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MISE A JOUR DES ETUDES ET ASSISTANCE TECHNIQUE POUR LA CONSTRUCTION DU BARRAGE DE BISRI

BARRAGE BISRI

AVANT PROJET DETAILLE

PIECE 6: DAM BREACH MODEL

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EXECUTIVE SUMMARY

This report considers the modeling of a potential dam break from the Bisri Dam in the Bisri River Basin using an unsteady HEC-RAS model. Topographic data for the Bisri River Basin was obtained from actual land survey and converted to a 5m x 5m cell-size Digital Elevation Model (DEM) representing the Bisri River Basin. The Bisri Dam is located at an elevation of 400m above sea level. The clay core rockfill dam has a maximum capacity of 125 million m^3.

The Bisri River Basin downstream of the Bisri Dam is very steep, dropping 400m in approximately 22 km distance to the mouth of the river at the Mediterranean Sea. The river flows through several deep and winding canyon sections interspersed with wide, flat reaches over this interval making the dam break modeling problem challenging as many cross-sections must be used in the model (10 m spacing between sections), along with a short time step (5 seconds).

A Potential Failure Mode Analysis (PFMA) of the Bisri Dam identified the main potential failure modes as due to seismic loading and flood overtopping. Overtopping and breaching after seismic activity is the most probable and worst mode of potential failure of the Bisri Dam (consideration of a river flood, even exceptional, would not add much to the peak flood generated by the dam breaching and reservoir emptying). It is the failure mode described and modeled in this report. The unsteady hydraulics of the dam breach due to this failure mode was modeled using U.S. Army Corps of Engineers HEC-RAS software. The breach formation time used in the model is 1.5 hours, as calculated using the U.S. Bureau of Reclamation recommended procedure.

The model results show a peak flow of 43,000 m^3/s at the dam and 41,000 m^3/s at the sea outlet. The flood wave generated by the breach is initially 28 m high and does not abate significantly until the reaching the coastal valley where it decreases to 10 m. The lag time between the peak flow at the dam and at the mouth of the river is 30 minutes; the flood wave travels 21.6 km in 30 minutes or 43.2 km/hr. Sensitivity analysis was performed on the time of the dam breach and the width of the formed breach, showing that the model results are sensitive to the breach formation time and not to the width of the breach formation.

Cross-section (distance in km from sea outlet)	Initial Rise Time *	Peak Time *	End Time *	Peak Flow	Flood Height
	hr:min	hr:min	hr:min	m3/sec	m
21.6 km(dam)	0:00	1:10	2:40	43000	28
19 km	0:20	1:10	3:00	42800	27
10.9 km	0:40	1:20	3:40	41700	25
5.4 km	0:50	1:30	4:10	41200	20
Sea outlet	1:00	1:40	4:50	41000	10

* Time from time of breach initiation

GIS mapping of the areas inundated by the dam break flood were undertaken using the HEC-GeoRAS software.

Validation of the HEC-RAS model was performed by using a three dimensional CFD mathematical model of commercial use "Flow-3D". Based on the comparison between one dimensional modeling (HEC-RAS) and three dimensional CFD modeling (Flow-3D) no significant differences were found.

The inundation mapping downstream the dam considers the envelope of both models. The resulting inundated areas were also mapped in Google Earth for easy interpretation by local communities and responsible officials.

A rough damage assessment based on the results of the flood model was also performed. The results provide an average estimate and should not be considered as a detailed cost assessment of the damage, since they are strongly depending on the quality of the damage functions and the availability of detailed datasets. The quality of the damage assessment also depends on the quality of the classification which was made considering satellite views, previous studies data and the field survey collected information. The total damage cost estimation is approximated to 110 to 130 Millions US$.

The dam break model results were also used in the preparation of an Emergency Action Plan developed for protecting downstream communities in the event of a dam break and subsequent flood.

1 INTRODUCTION

1.1 Overview

The principal purpose of the Bisri Project is to provide a reliable water supply for the City of Beirut, using the water resources of the Bisri River at a site approximately 30 kilometers south of Beirut. A secondary purpose includes water supply for generating hydroelectric energy.

The Bisri Dam Project is located on the Bisri River, approximately 17 kilometers inland from the City of Sidon, which is on the coast of the Mediterranean Sea. The City of Beirut lies approximately 30 kilometers to the north and west of the dam site.

1.2 Main Purpose of this Report

The purpose of this report is to look at the issue of modeling a potential dam break from the Bisri Dam in the Awali River Basin using an unsteady US Army Corps of Engineers HEC-RAS model. The Bisri River drains the western slope of the mountains named Jabal el Barouk and Jabal Niha. These mountains, rising to elevations higher than 1,900 m above mean sea level, are characterized by a continuous snow cover throughout most winter months. Downstream the dam location, the river flows through a narrow valley, a canyon in some places dropping 400 m to sea over some 22 km.

The main task of this report are:

- Modeling a potential dam break from the Bisri Dam using an unsteady U.S. Army Corps of Engineers HEC-RAS (USACE, 2010) model for the dam and the downstream river to the sea.
- Validating the HEC-RAS Model by comparison the FLOW 3D Model.
- Performing a damage assessment based on the Dam Break Model results.
- Drafting an Emergency Action Plan developed for protecting downstream communities in the event of a dam break and subsequent flood.

2 BISRI RIVER BASIN

2.1 Introduction

The Bisri Dam Project is located in Southern Lebanon, east of the coastal city of Sidon. The proposed dam site is located on the Bisri River, at an elevation of 395 m, just east of the village of Bisri. The area of the project watershed is 215 km2, mostly draining the western slope of the mountains named Jabal el Barouk and Jabal Niha. These mountains, rising to elevations higher than 1,900 m above mean sea level, are characterized by a continuous snow cover throughout most winter months.

The project watershed is located between latitude 33^{o} 30' and 33o 45' North and longitude 35^{o} 32' and 35^{o} 46' East. Towns, villages and farms are scattered throughout the watershed primarily below 1,300 m in elevation. The town of Jezzine is the largest population center in the watershed.

The watershed hydrology is characterized by a rainy season of approximately seven months which begins in October or November of each year and lasts into April or May. Rainfall during the months of June through August is extremely rare. Streamflow is normally highest in February. During September, the average is lowest.

The annual precipitation in the Bisri River Basin averages 1255 mm/year and ranges between 900 mm/year inland and 1300-1400 mm/year over the mountains. The average flow for the basin is approximately 130 million m_3 per year for the period 1952-2010, 15% occurring in the summer (May-October) and 85% during the winter (November-April).

Floods created by heavy winter precipitation are common occurrences in the valley and their impacts have been increasing recently. In February 2003 one of the largest floods was experienced in the basin with an estimated return period of about 70 years or 1.4 % probability of exceedance in any year. This flood occurred after approximately 10 consecutive days of heavy rainfall in combination with snowmelt. Limited flow data exists in the Bisri River Basin (only daily discharge values with unknown accuracy and limited duration) and some historical flooding information has been collected from accounts of witnesses.

