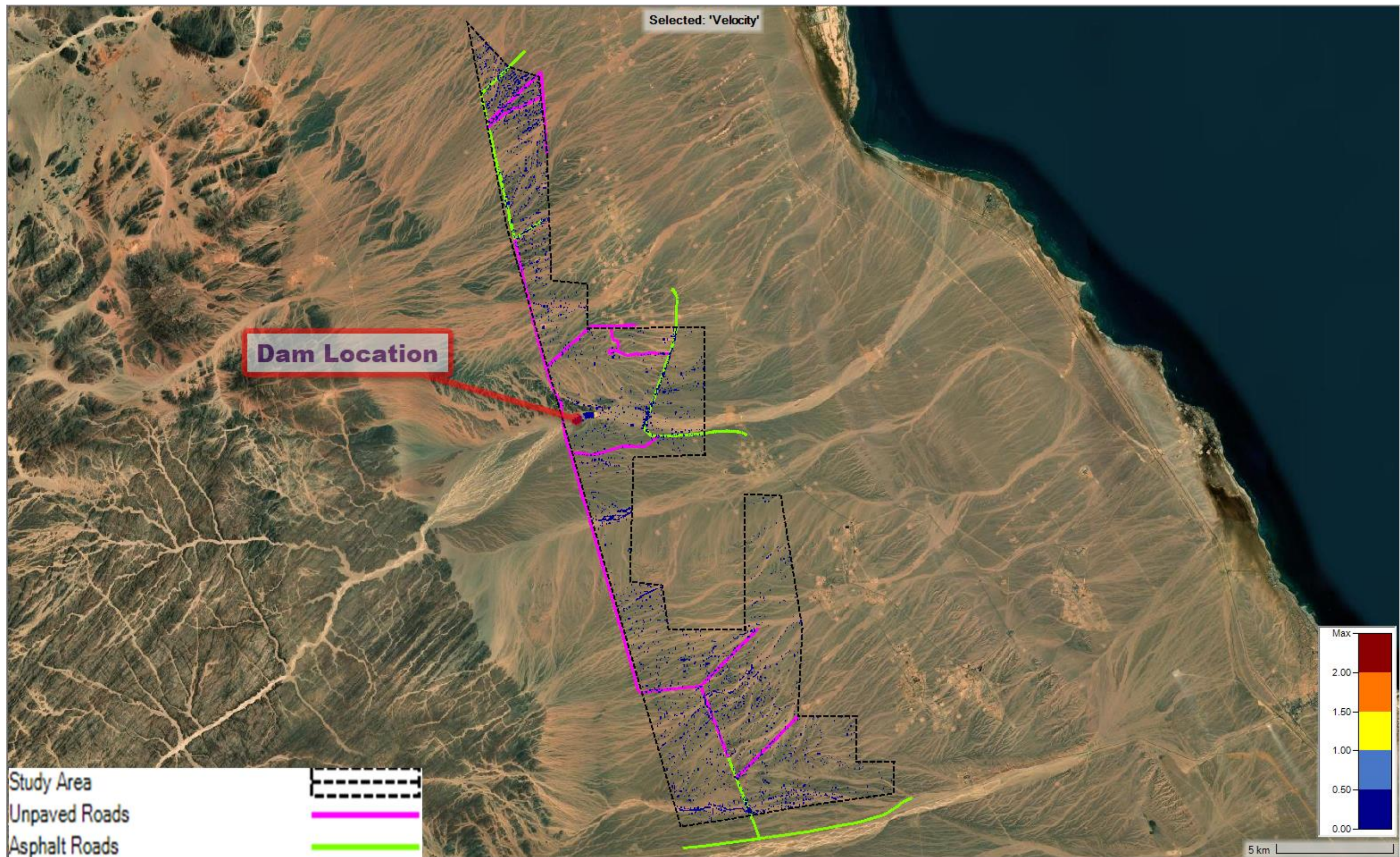


Figure A.18: Velocity Map for return period of 2 years

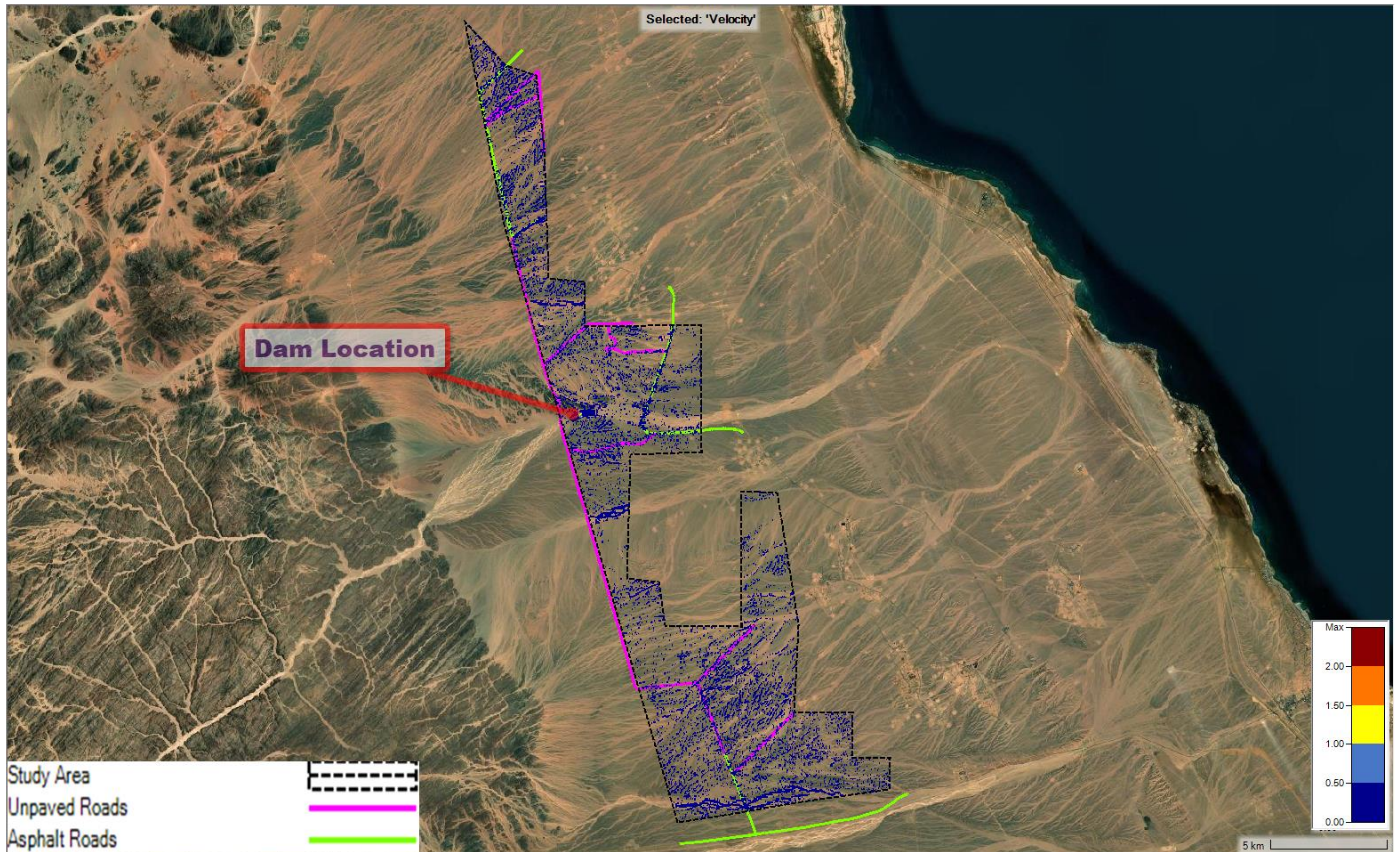


Figure A.19: Velocity Map for return period of 5 years

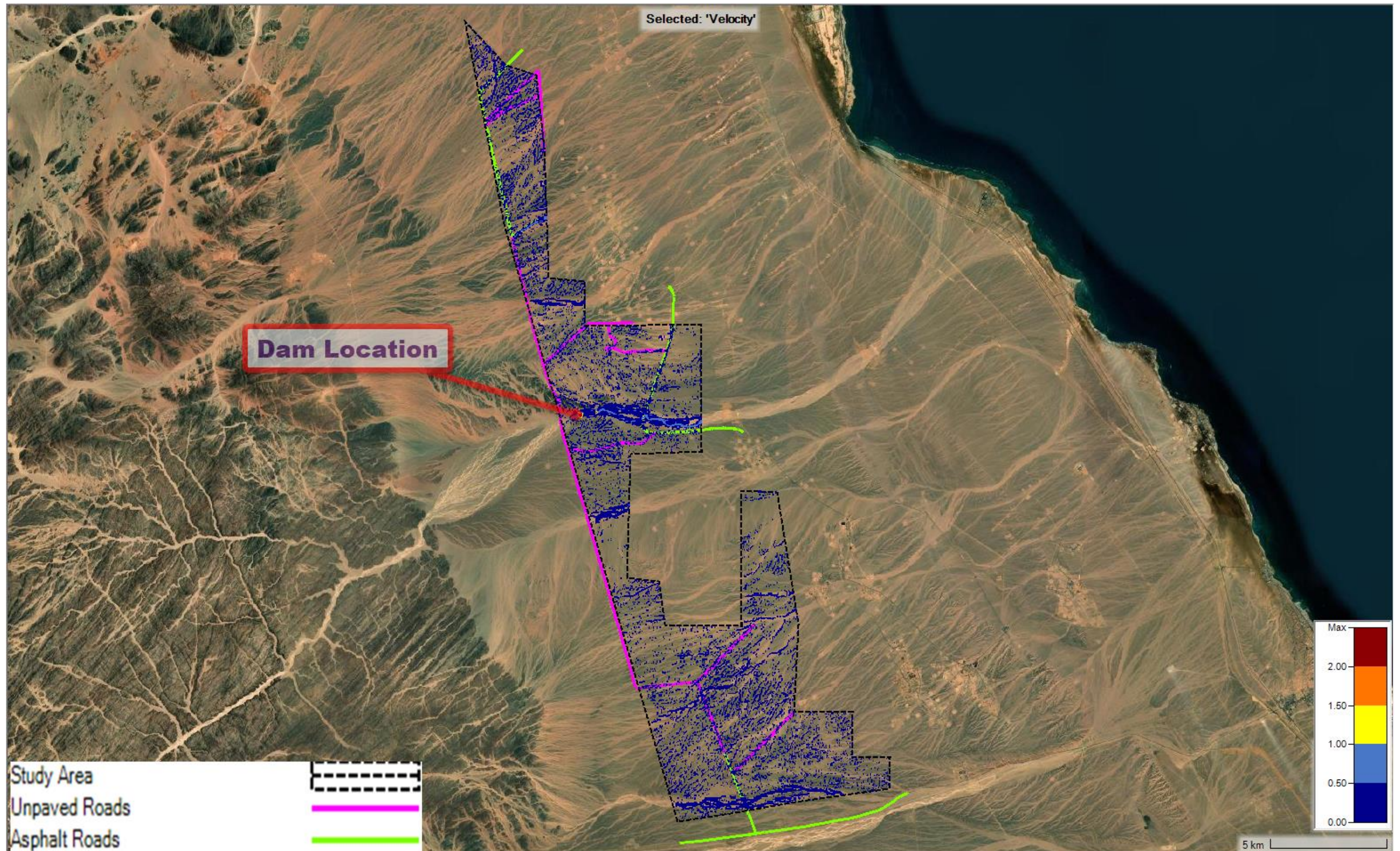


Figure A.20: Velocity Map for return period of 10 years

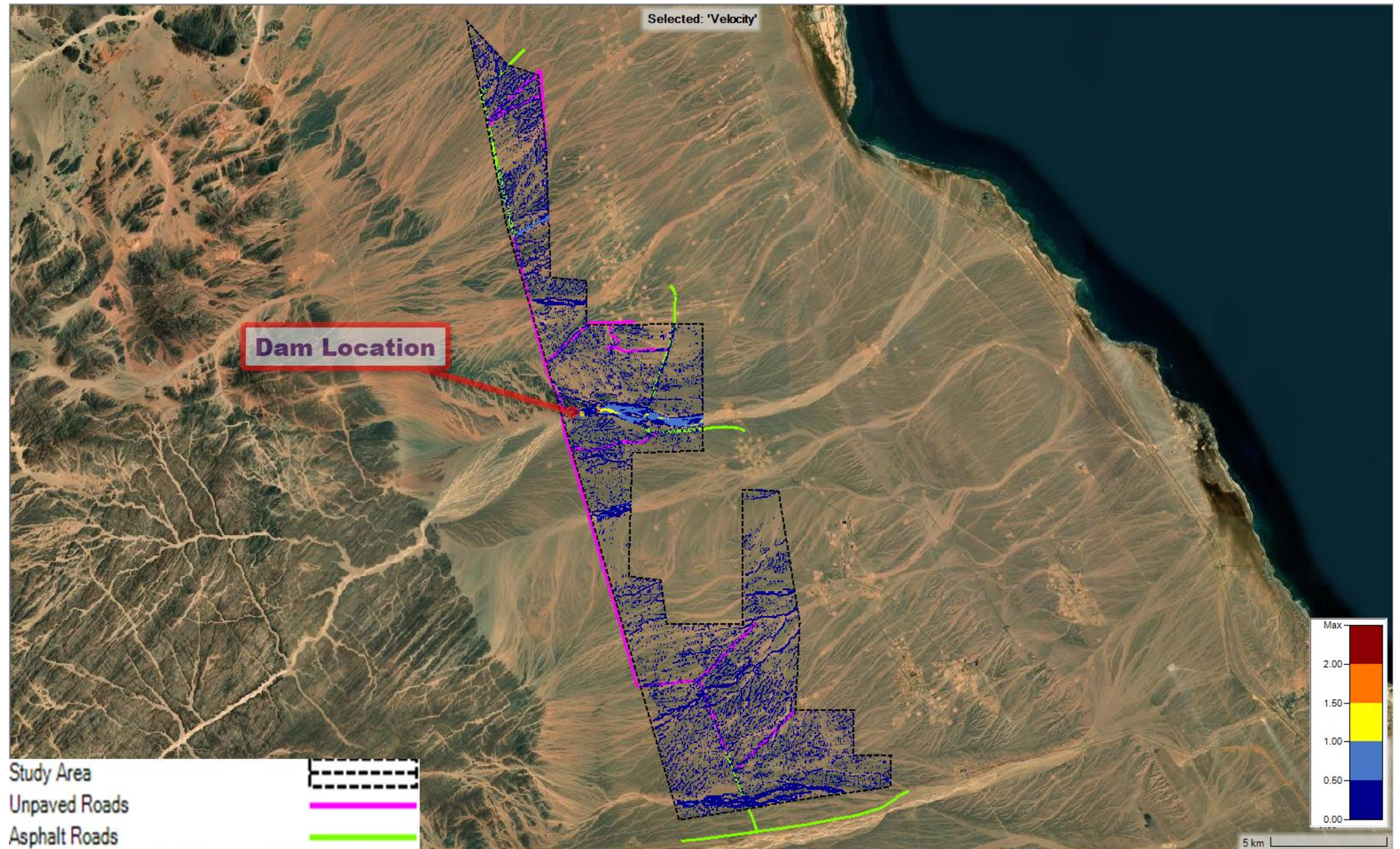


Figure A.21: Velocity Map for return period of 20 years