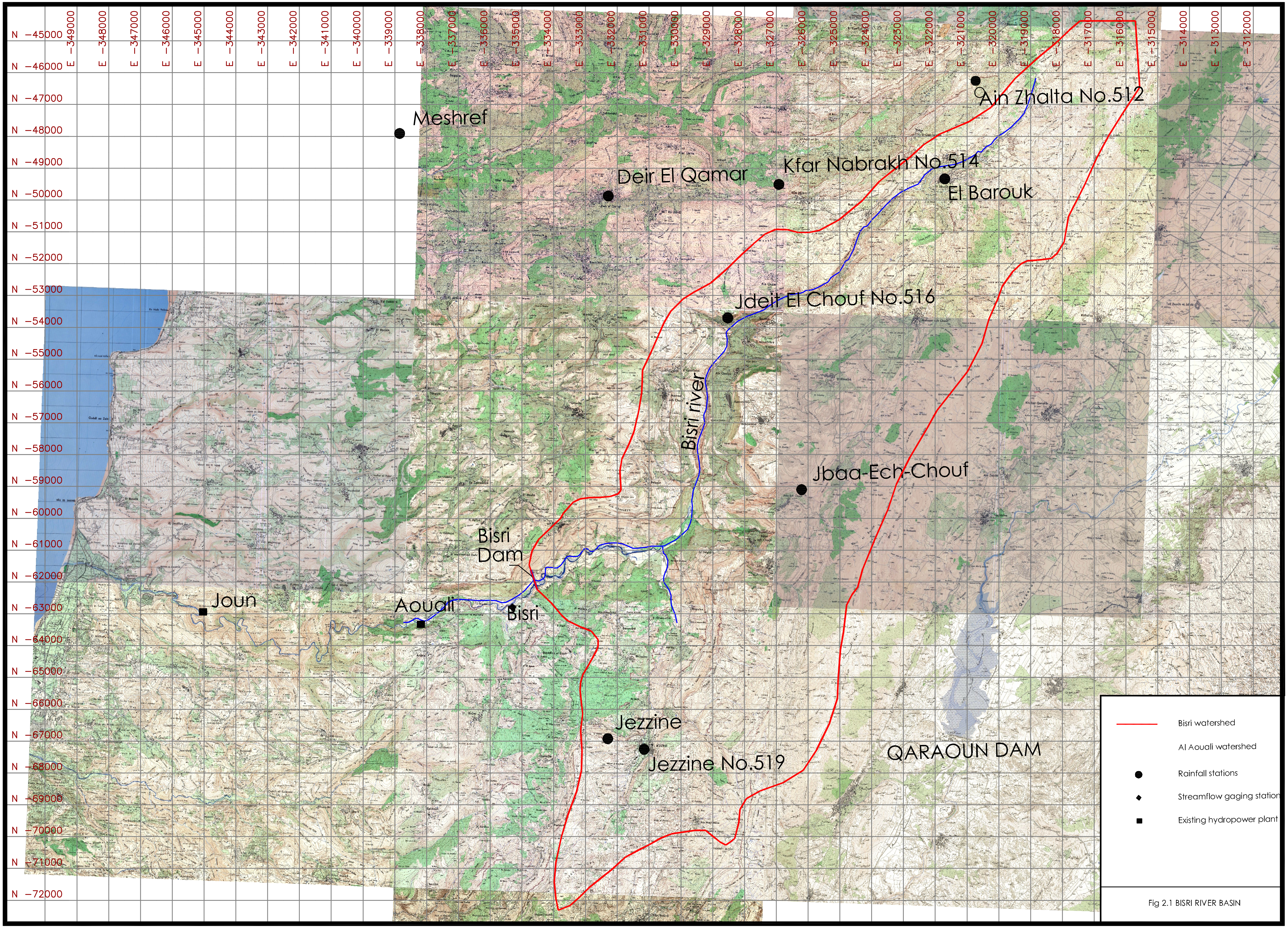
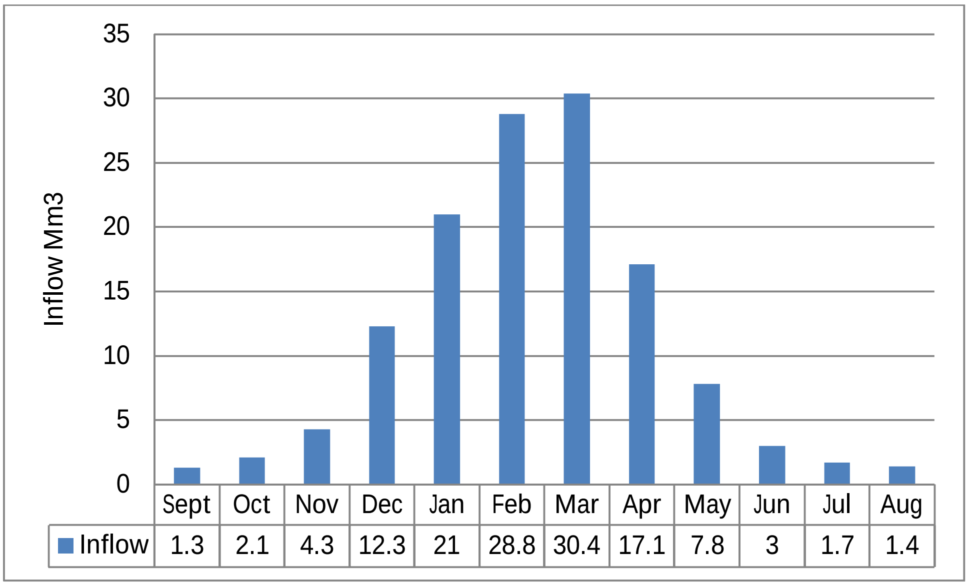


Fig 2.1 BISRI RIVER BASIN

Table 2-1 Average Monthly Bisri River Flows at Bisri Dam inflow (1952-2010)

Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Mm^3	m^3/s
1.3	2.1	4.3	12.3	21.0	28.8	30.4	17.1	7.8	3.0	1.7	1.4	131.2	4.2

Figure 2-2 Average Monthly Bisri River flows at Bisri Dam



2.2 Topographic Data

Topographic data for the Bisri River Basin was obtained by actual land survey.

The area between the dam and the sea was surveyed as shown on the drawings submitted separately (Scale 1/5,000).

Coordinates and elevations of National Bench Marks and Delta points existing in the study area were obtained from "Ministère de la Défense Nationale- Armée Libanaise- Direction des Affaires Géographiques".

A visit to the site and adjacent areas was conducted to locate the bench Marks in order to determine the traverse and reach with it the project site with no tolerance and with an acceptable accuracy. After shifting the coordinates to the site, several benchmarks were located.

Benchmarks points located inside and outside the project limits were marked on concrete elements such as rooms and houses and huge rocks. All these points (inside & outside project) are given as X, Y, Z with relation of National Lebanese Grid and Levels.

These maps were scanned and georeferenced according to the local coordinate system in Lebanon (Double Stereographic Projection). The contours lines from the maps were digitized on 5-meter intervals and the contours were converted to a 5m x 5m cell-size raster file (Digital Elevation Model or DEM) representing the Bisri River Basin. The final DEM is shown in Figure 2.3 along with an outline of the lake behind the Bisri Dam and the Bisri River from the lake to the sea. The elevation change from the dam to the sea is shown in Figure 2.4.

Figure 2-3 Digital Elevation Model (DEM) of the Bisri River Basin below Bisri Dam

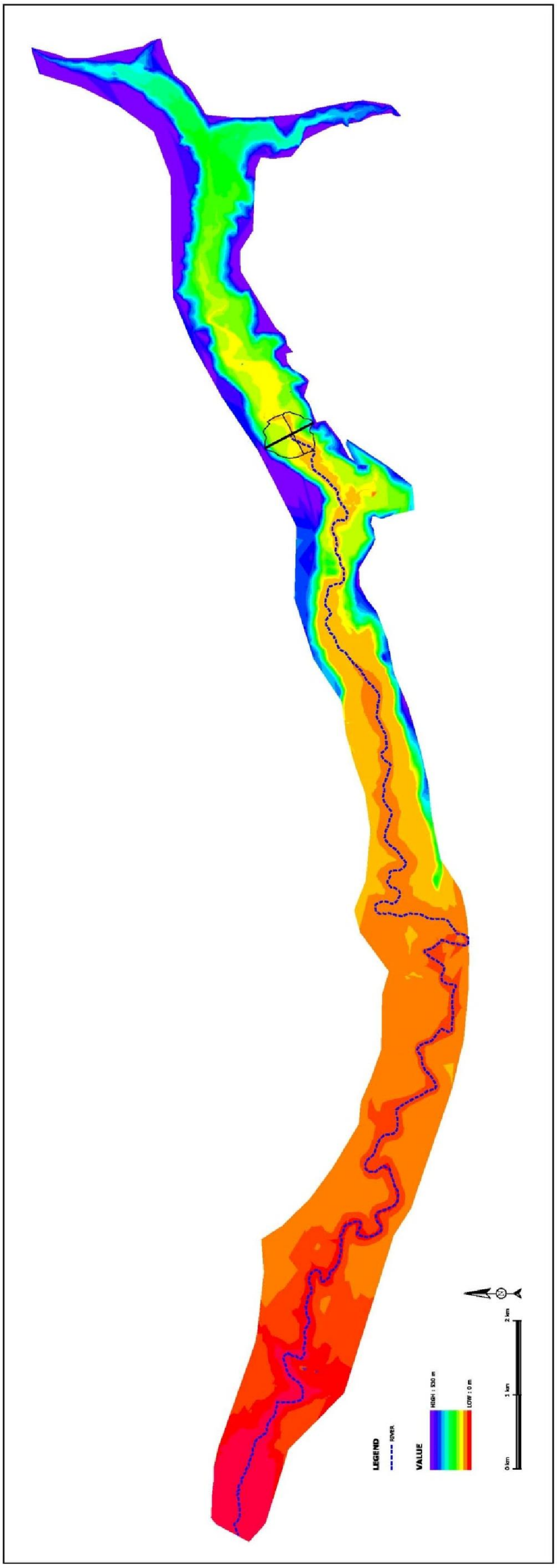
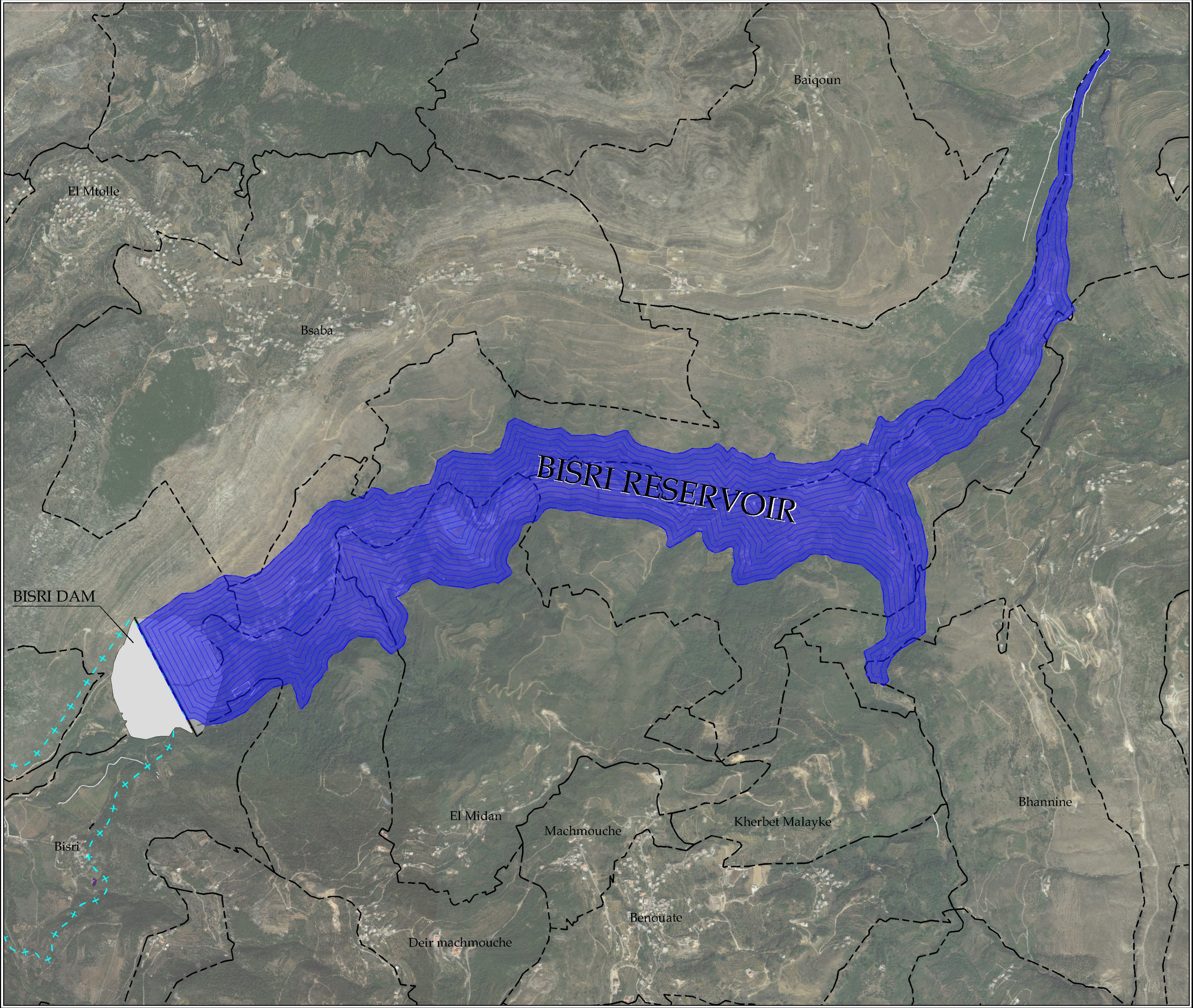


Figure 2-4 Bisri River Basin elevation profile from Bisri Dam to the Mediterranean Sea

2.3 Bisri Dam

2.3.1 Basic Characteristics of the Dam

The Bisri dam site is situated in a wide valley with moderately sloping abutment walls. The general site plan for the dam and reservoir is shown in Figure 2.5. The reservoir for the proposed Bisri Dam extends about 4 km upstream of the dam axis on the Bisri River and then branches out along both the Nahr Barouk awards the north and the Ouadi Bhannine towards the south. The catchment area above the dam is 215 km2. The dam has a maximum capacity of 125 million m^3 (at water level elevation of 461m above mean sea level. The dam has a length of 790m and is a clay core rockfill dam with the principal characteristics as summarized in Table 2.2. The maximum height of the dam is 73 m, and it is 10m at the crest level. The full lake covers an area of about 4 km^2. The dam is multipurpose, including: hydropower generation and domestic water supply. The maximum flood elevation for the spillway is 467.4m where the area of the lake is 4.3 km^2. The minimum operational level is 422m. Plan and center cross-section views of the dam are shown in Figure 2.6 and 2.7.