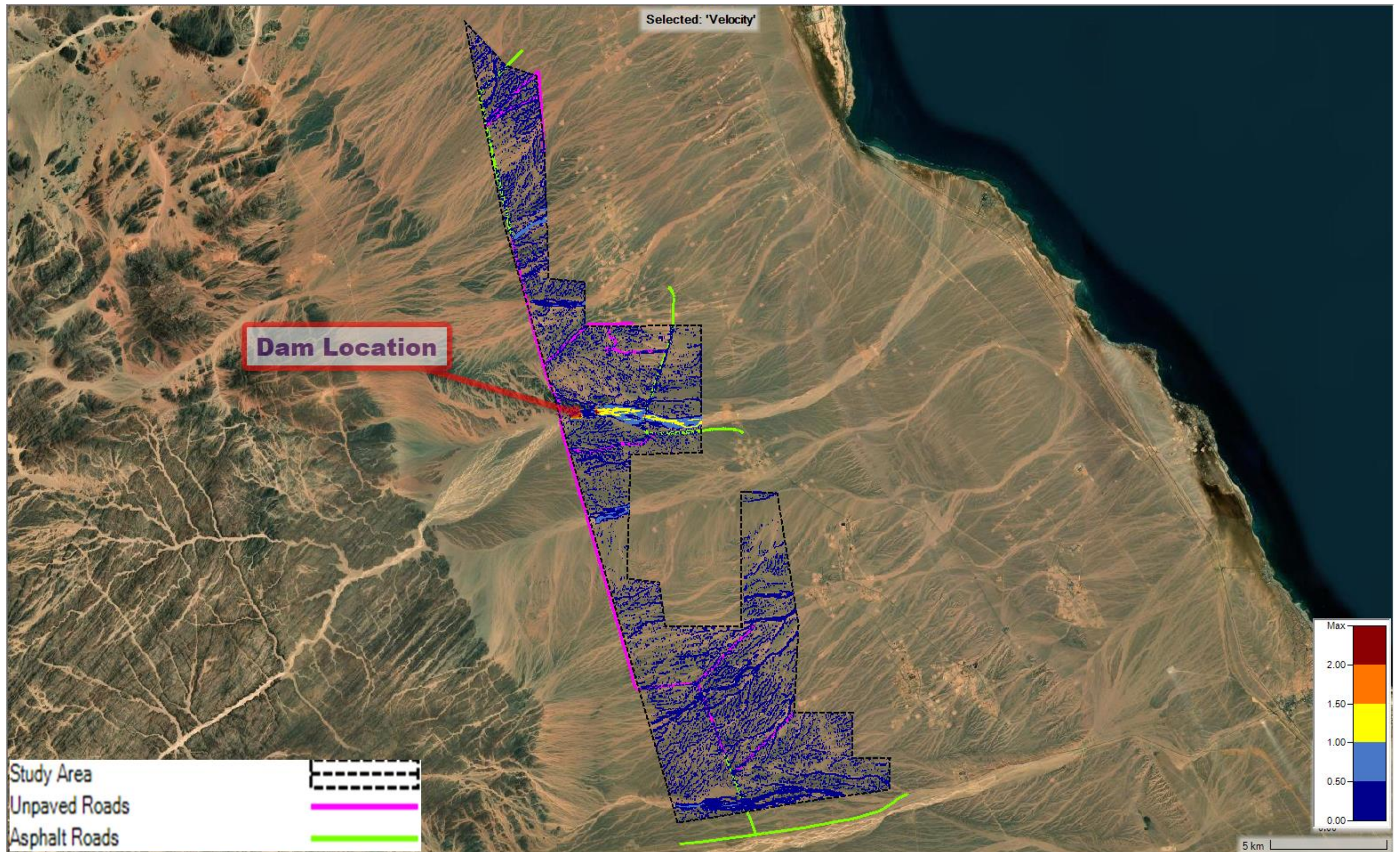


Figure A.22: Velocity Map for return period of 50 years

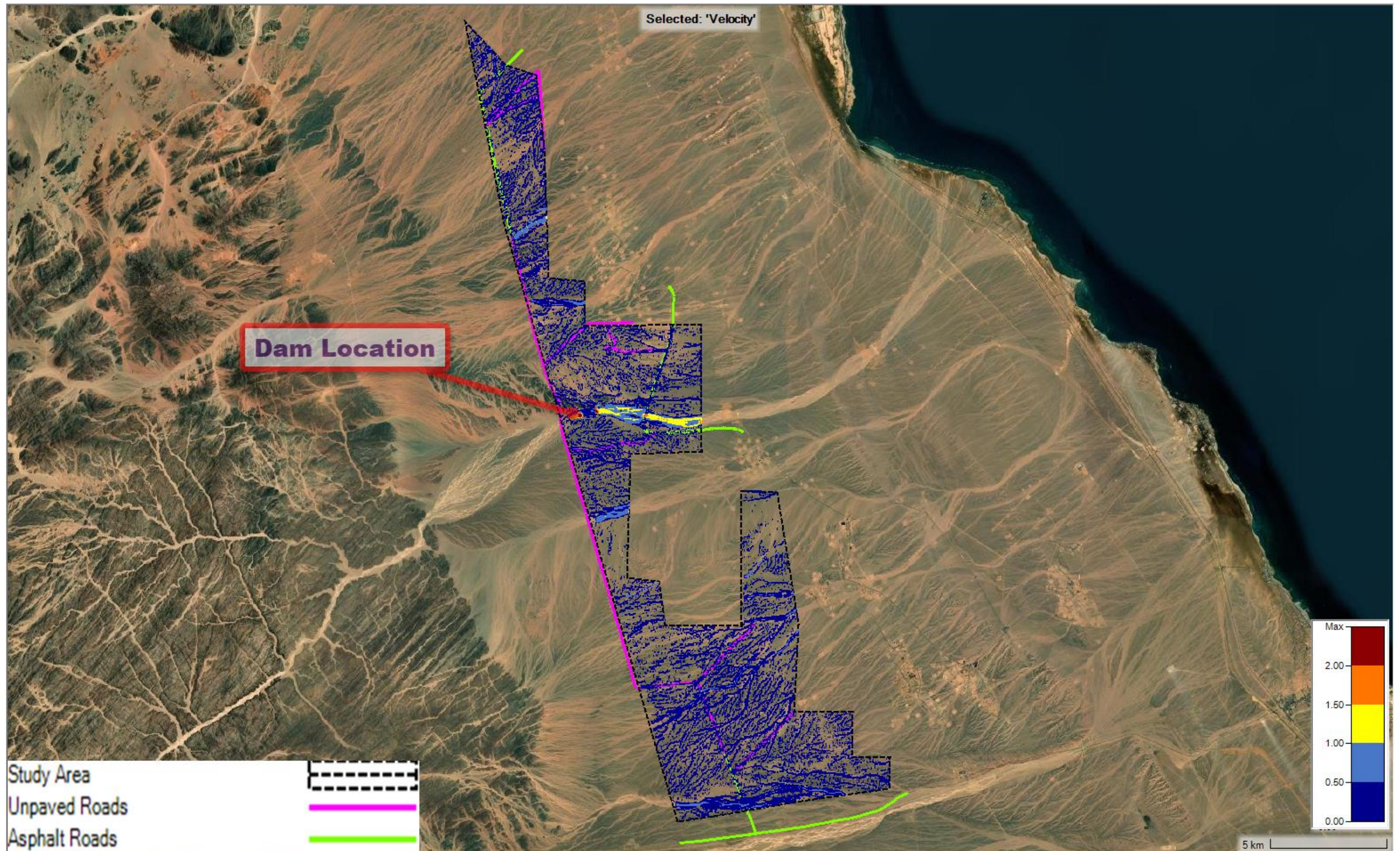


Figure A.23 : Velocity Map for return period of 100 years

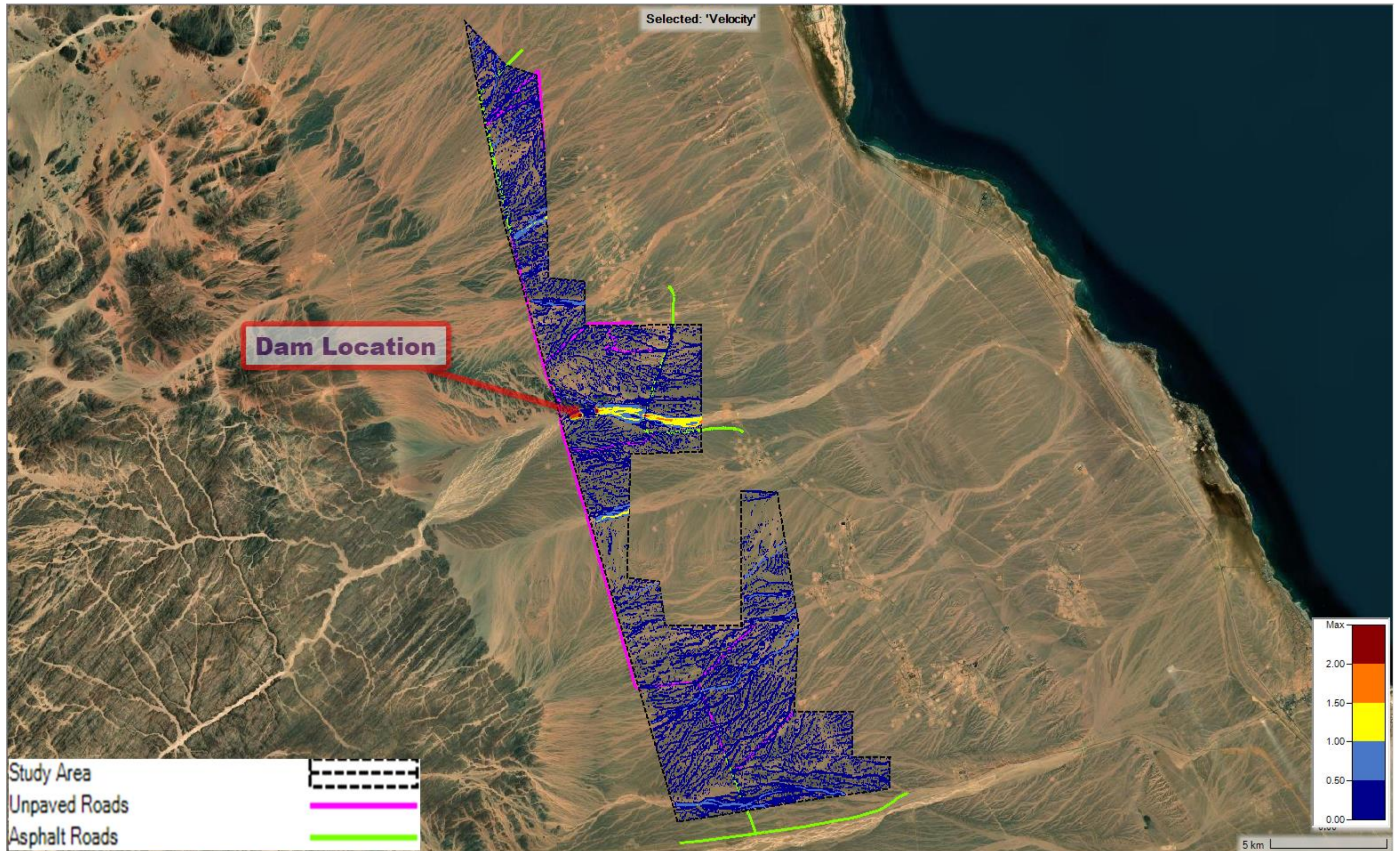


Figure A.24: Velocity Map for return period of 100 years taking climate change into consideration