Legend

Flood Limit

River

Fig. 2.5

BISRI DAM & RESERVOIR

Figure 2-6 Bisri Dam plan view

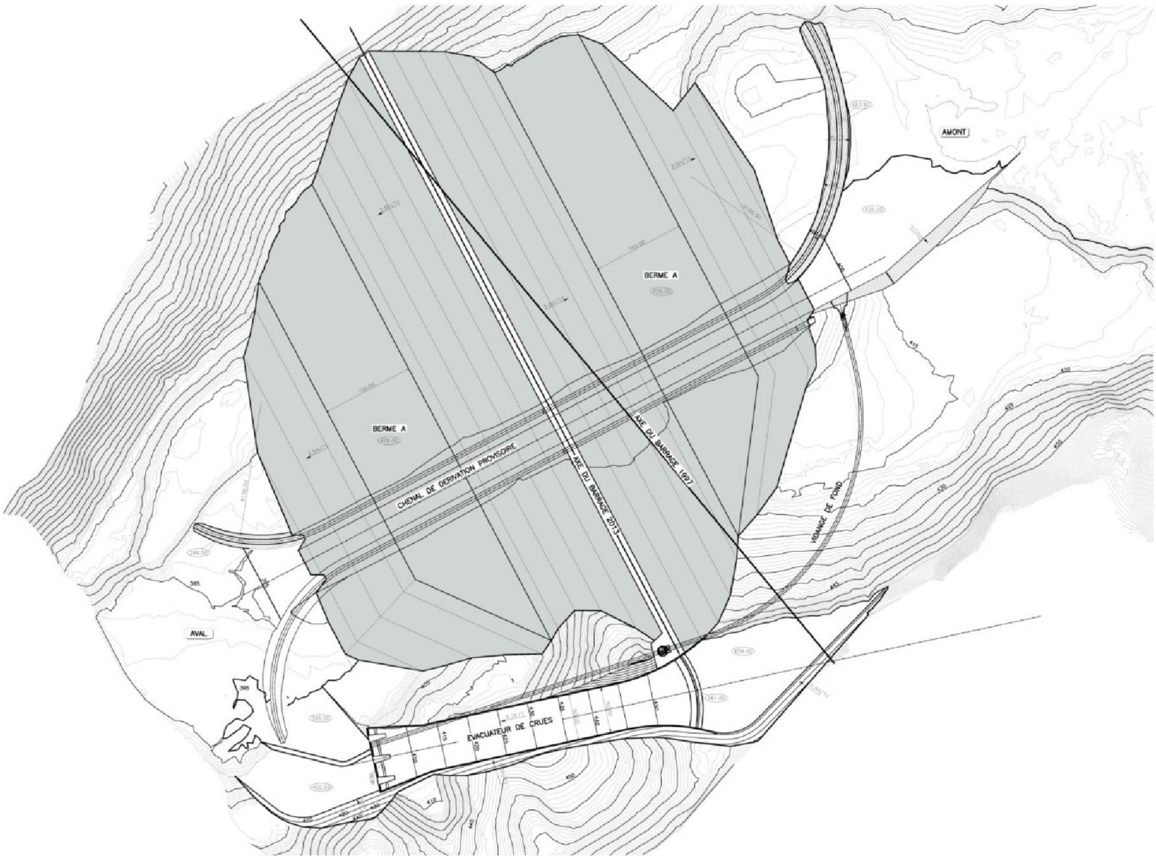


Figure 2-7 Bisri Dam main section view

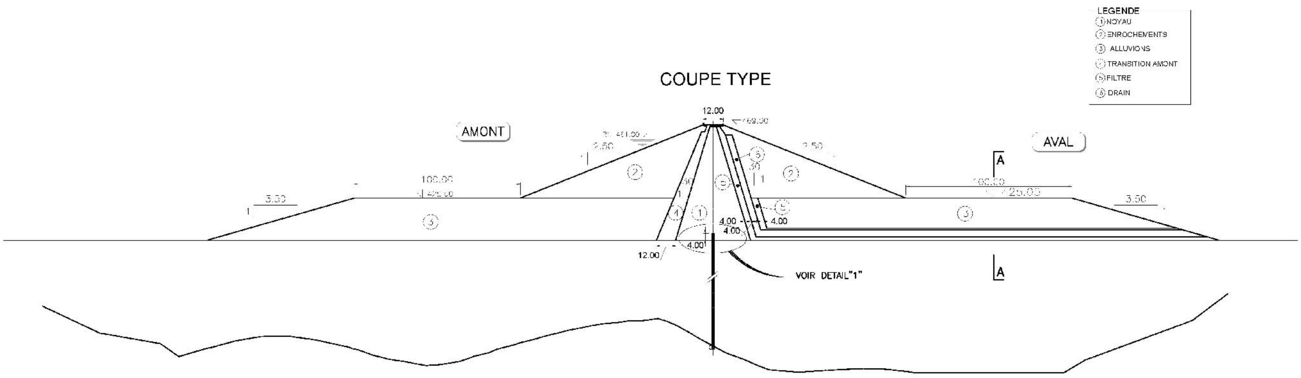


Table 2-2 Bisri Dam Charactistics

HYDROLOGY	
Average Inflow Mm^3	131
Probable Maximum Flood, m^3/s	3000
100 years Return Period Flood, m^3/s	550
RESERVOIR	
Maximum Water Level MWL, m	467.4
Normal Water Level NWL, m	461
Reservoir Volume Under NWL, Mm^3	125
Minimum Operation Level, m	422
DAM	
Type	Clay Core Rockfill Dam
Crest Level, m	469
Maximum Dam Elevation, m	73
Crest Length, m	790
Crest Width, m	10
Upstream Face Slope	2.5H:1V then 3.5H:1V
Downstream Face Slope	2.5H:1V then 3.5H:1V

2.3.2 Potential Failure Mode Analysis

A Potential Failure Mode Analysis (PFMA) was performed for the Bisri Dam to identify potential failure modes under static loading, normal operating water level, flood water level, and earthquake conditions. The PFMA results indicate that, while the risk of failure is very low, the most probable failure modes are seismic loading and flood overtopping.

Seismic loading failure:

The dam is located in an earthquake-prone zone where high intensity earthquakes are considered probable. The Bisri Dam is considered to be susceptible to damage and potential catastrophic failure under high earthquake loading. Deformations result in freeboard loss to such a degree that the crest is lower than the reservoir, causing a breach by overtopping erosion of the rockfill structure. Such a breach would enlarge through progressive erosion and collapse of the crest of the dam resulting in a catastrophic loss of the reservoir. This breach could form whether or not there is flow through the rockfill (piping) as the result of damage to the upstream face of the dam.

Flood overtopping failure:

An extreme flood occurrence causing the dam to be overtopped has significant potential to cause a rapid breach of the dam if overtopping is significant. Flow over an embankment dam (earth or rockfill) usually leads to erosion of material on the downstream slope and failure of the dam. Overtopping of Bisri Dam could result in movement of the material on the downstream slope of the dam with progressively more material dislodged causing collapse of the concrete face panels resulting in higher flows over the dam until total collapse occurs.

2.3.3 Dam Failure Scenarios

Three types of failure scenarios for the Bisri Dam could be considered, as follows.

Seismic loading failure:

An earthquake weakens the dam, which fails when the reservoir is full with a breach opening from the top and reaching a width equal to 1-2 H (H = dam height of 73m) with slopes 1/1 and a failure time of about 1 hour. Breaching parameters are calculated according to the US Bureau of Reclamation standard of practice as described in Froelich (1995a, b) and Wahl (2004). Initial conditions are minimal river flow, 200 m^3/s. Upstream flow conditions are the flow generated automatically by HEC-RAS based on the breach starting at a given time, 1 hour after the start of simulation and developing as mentioned above. Downstream boundary condition is the river outlet into the sea.

Flood overtopping failure:

The reservoir is full and a large flood comes. The spillway for Bisri Dam is uncontrolled (i.e. it operates automatically when water level reaches the overflow) and is sized for very large flood discharges (i.e. PMF), so the overtopping risk is almost nil. This risk could become of consideration only if the spillway and bottom gate are blocked/non-operational during a very large flood that overtops the dam causing failure. This scenario would have actually have the same consequences as the seismic failure: breaching would be similar while the addition of a large flood (hundreds of m^3/s) is negligible considering the flood generated by the reservoir emptying (tens of thousands of m^3/s).

For this report, the primary mode of potential failure of the Bisri Dam is considered to be breaching and overtopping due either to seismic activity or flooding.

3 DAM BREAK MODELING

3.1 Introduction

Dam break modeling requires the solution of an unsteady (rapidly time varying) river flow hydraulics problem. Many early dam-break investigations assumed that the breach or opening formed in a failing dam encompassed the entire dam and occurred instantaneously. While this assumption may be nearly appropriate for concrete arch dams, it is not valid for earthen dams or concrete gravity dams. Because earthen dams generally do not fail completely nor instantaneously, dam break models allow for the investigation of partial failures occurring over a finite interval of time (Fread et al., 1991). The U.S. Army Corps of Engineers HEC-RAS software (USACE, 2010) includes the capability to model the unsteady hydraulics of an embankment dam breach due to several failure mode options. Using HEC-RAS for the routing modeling of dam failures is the current standard procedure in the US, and notably for US Army Corps of Engineers and US Bureau of Reclamation.

The primary input variables of importance in the dam break analysis are (Wahl, 1998):

1. Reservoir volume when breaching commences (m^3). This is often taken as the full reservoir volume for overtopping failure cases;
2. Reservoir water surface elevation when breaching commences (m). This is often taken as the top of the dam for overtopping failure cases;
3. Breach depth (h) – the vertical extent of the breach, measured from the dam crest to the invert of the breach (m). This is often taken as the elevation of the river channel at the upstream base of the dam. The bottom of a fully formed breach usually is the dam foundation, which is more resistant to erosion than the embankment material. However, the height might be limited by the volume of water in the reservoir at the time of failure, or by the presence of a layer of erosion-resistant material located in the embankment (Froehlich 2008).
4. Breach width (B) – the final width of the breach (m). The breach width and rate of formation have an impact on the peak flowrate and the inundation level downstream from the dam.
5. Breach initiation time – the time from the first flow over or through the dam that will initiate warning, evacuation, or heightened awareness of the potential for dam failure. The breach initiation time ends when breach formation starts.
6. Breach formation time (t) - the time required for the breach formation (hours). The breach formation time is the duration of time between the first breaching of the upstream face of a dam until the breach is fully formed. For overtopping failures the beginning of breach formation is after the downstream face of the dam has eroded away and the resulting crevasse has progressed back across the width of the dam crest to reach the upstream face;

3.2 Estimating Dam Breach Parameters

3.2.1 Maximum Breach Discharge

Several researchers have compiled data on the failure of rock-filled embankment dams (Froehlich 1995; Wahl 2004; Froehlich 2008). Wahl (2004) compared the uncertainty of several breach parameter prediction formulas, including the aforementioned equations. The Froehlich equations were found to have the smallest uncertainty and are currently considered as standard procedures.

Using data from numerous embankment dam failures, Froehlich (1995) related the peak outflow in a dam breach to a power function of both the breaching head and outflow volume

$Q_{max} = 0.607KV^{0.295}\,h^{1.24}$ (1)

where

- Qmax is the peak flow (m3/sec),
- h is the height of the dam breach (m),
- V is the reservoir volume (m3),
- K is an overtopping multiplier (1.4 for overtopping failure, 1.0 for piping failure).

The maximum volume of Bisri Dam is about 125 million m^3. Eq. 1 can be used to compute the hypothetical maximum outflow from Bisri Dam as

$Q_{max} = 0.607(1.4)(132x10^6)^{0.295}\,(73)^{1.24} = 42{,}503\ m^3/sec$ (2)

3.2.2 Breach Development Time

The expression developed for the breaching time (t, hr) is (Froehlich 1995)

$t = 0.00254V^{0.53}\,h^{-0.9}$ (3)

In the case of Bisri Dam, the breaching time is approximated as

$t = 0.00254(125x10^6)^{0.53}(73)^{-0.9} = 1.05$ hr (4)

3.2.3 Breach Width

An expression for the breach width (*B*, m) was also developed (Froehlich 1995)

$B = 0.1803V^{0.32}\,h^{0.19}$ (5)

In the case of Bisri Dam, the final breaching width can be approximated as

$B = 0.1803(125x10^6)^{0.32}(73)^{0.19} = 158.9$ m (6)

3.3 Representation of Bisri River and Bisri Dam in Hec-Ras

3.3.1 Bisri River

The Bisri River Basin downstream of the Bisri Dam is very steep, dropping 400m in the approximately 22 km distance to the mouth of the river at the Mediterranean Sea. The river flows through several deep and winding canyon sections interspersed with wide, flat reaches over this interval. These aspects of the river make the dam break modeling problem challenging as it is difficult to determine the appropriate number and placement of cross-sections for the model as well as the best model time step for the simulations.

The final DEM is shown in Figure 2.3 along with an outline of the lake behind the Bisri Dam and the Bisri River from the lake to the sea. Initial river cross-sections for the HEC-RAS model were generated using this DEM. The initial set of river cross-sections are shown in Figure 3.1.

The stability of the HEC-RAS model is function of the distance between the cross sections and the time step used in the simulation. The minimum value allowed by HEC-RAS is one second. A one second time step was used for the Bisri model to achieve stability of the calculations. Other, larger time steps were tested, but not found to result in stable calculations.

New cross-sections with a shorter distance between them were interpolated between the initial sections at locations where the HEC-RAS solution became unstable. First, all of the initial river cross-sections were interpolated to 30 m and then further interpolation to 20 m was carried out. Finally, some reaches of the river had to be interpolated to 10 m distance between cross-sections in order to achieve a stable solution.

The roughness of the terrain due to ground materials and vegetation is represented in the HEC-RAS calculations by the Manning roughness coefficient. The roughness coefficient was considered homogeneous for the entire Bisri River model with a value of 0.05. According to Chow (1959) this value is recommended for mountain streams.

Figure 3-1 Initial cross-sections for Bisri River HEC-RAS model

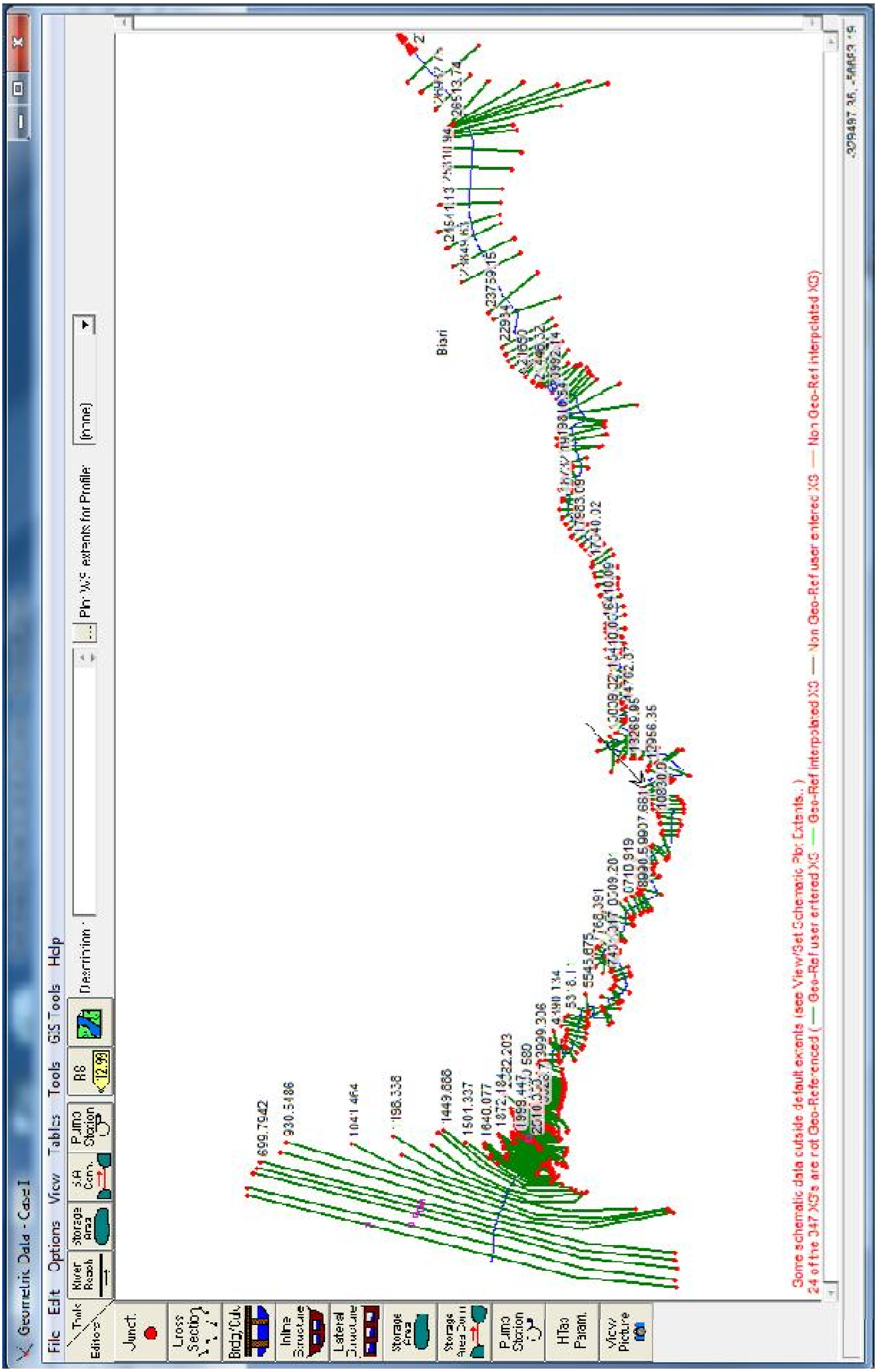
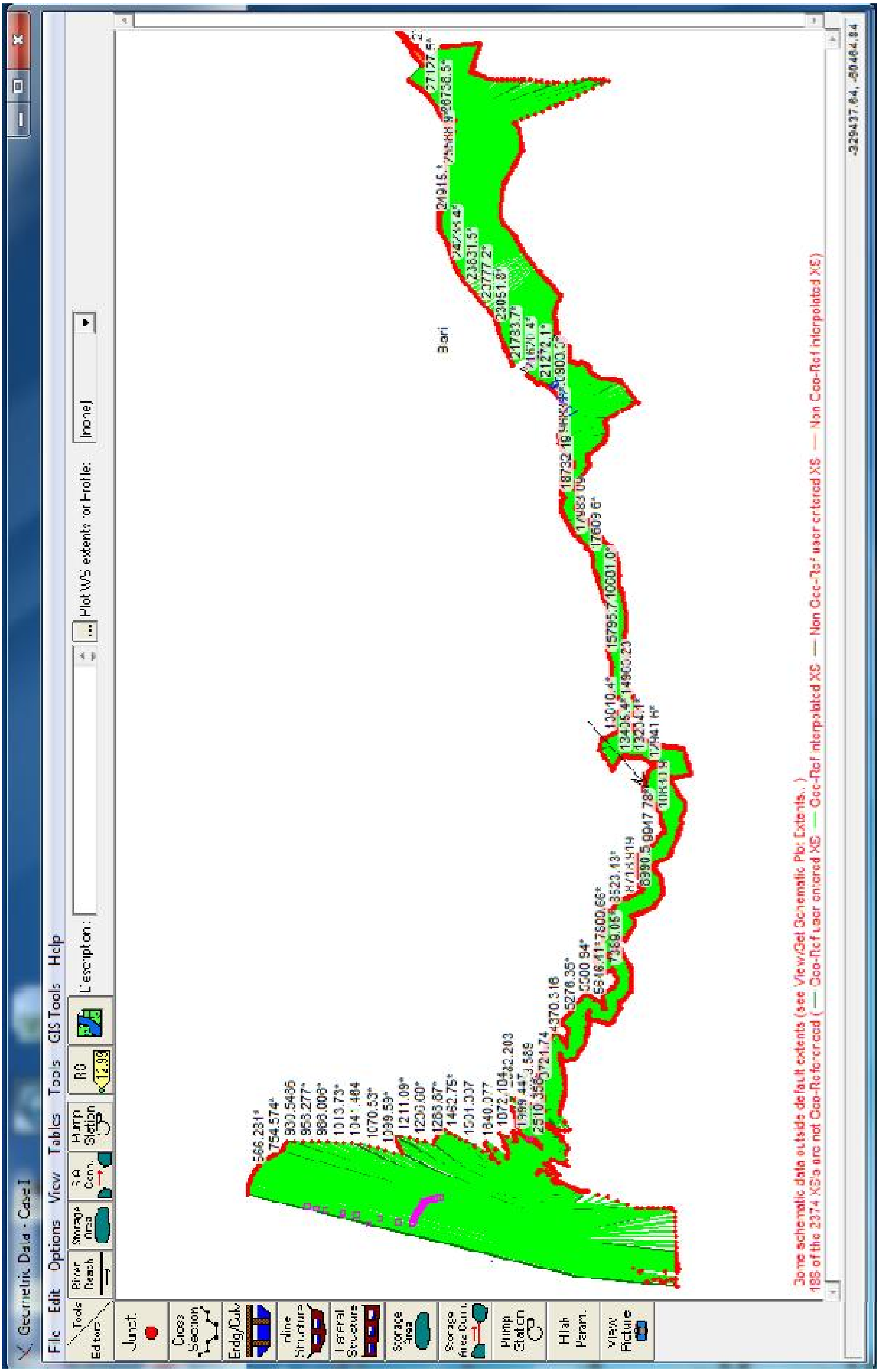