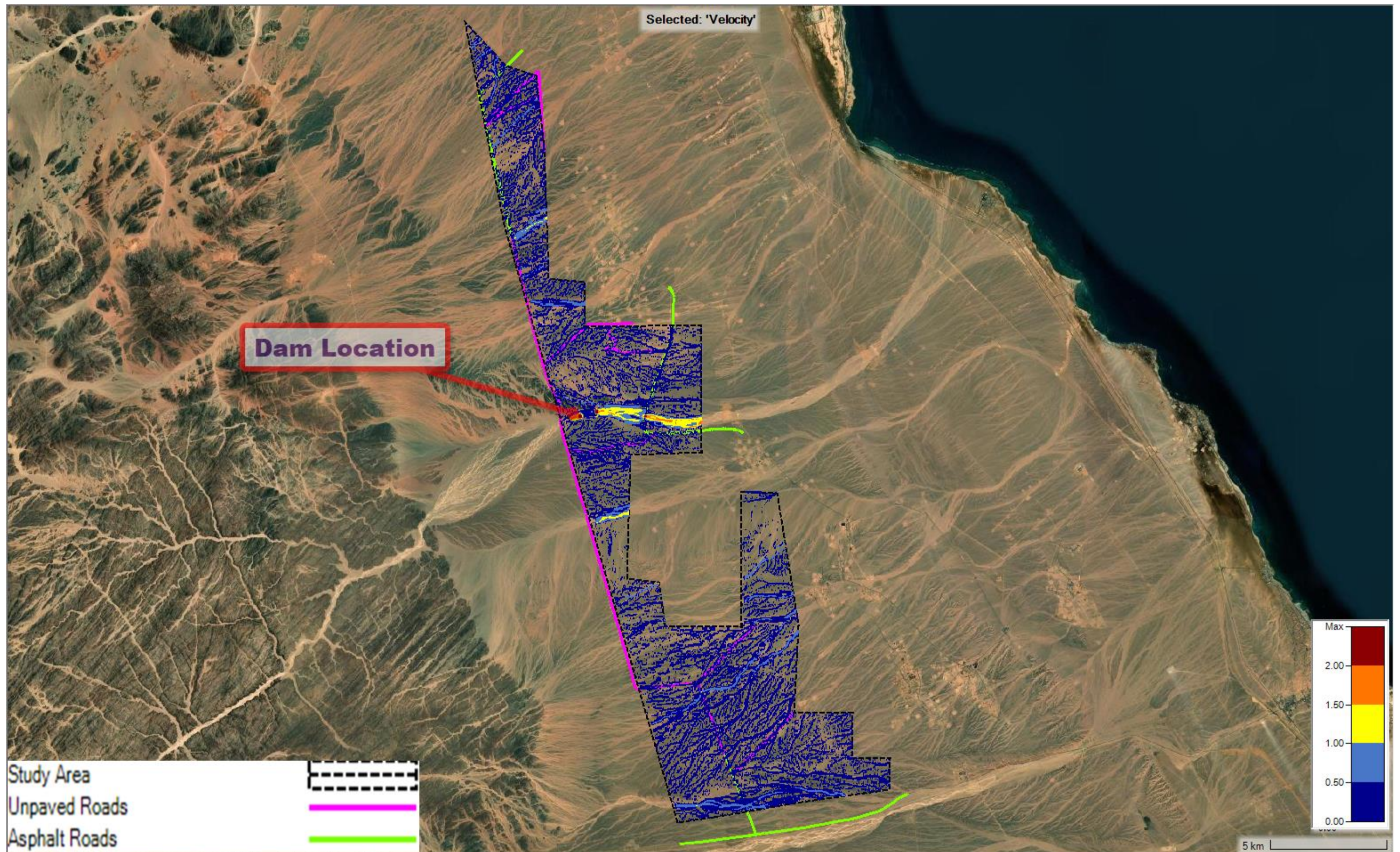


Figure A.25: Velocity Map for return period of 200 years

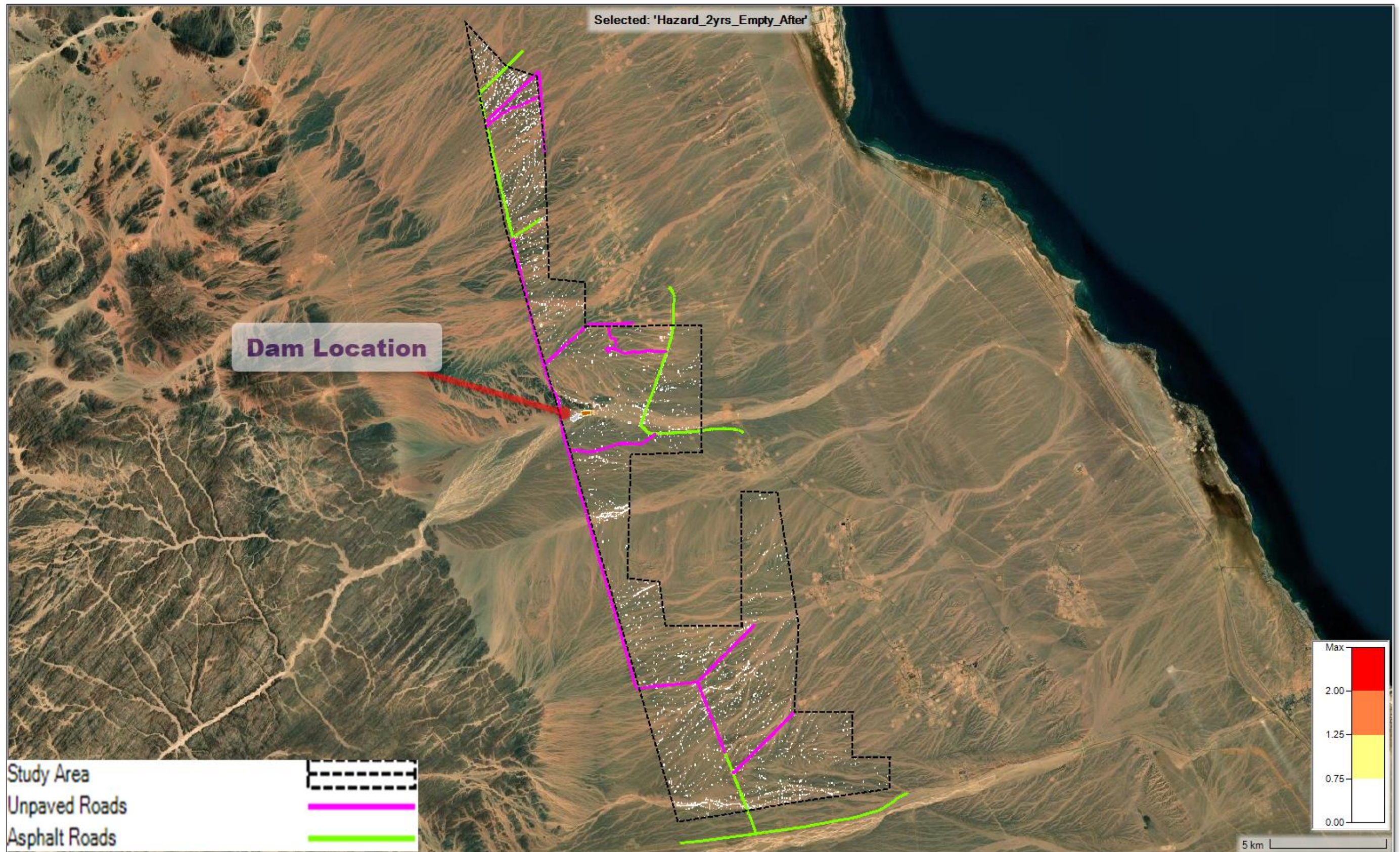


Figure A.26: Hazard Map for return period of 2 years

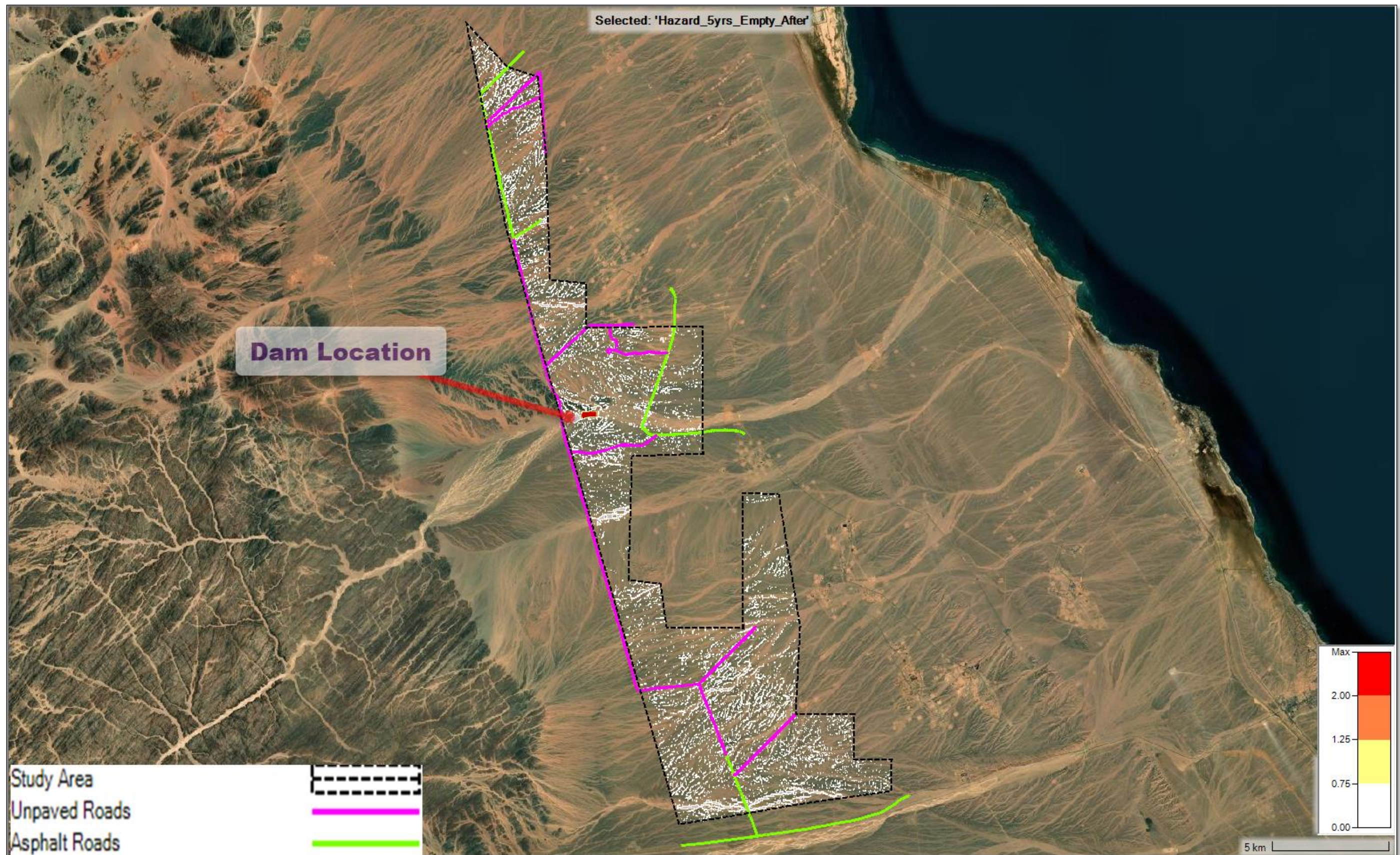


Figure A.27 : Hazard Map for return period of 5 years

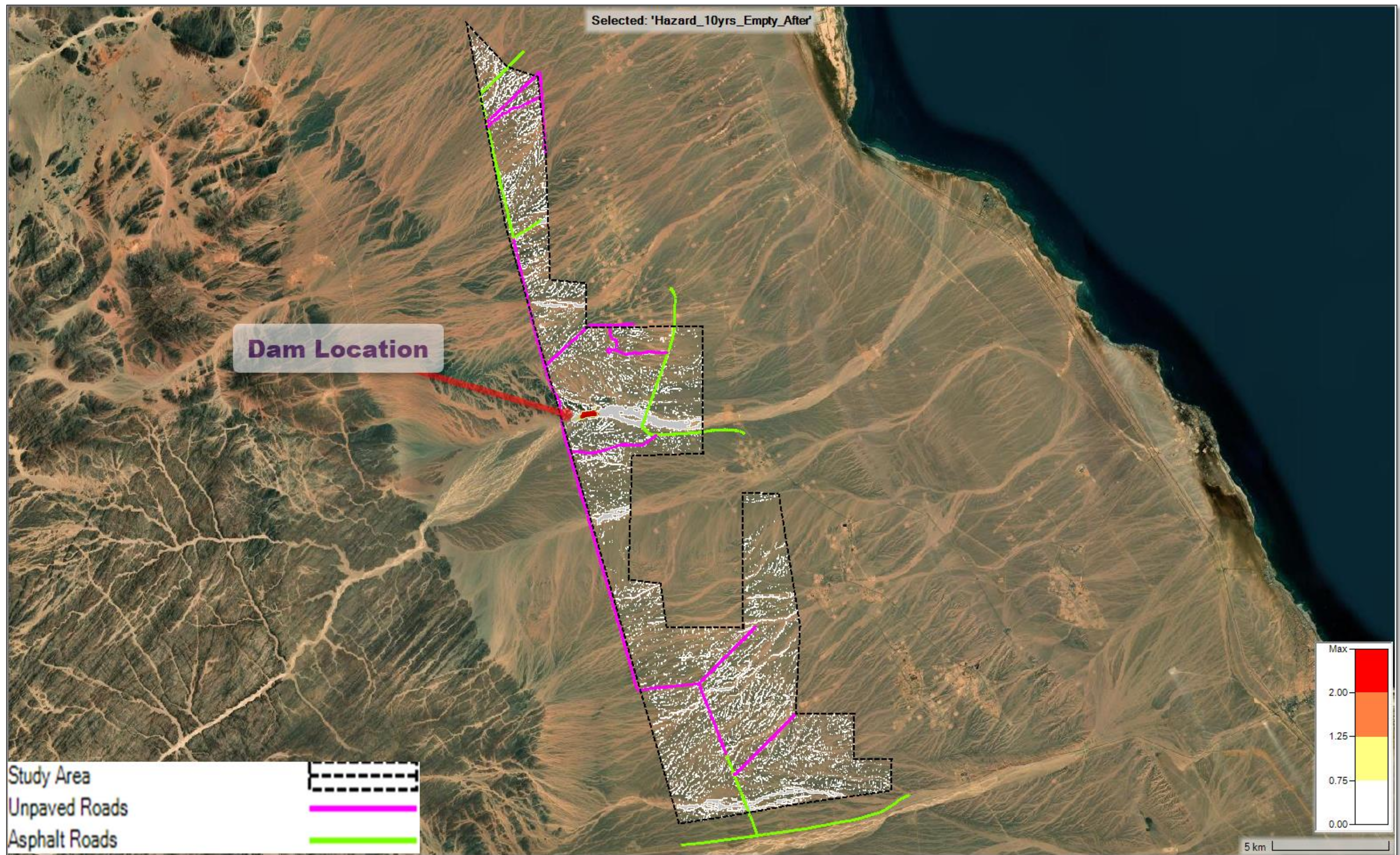


Figure A.28: Hazard Map for return period of 10 years