Figure 3-2 Interpolated cross sections for Bisri River dam breach model



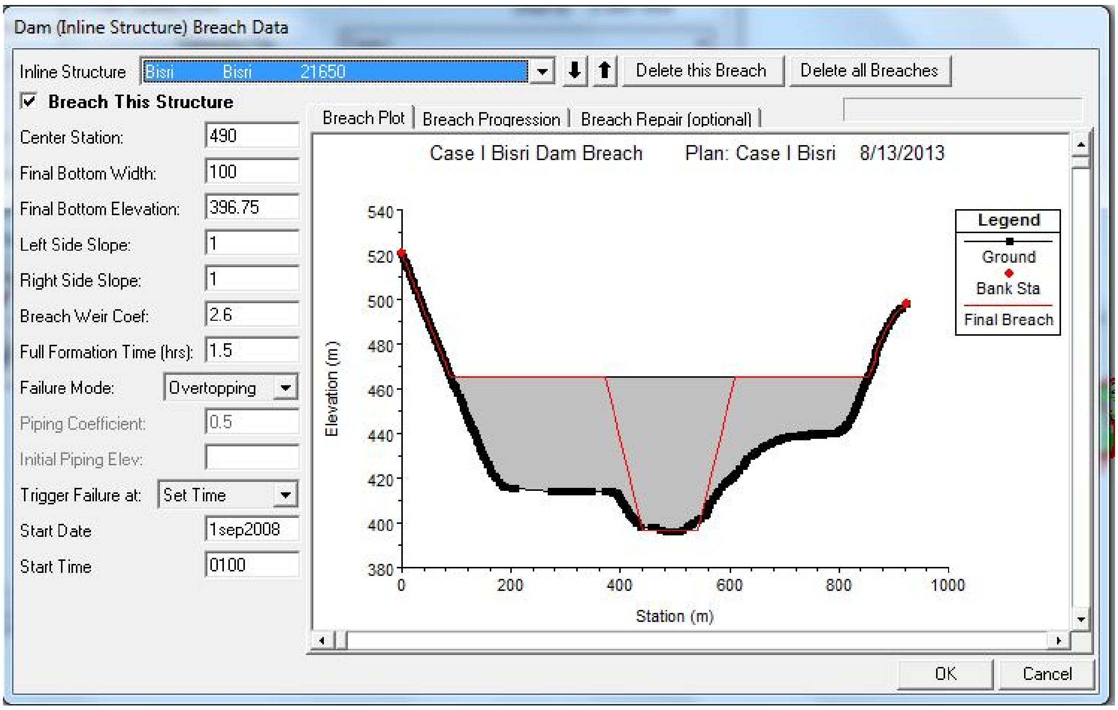
3.3.2 Bisri Dam Breach Data

HEC-RAS allows the modeling of the breach process by entering key data and assumptions regarding the dam, the reservoir and the breach most probable characteristics, as shown in Table 3.1 and Figure 3.3. The breach formation time for an embankment dam with the same characteristics as Bisri Dam was estimated to be 1.05 hours (Froehlich equations). The breach formation time used in the model was set to 1.5 hours to test stability of the model. The breach is produced by overtopping, since this is the most probable case. The bottom width of the breach is 100 m, representing the river channel width at the bottom of the dam (see Figure 3.4). In order to have a stable model, the river was considered wet at the beginning of the simulation with an initial flow of 200 m^3/sec.

Table 3-1 HEC-RAS Dam Breach Plan for Bisri Dam on Bisri River

Item	Value
River station of Dam	21650 m (upstream from the sea)
Pilot Flow	200 m^3/sec
Upstream Embankment slope	2.5:1 then 3.5:1
Downstream Embankment slope	2.5:1 then 3.5:1
Center station	490 m
Final Bottom Width	100 m
Final Bottom Elevation	397 m
Left side slope	1:1
Right side slope	1:1
Full formation time	1.5 hr
Failure mode	Overtopping
Trigger Failure	Set Time
Start time	0100

Figure 3-3 Bisri Dam breach model data



3.4 Hec-Ras Unsteady Flow Analysis Parameters

To model the dam breach process in HEC-RAS, an unsteady flow calculation is performed. A simulation period of 23 hours was used with the dam breach initiated one hour after the start of the simulation. The Bisri Dam is modeled as an “inline structure” in the HEC-RAS model. The dimensions of the dam are known from the plan (Fig. 2.6) and section (Fig. 2.7) illustrations and the data in Table 2.2. The data needed to represent the dam breach in HEC-RAS are shown in Table 3.1 and Figure 3.3.

Boundary condition and initial condition data must be entered for the unsteady analysis. Boundary conditions at the upstream river reach above the dam was entered as a constant flow rate of 200 m^3/sec. The downstream boundary condition at the sea was as a normal depth boundary condition with a water surface slope of 0.002 m/m. Also, the initial flow in the basin at the start of the simulation period was set to 200 m^3/sec in each section. A number of computational parameters have to be set in order to achieve a stable simulation when modeling a dam break flood. These parameters are shown in Figures 3.5 and 3.6.

Figure 3-4 Boundary and initial condition data for Bisri Dam breach model

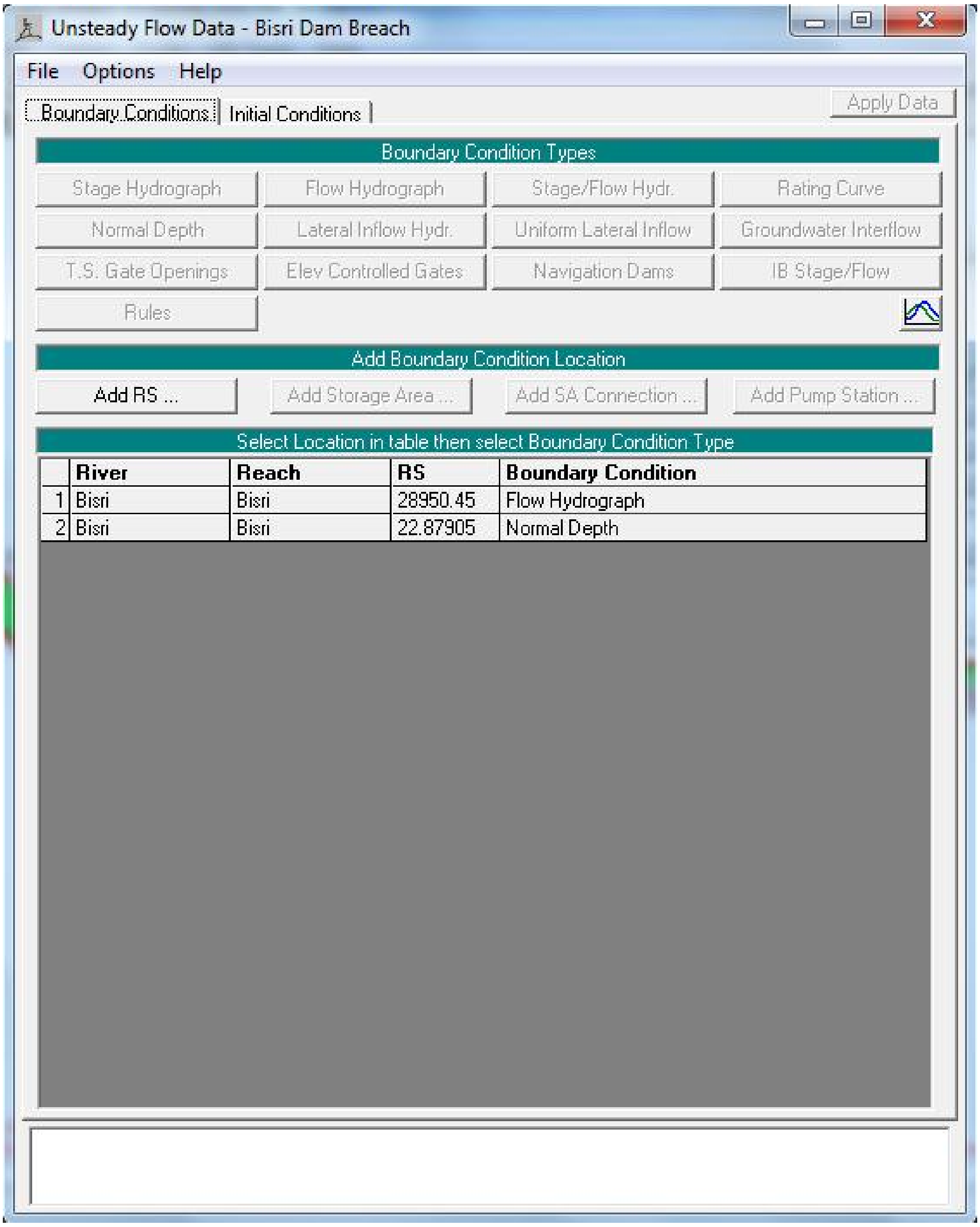


Figure 3-5 Unsteady flow simulation parameters for Bisri Dam breach model

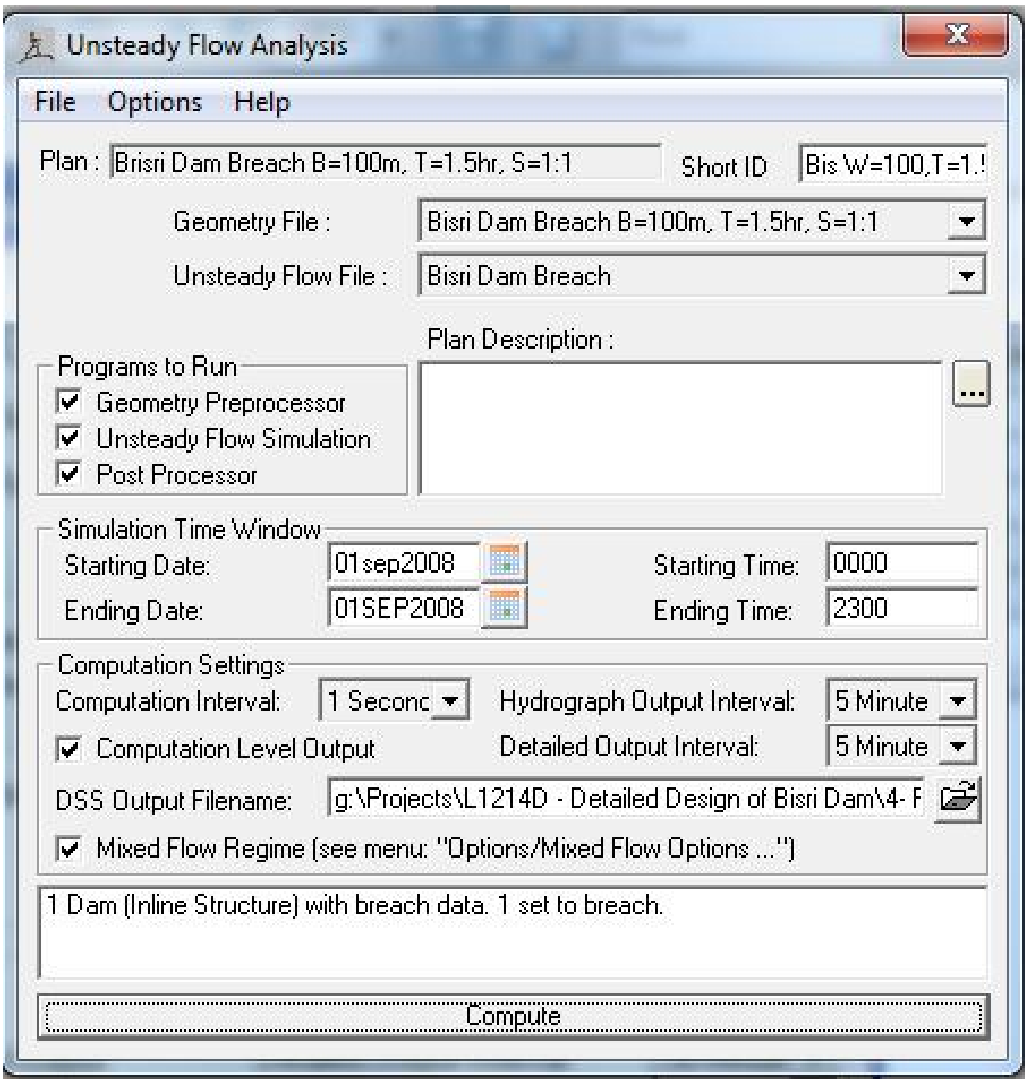
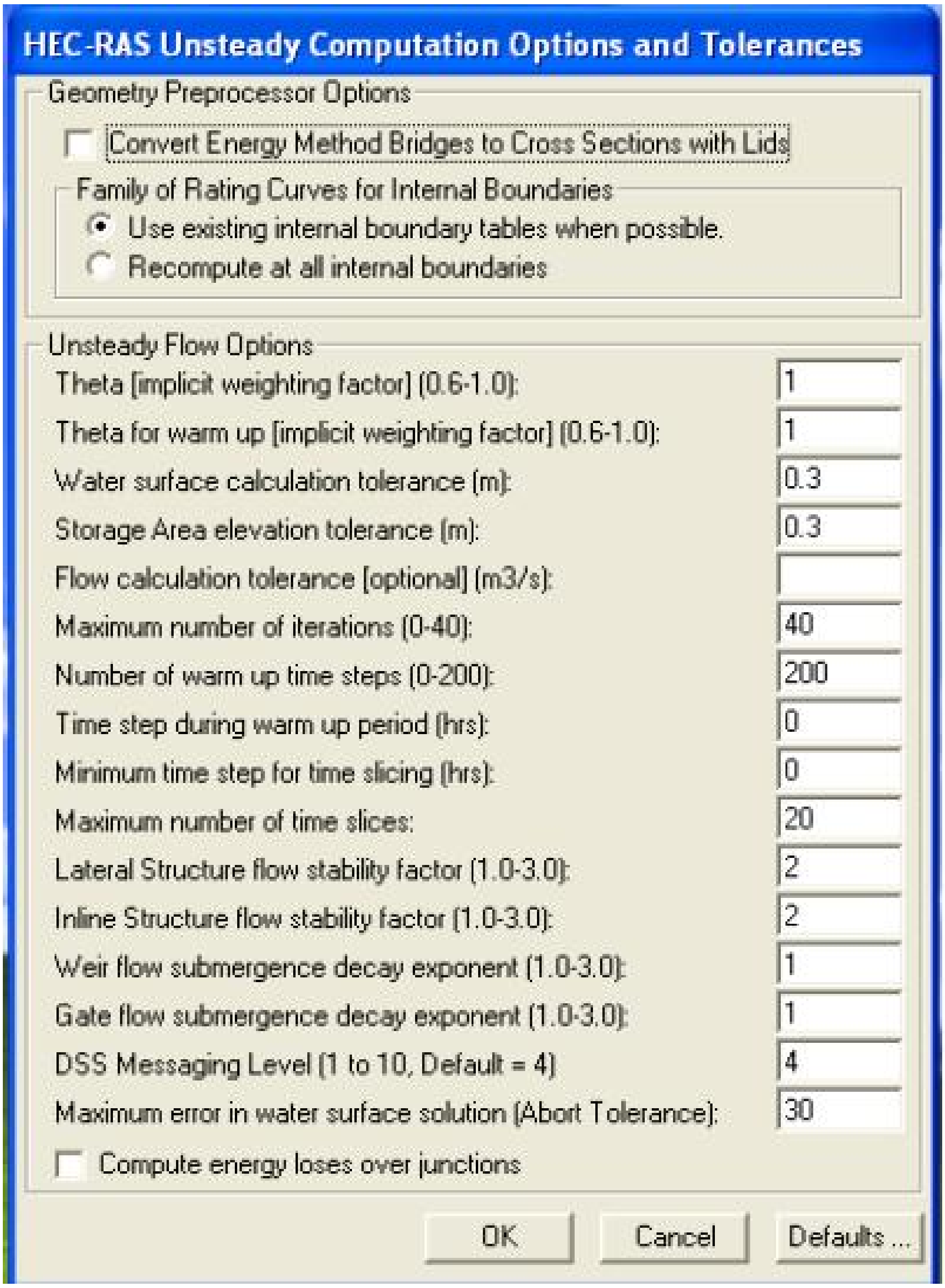


Figure 3-6 Computational parameters set for the Bisri Dam breach model



4 RESULTS

4.1 Dam Breach Time of 1.5 Hours

The time for the dam to breach is 1.5 hours, the peak of the outflow from the dam occurs 1 hour and 25 minutes after the beginning of the breaching process. The maximum flow rate from the dam is 43,000 m^3/sec. This value is comparable to the previous estimate (from Froehlich equations) of 42,500 m^3/s.