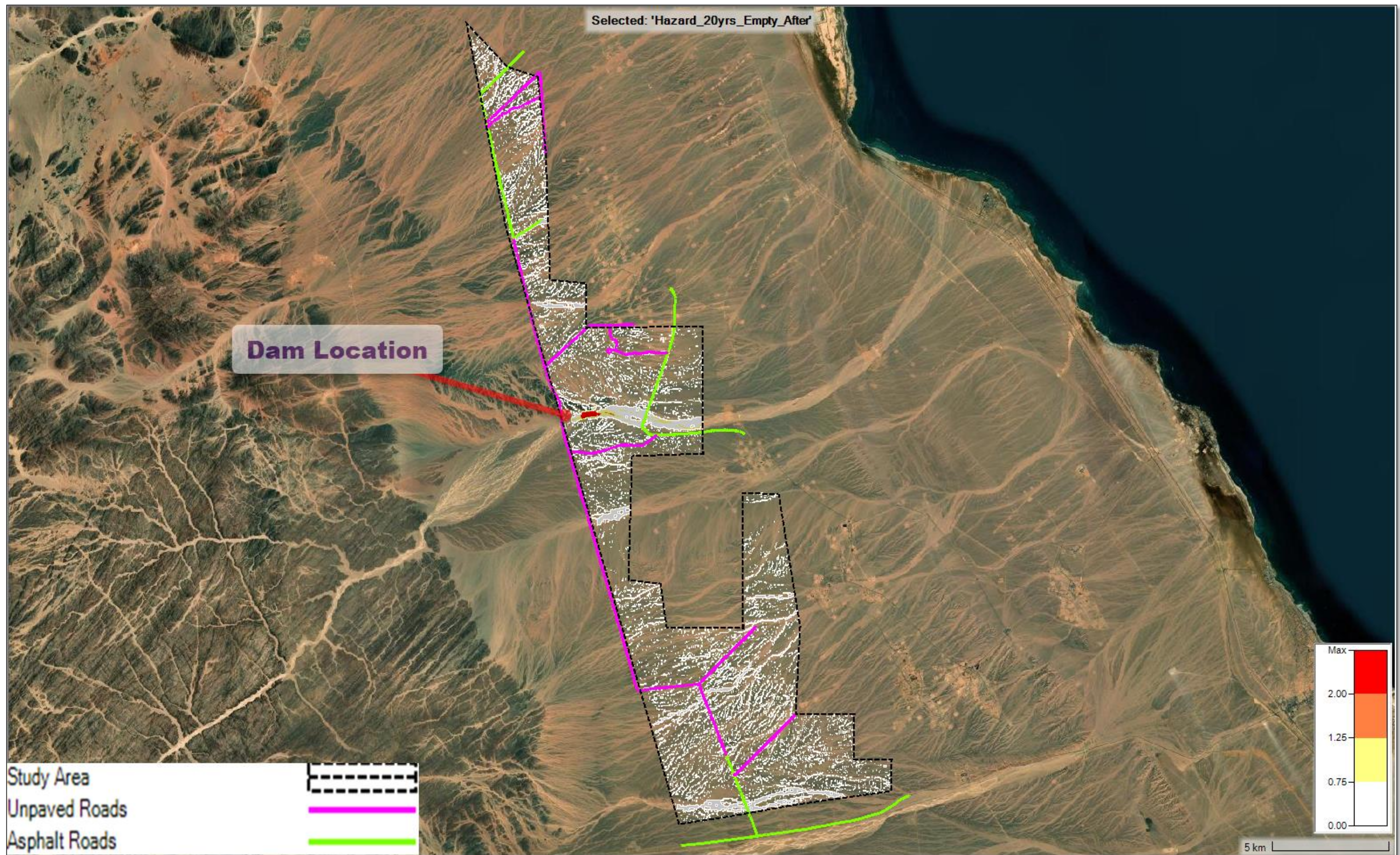


Figure A.29: Hazard Map for return period of 20 years

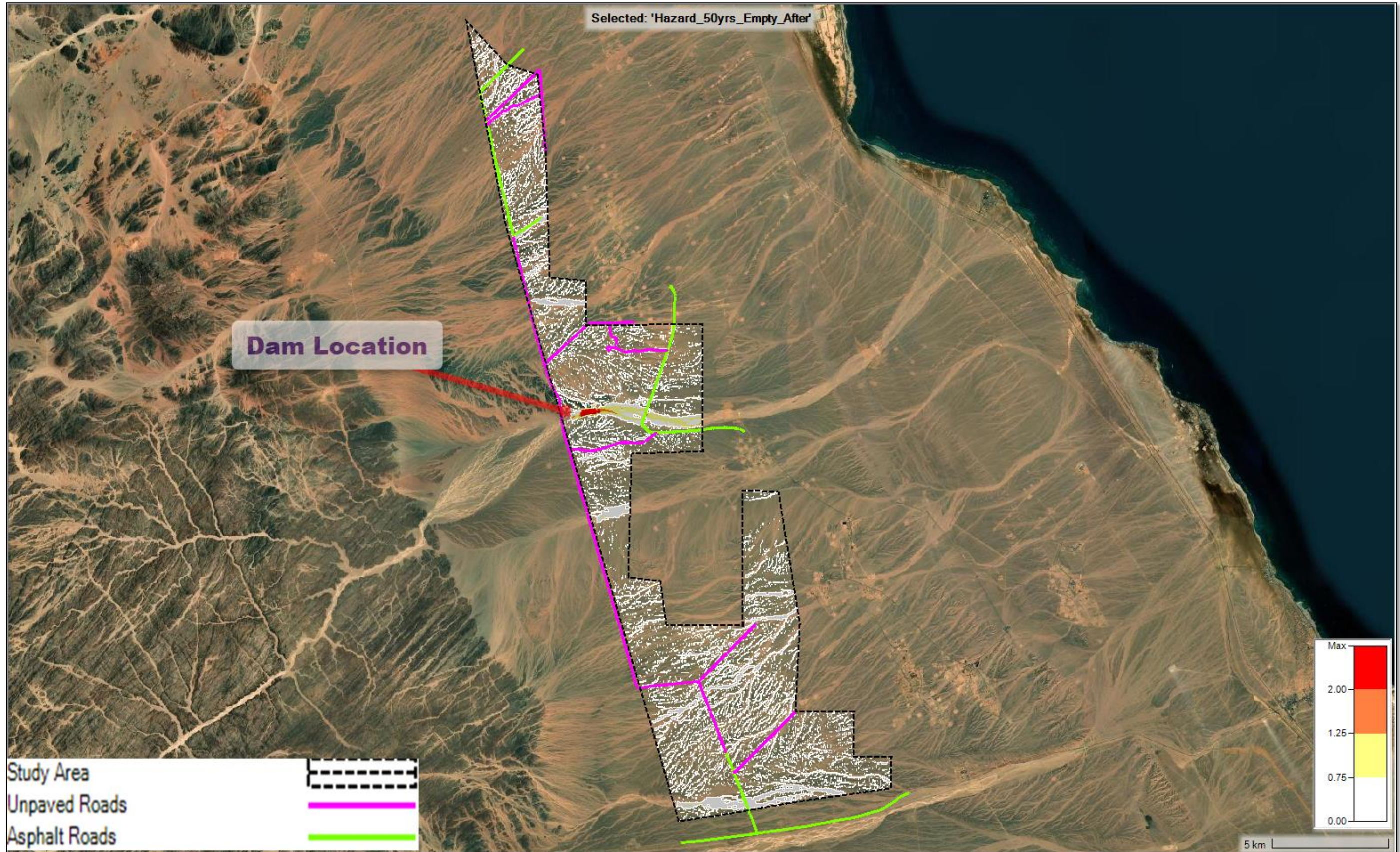


Figure A.30: Hazard Map for return period of 50 years

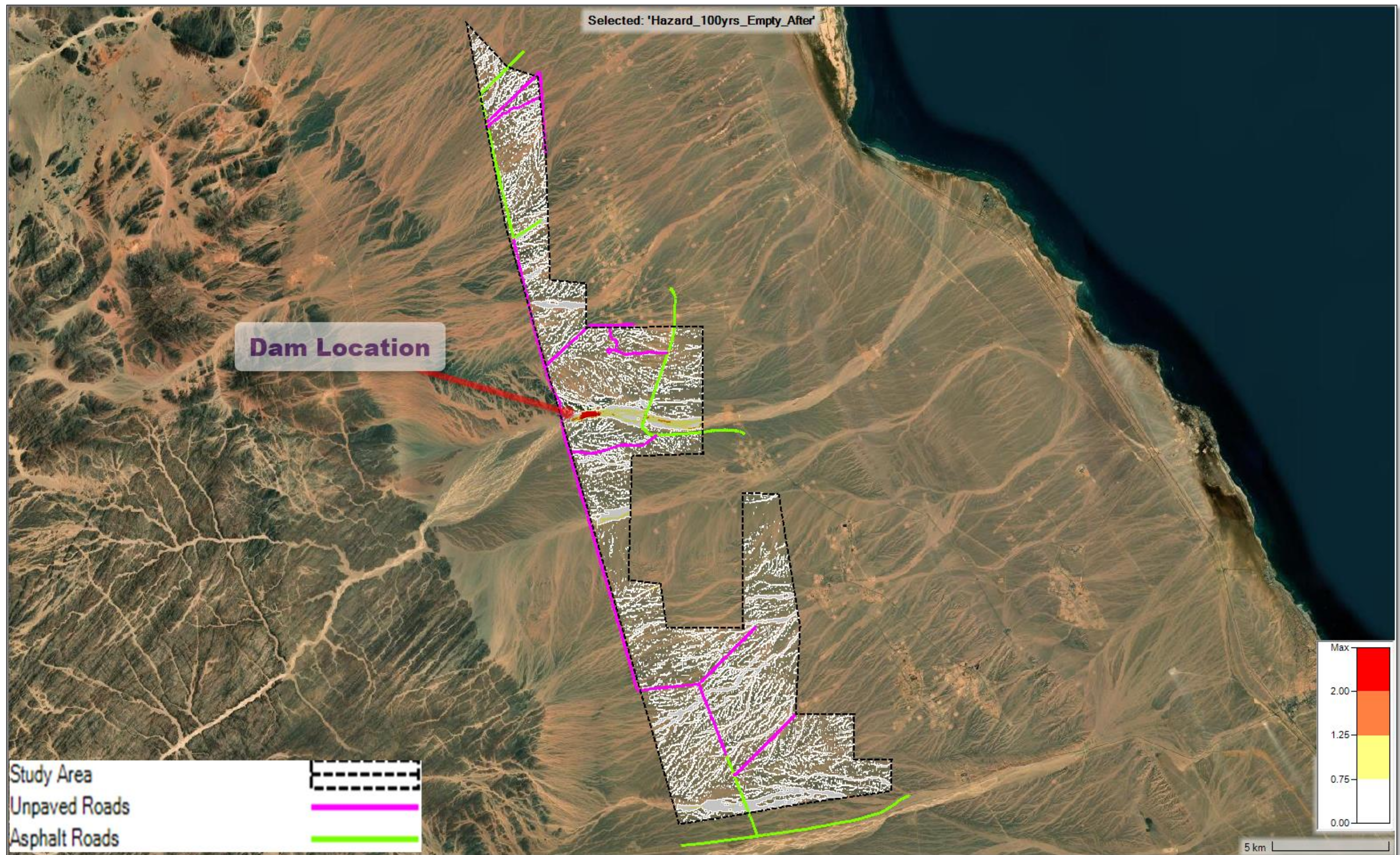


Figure A.31 : Hazard Map for return period of 100 years

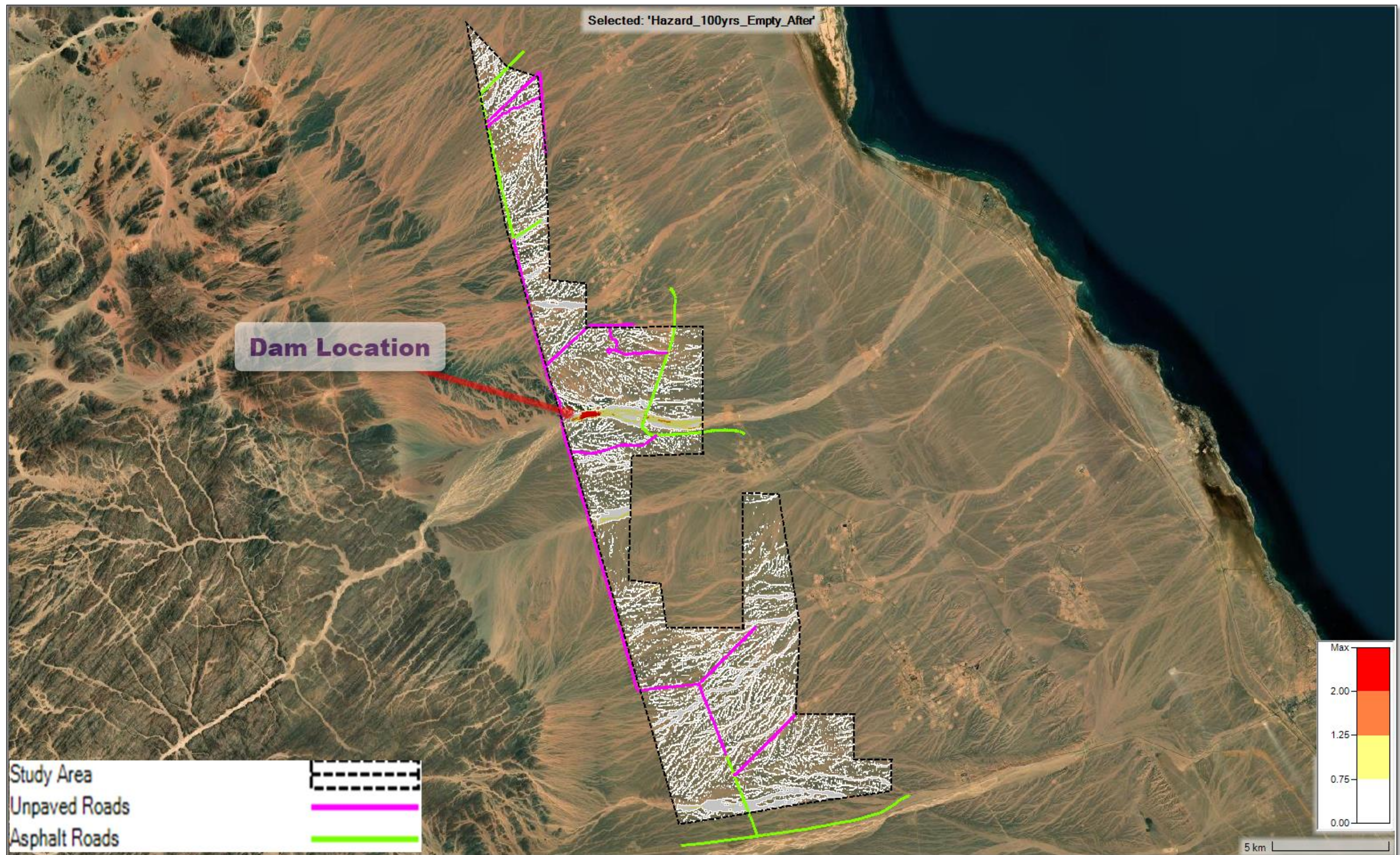


Figure A.32: Hazard Map for return period of 100 years taking climate change into consideration

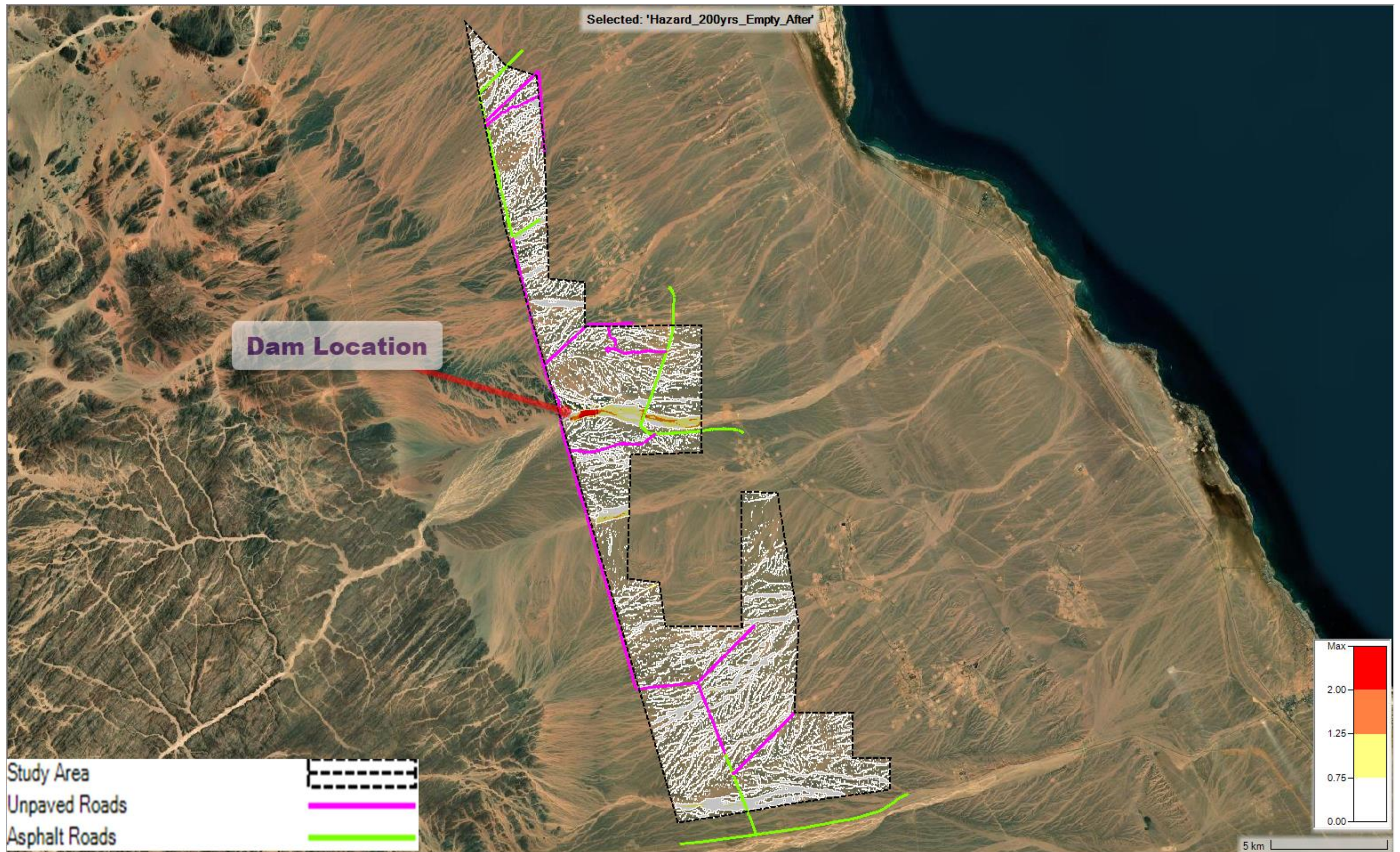


Figure A.33: Hazard Map for return period of 200 years

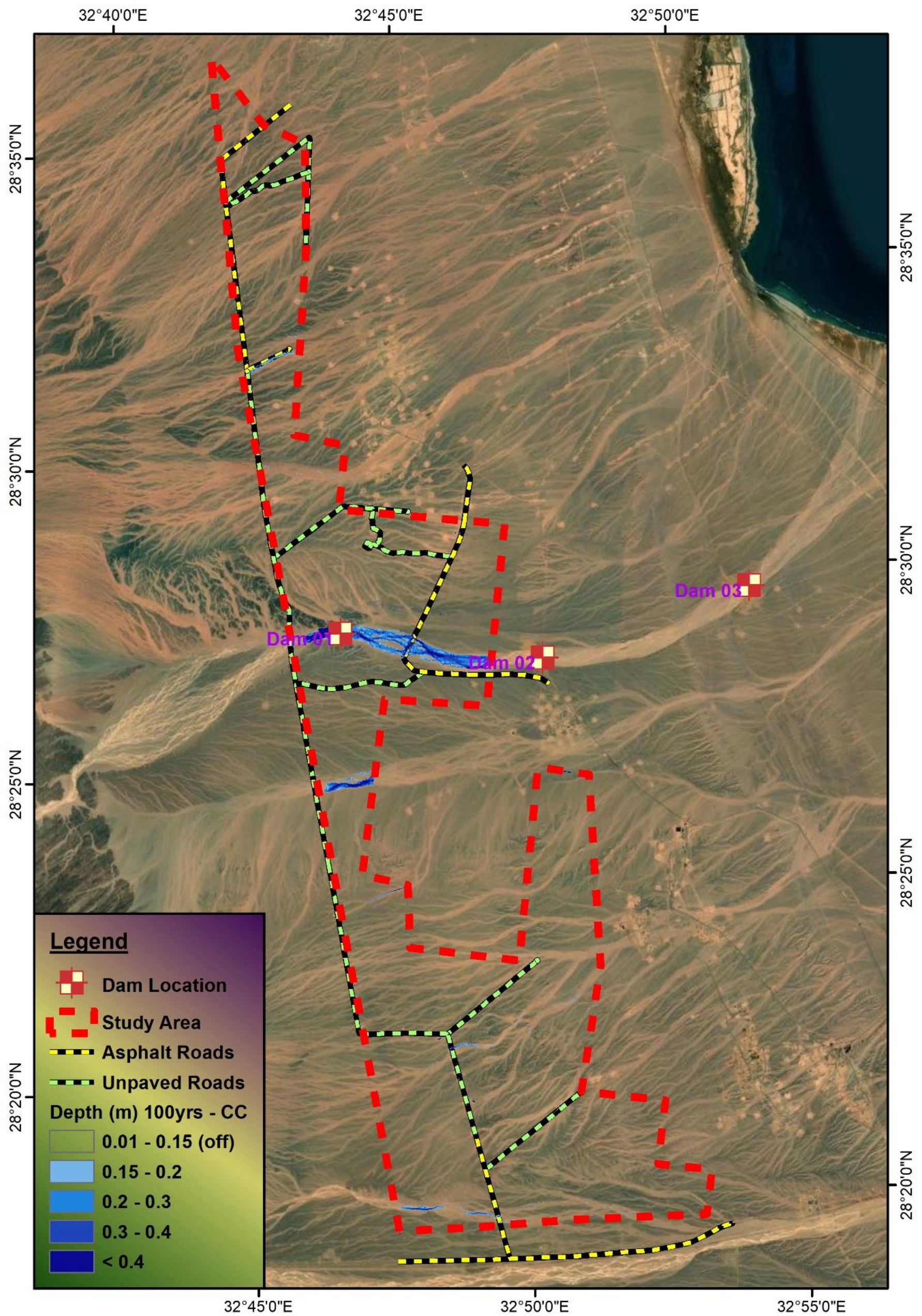


Figure A.34: Depth map for return period of 100 years taking climate change into consideration and excluding flood depths below 0.15 m

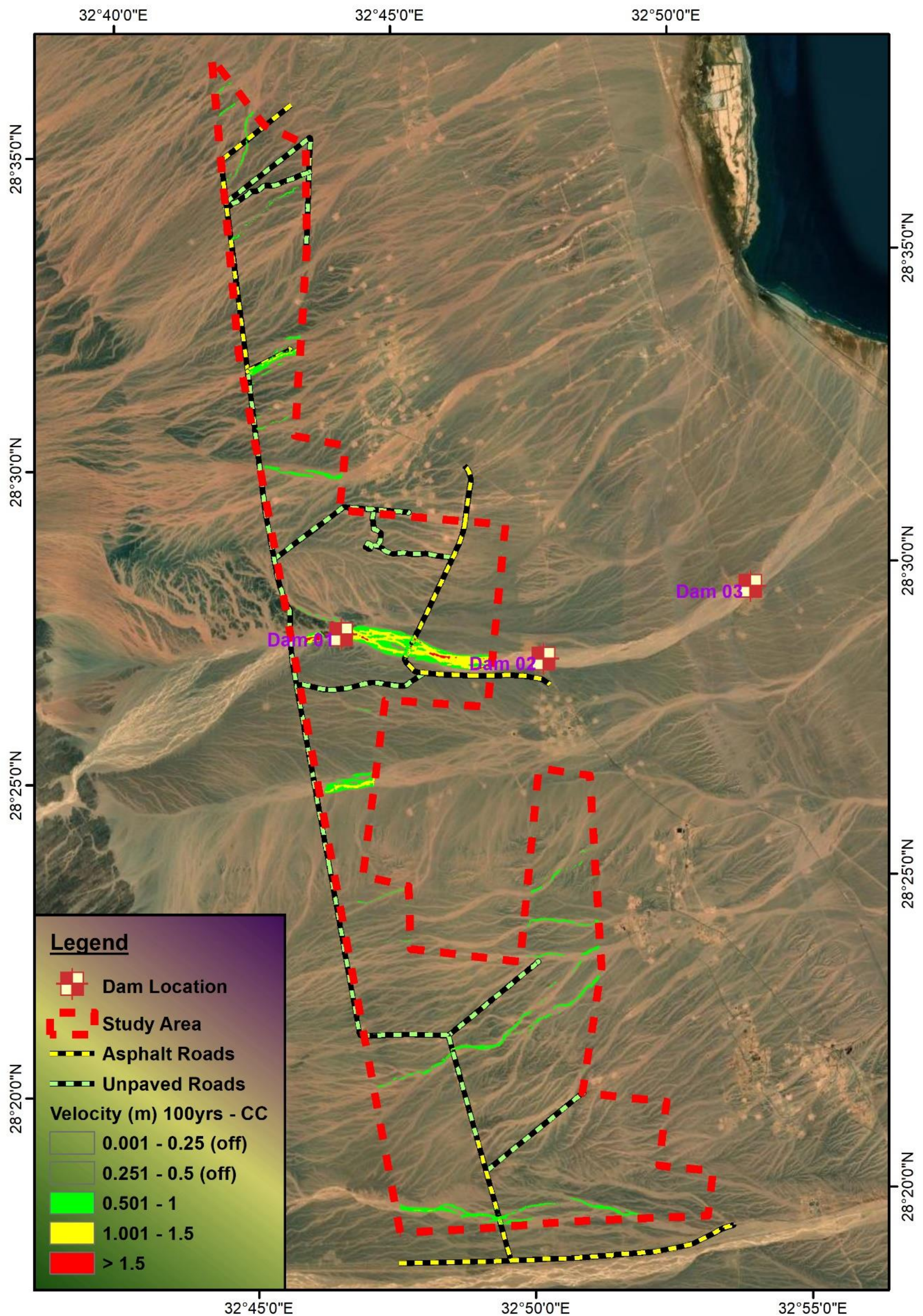


Figure A.35: Velocity map for return period of 100 years taking climate change into consideration and excluding flood depths below 0.5 m/s

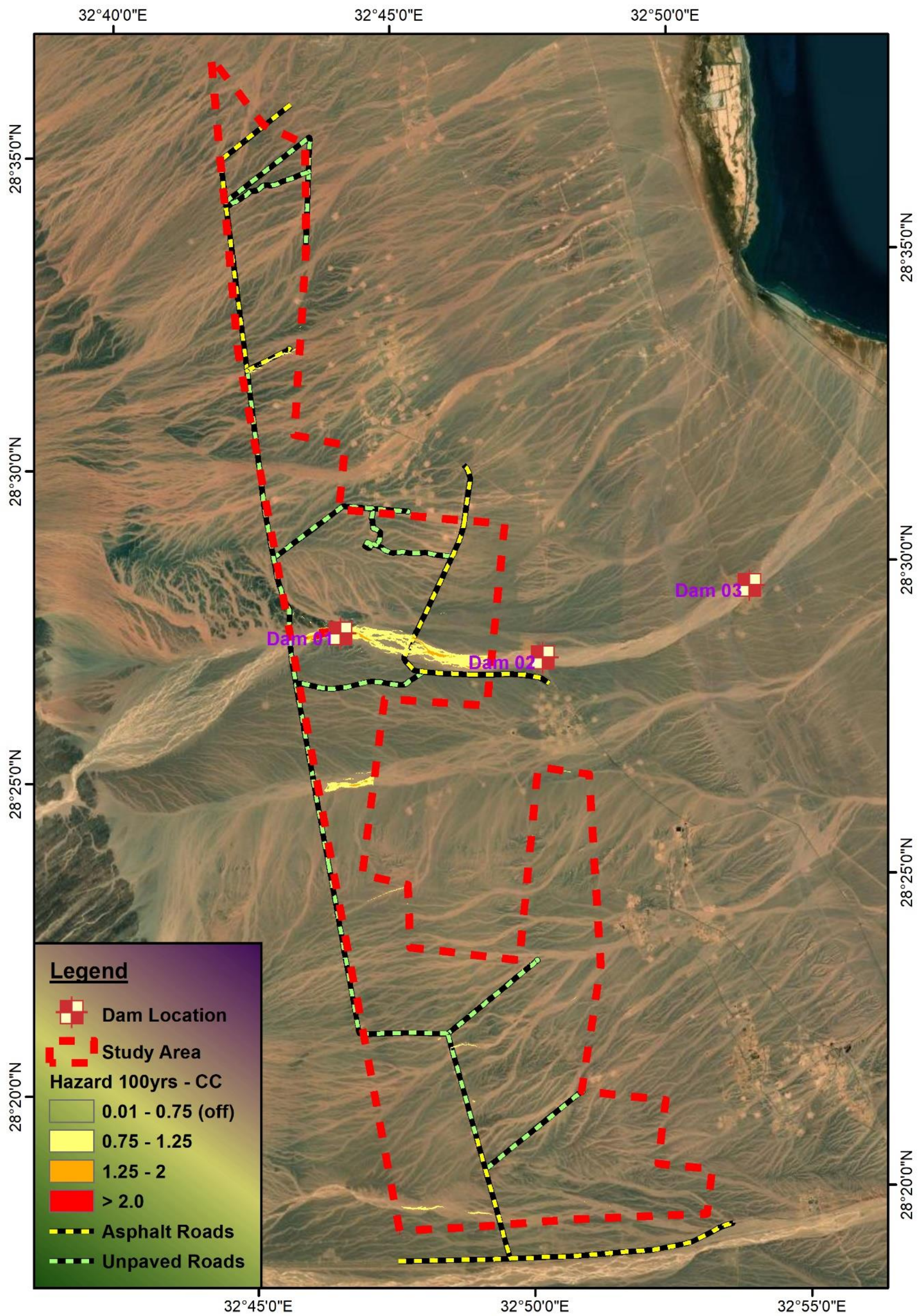


Figure A.36: Hazard map for return period of 100 years taking climate change into consideration and excluding low hazard areas

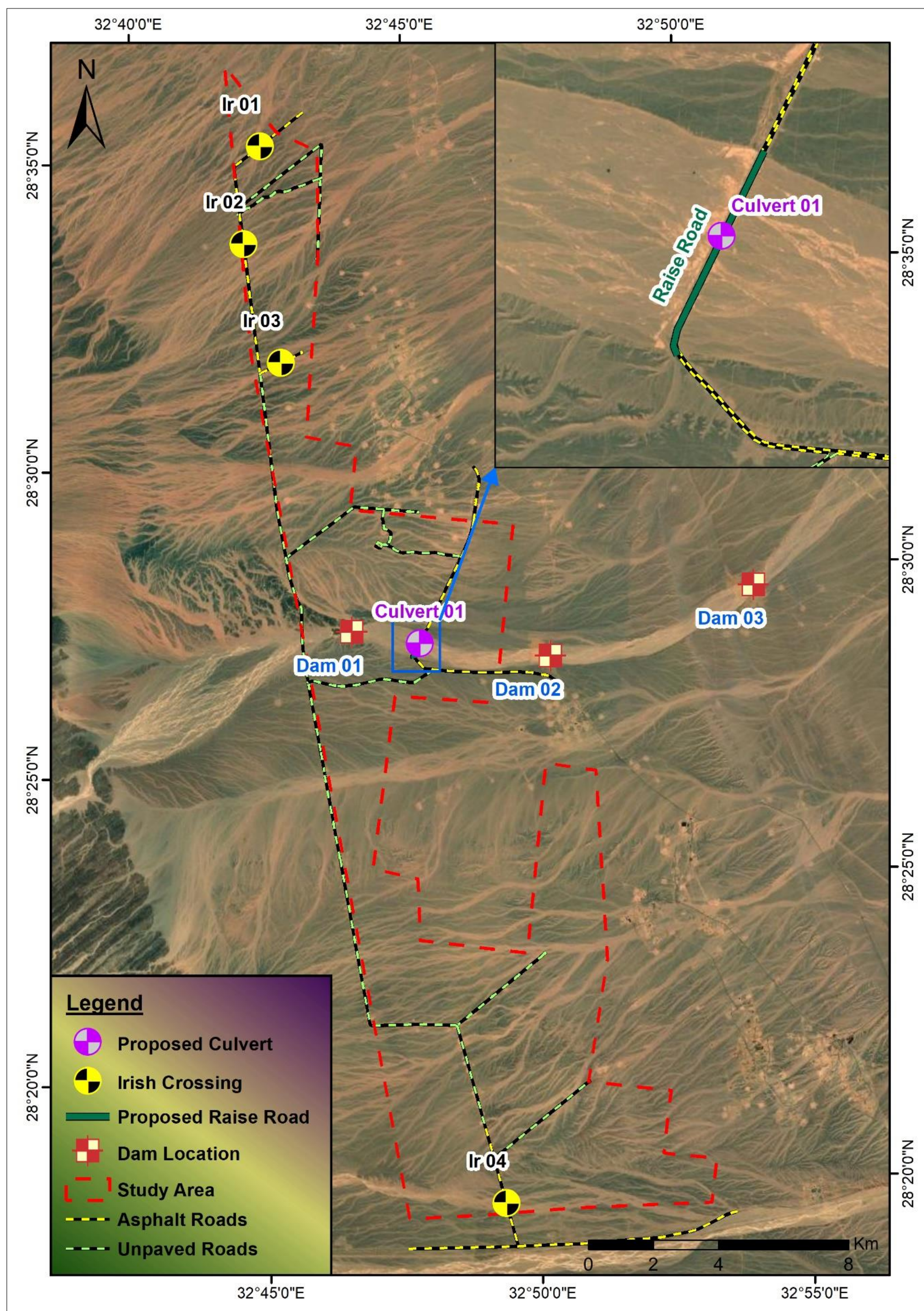


Figure A.37: Locations of proposed protection measures on satellite image

Culvert Analysis Report Culvert-1

Culvert Summary

Computed Headwater Elevation	242.32 m	Discharge	152.3000 m ³ /s
Inlet Control HW Elev.	242.13 m	Tailwater Elevation	N/A m
Outlet Control HW Elev.	242.32 m	Control Type	Entrance Control
Headwater Depth/Height	1.21		

Grades

Upstream Invert	240.50 m	Downstream Invert	240.33 m
Length	25.00 m	Constructed Slope	0.007000 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.90 m
Slope Type	Steep	Normal Depth	0.88 m
Flow Regime	Supercritical	Critical Depth	1.04 m
Velocity Downstream	3.69 m/s	Critical Slope	0.004229 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	2.00 m
Section Size	2000*1500	Rise	1.50 m
Number Sections	23		

Outlet Control Properties

Outlet Control HW Elev.	242.32 m	Upstream Velocity Head	0.52 m
Ke	0.50	Entrance Loss	0.28 m

Inlet Control Properties

Inlet Control HW Elev.	242.13 m	Flow Control	Unsubmerged
Inlet Type	18.4° wingwall flares - offset	Area Full	69.0 m ²
K	0.49300	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	3
C	0.02270	Equation Form	2
Y	0.89700		

Figure A.38: Culvert analysis report

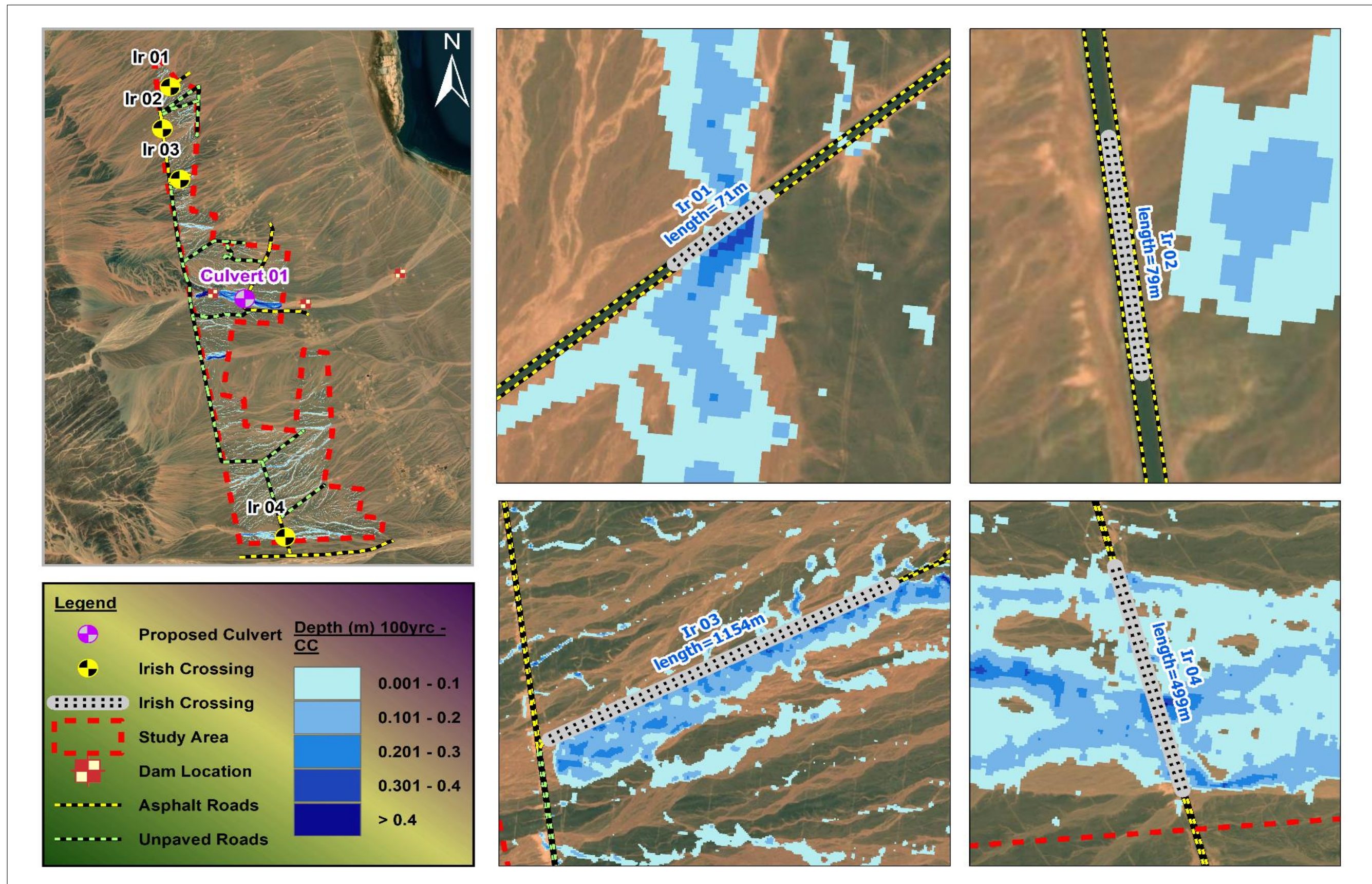


Figure A 39: Locations of proposed Irish crossings on Depth Map for return period of 100 years + CC

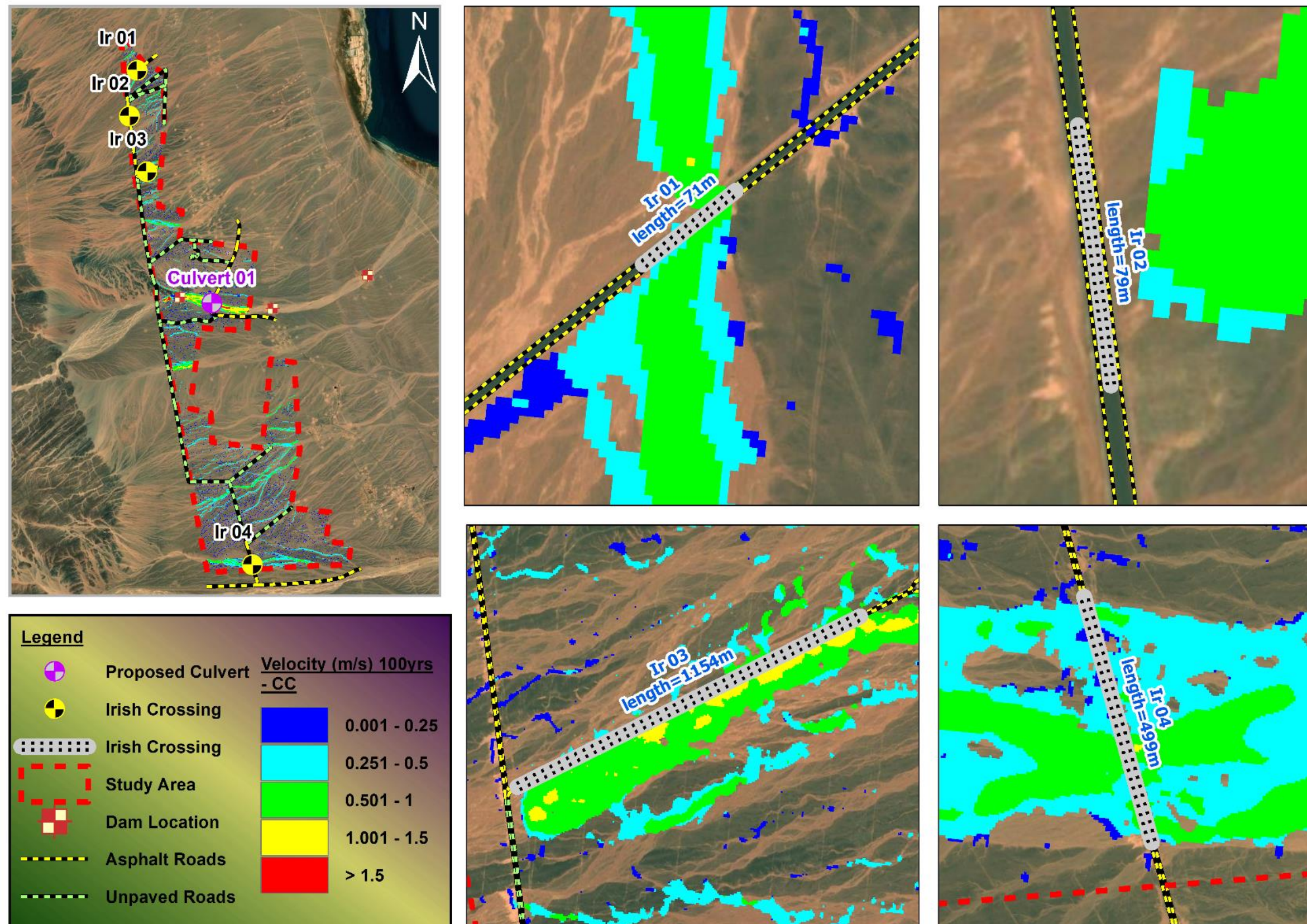


Figure A.40: Locations of proposed Irish crossings on Velocity Map for return period of 100 years + CC

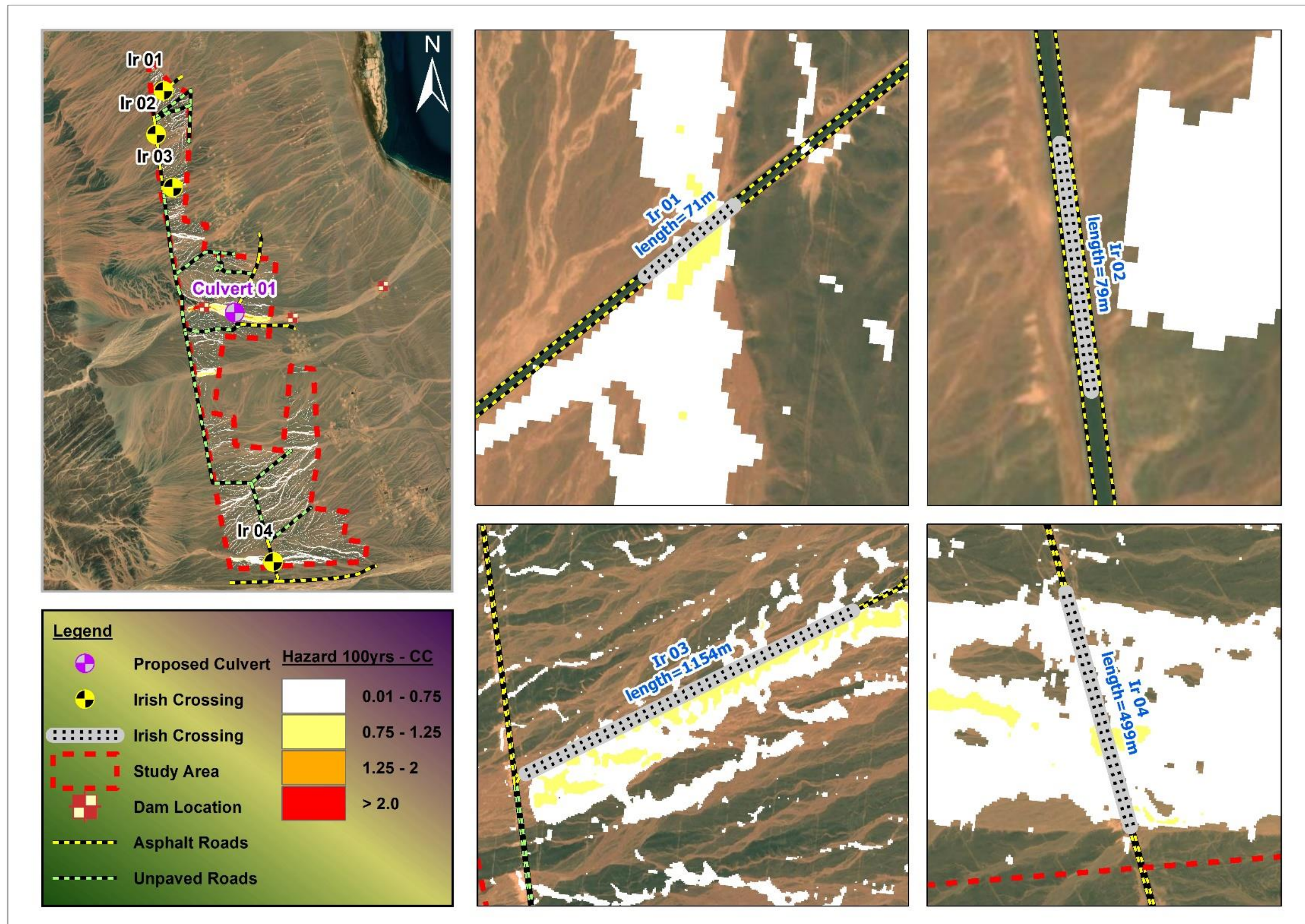


Figure A.41: Locations of proposed Irish crossings on Hazard Map for return period of 100 years + CC

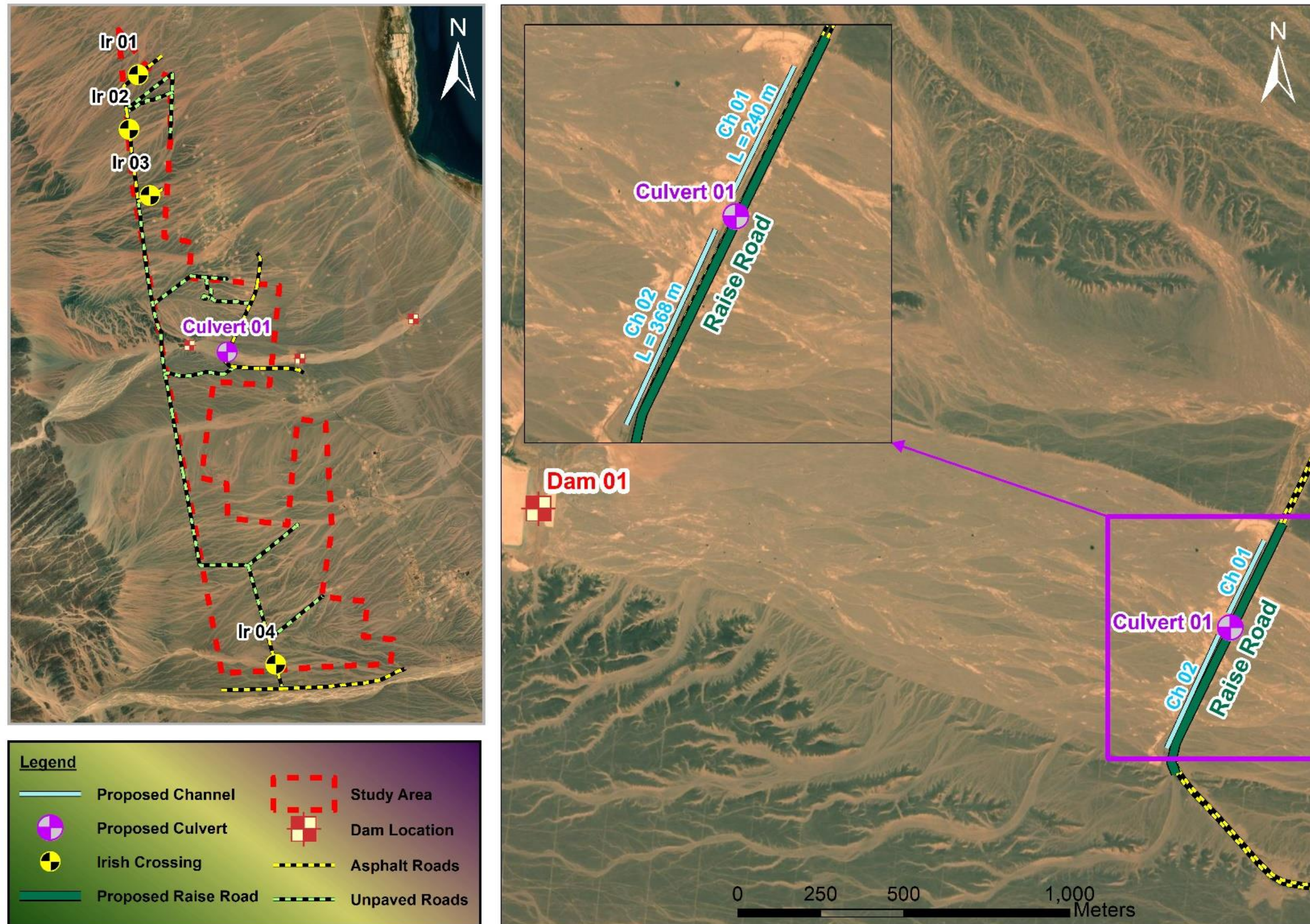


Figure A.42: Locations of proposed protection measures for asphalt road at the intersection with Wadi Hawashi on satellite image

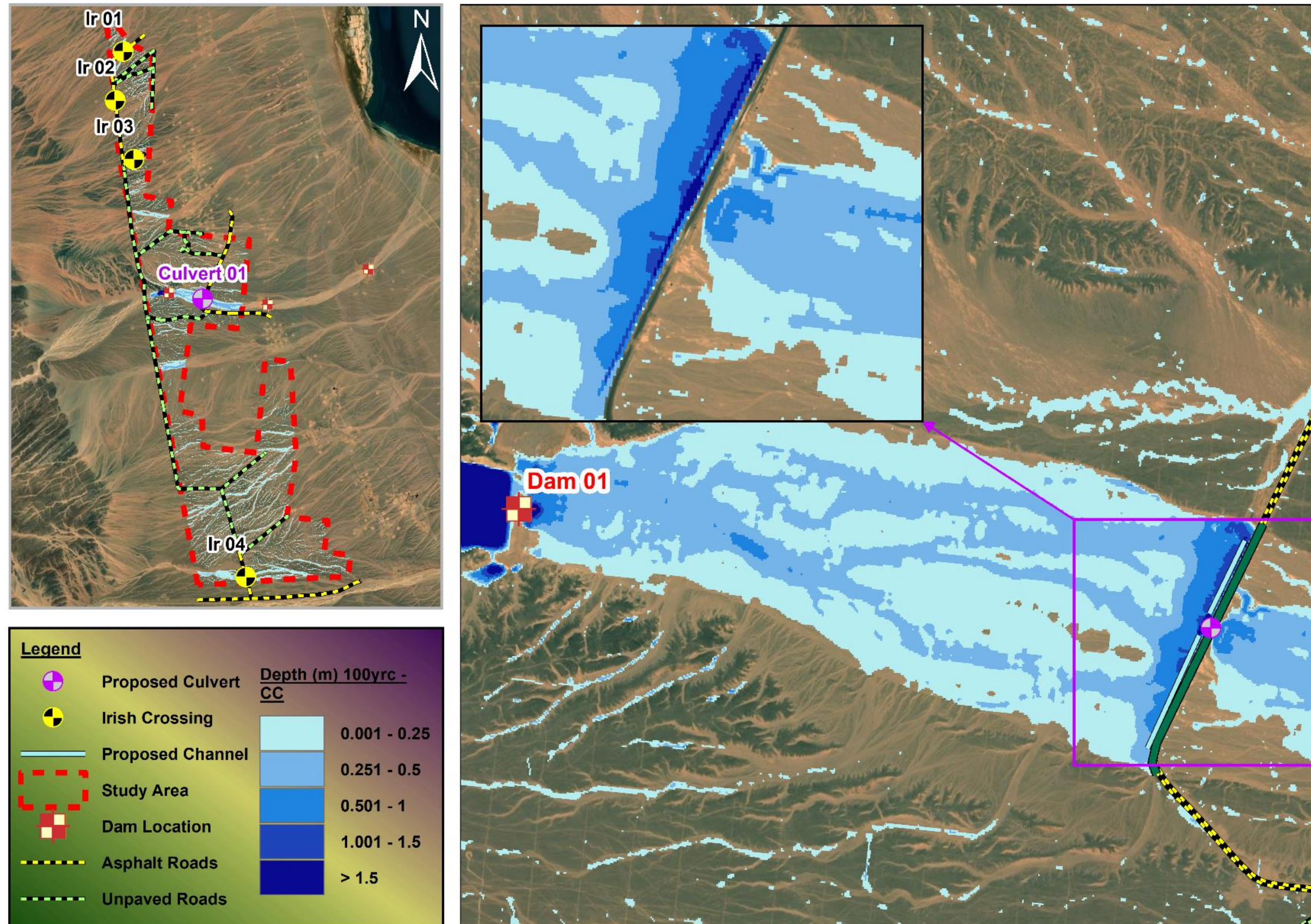


Figure A.43: Proposed culvert and channel on Depth Map for return period of 100 years + CC

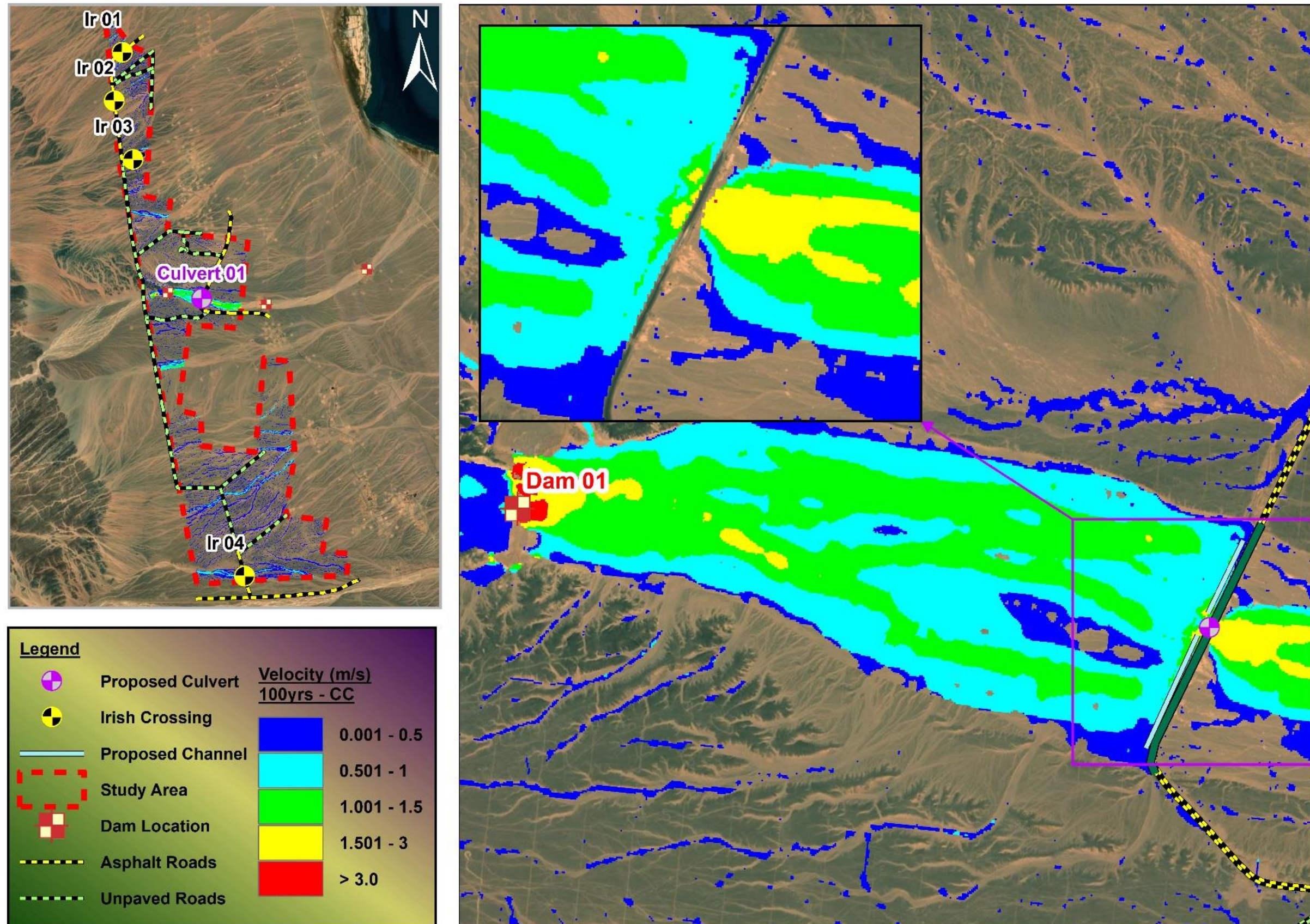


Figure A.44 : Proposed culvert and channel on Velocity Map for return period of 100 years + CC

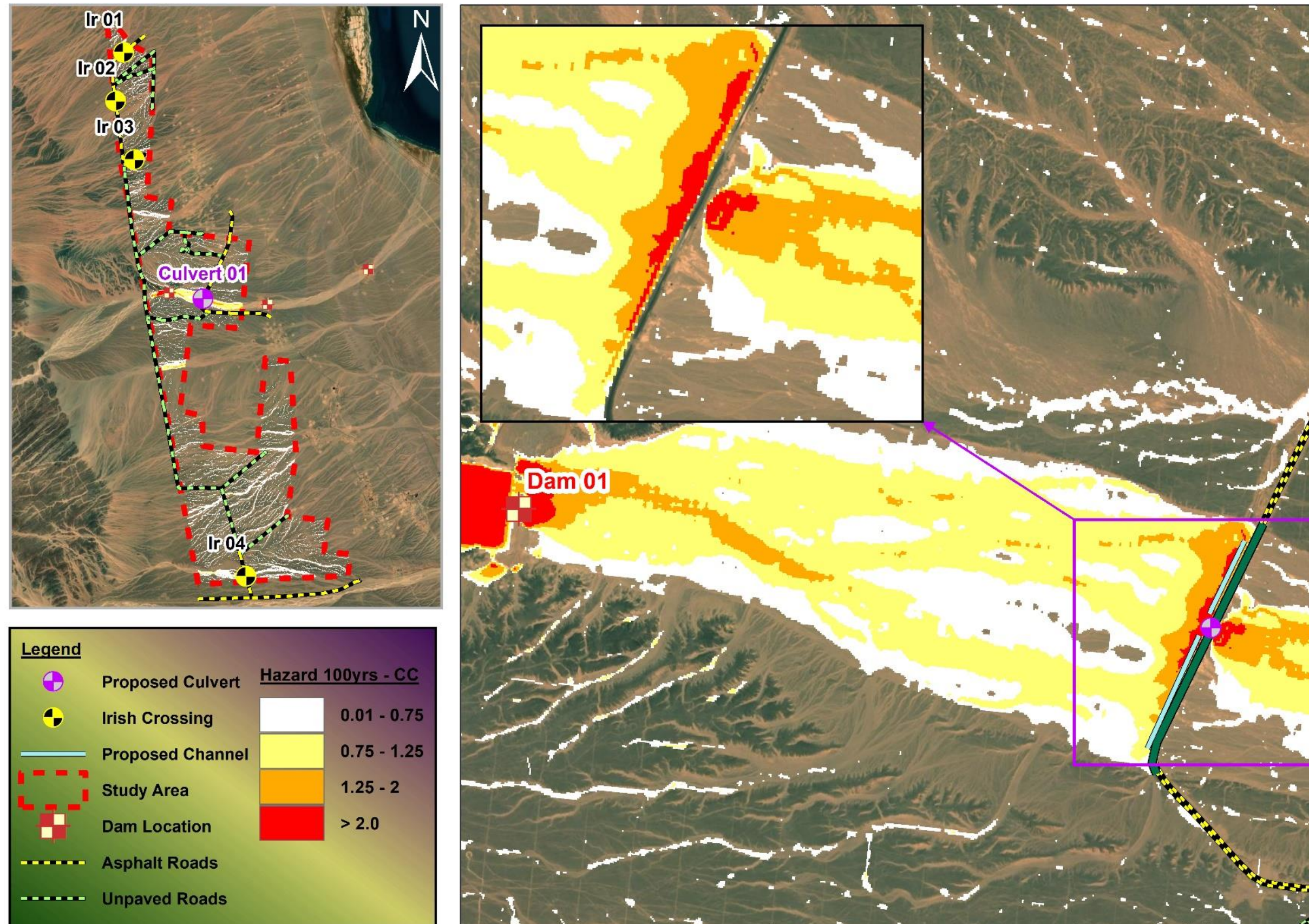


Figure A.45: Proposed culvert and channel on Hazard Map for return period of 100 years + CC