Table 4.1 lists some selected sections along with the main results: initial stage (water elevation) in the river before the dam breach; the maximum stage of the river during the flood; the height of the flood wave passing the section; and the time of the peak of the flood. The flood wave is about 30 m high and does not attenuate much till reaching the coastal valley. The peak flow abates progressively from initially 43,000 m^3/s to 41,000 m^3/s at the sea outlet.

Figures 4.1 and 4.2 show the water elevation, flow rate and cross-section for the cross section at the dam and at the sea outlet. From this it is possible to determine that the lag time between the peak flow below the dam at river station 21650 and the peak flow at the downstream cross section at the mouth of the river is 30 minutes. Hence, the dam breach wave would travel the 21.6 km in 30 minutes that is at a pace of 43.2 km/hr.

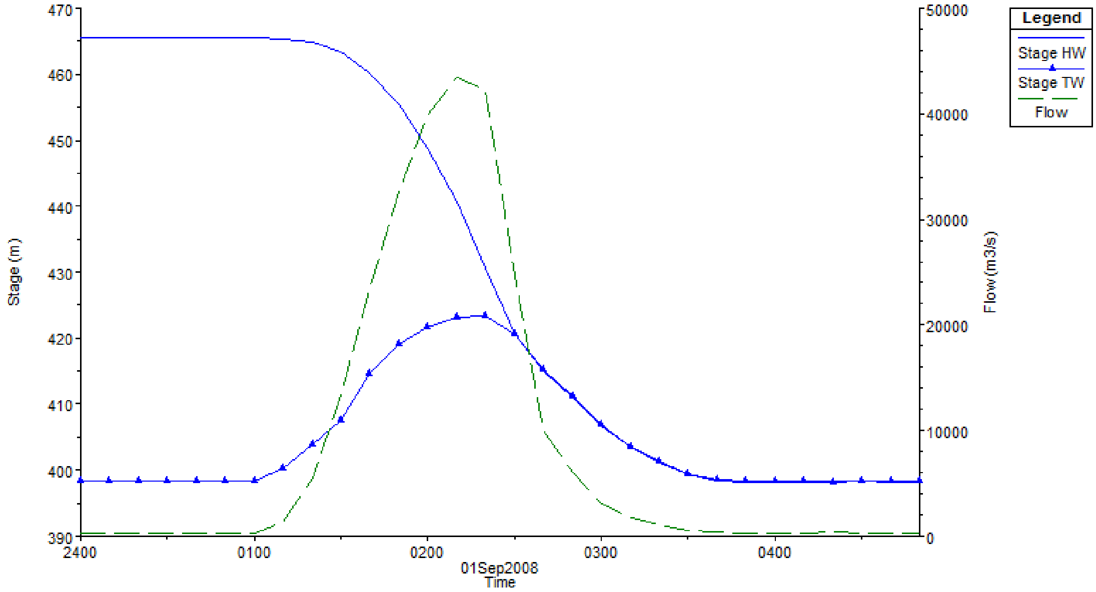
Figures 4.3 to 4.18 show the water levels at several times counting from the initiation of the breach and Figure 4.19 shows the maximum flood Plain. Figure 4.20 shows the Flood Hydrographs corresponding to different locations (0km corresponds to the sea mouth).

Table 4-1 Maximum stage, flow and time of peak flow for selected Bisri River stations below Bisri Dam

Cross-section (distance in km from sea outlet)	Initial Rise Time *	Peak Time *	End Time *	Peak Flow	Flood Height
	hr:min	hr:min	hr:min	m^3/sec	m
21.6 (dam)	0:00	1:10	2:40	43200	28
19 km	0:20	1:20	3:00	43100	27
10.9 km	0:40	1:30	3:40	42100	25
5.4 km	0:50	1:40	4:10	41100	20
Sea outlet	1:00	1:40	4:50	41000	10

* Time from time of breach initiation

Figure 4-1 (a) Hydrograph at Dam, (b) Cross Section just Downstream Dam



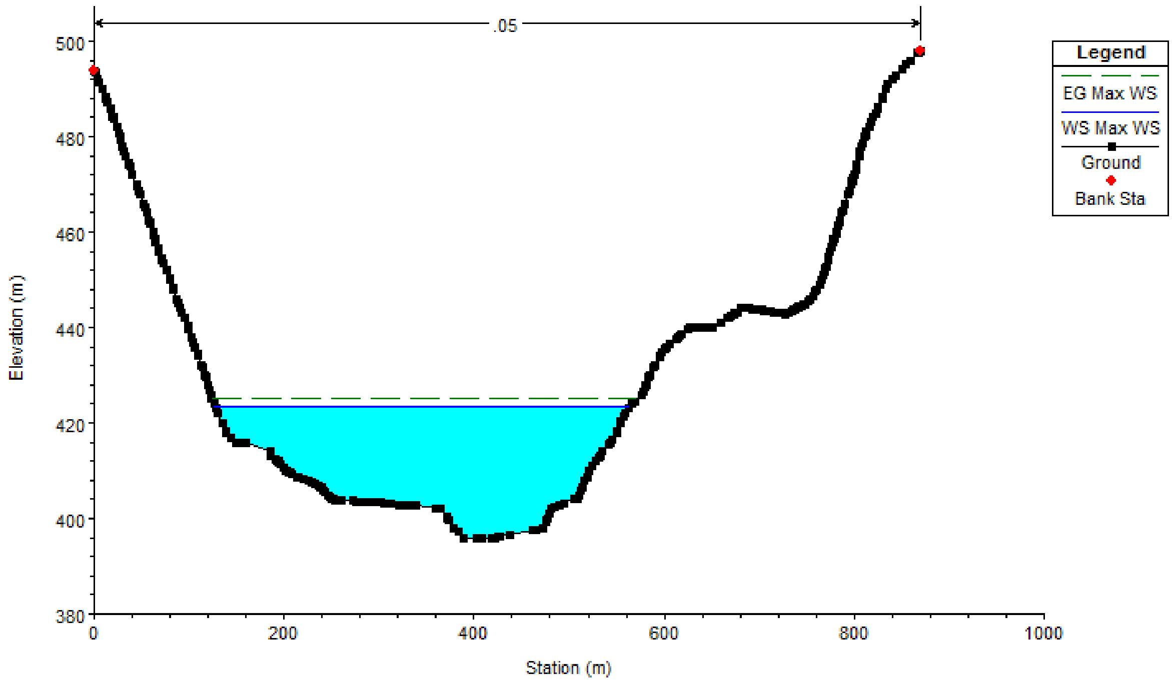
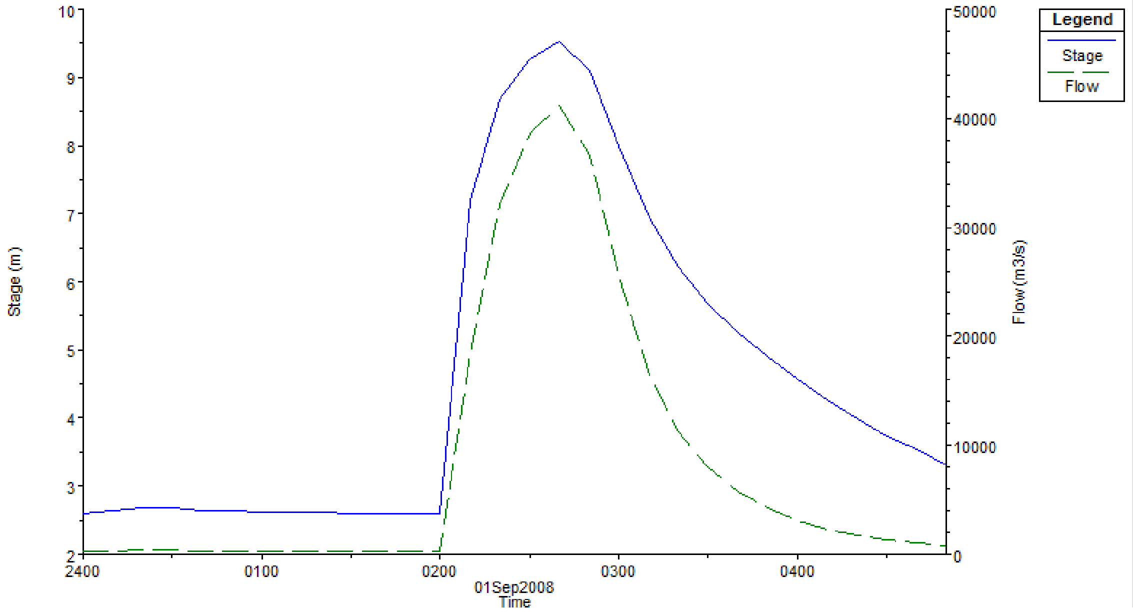
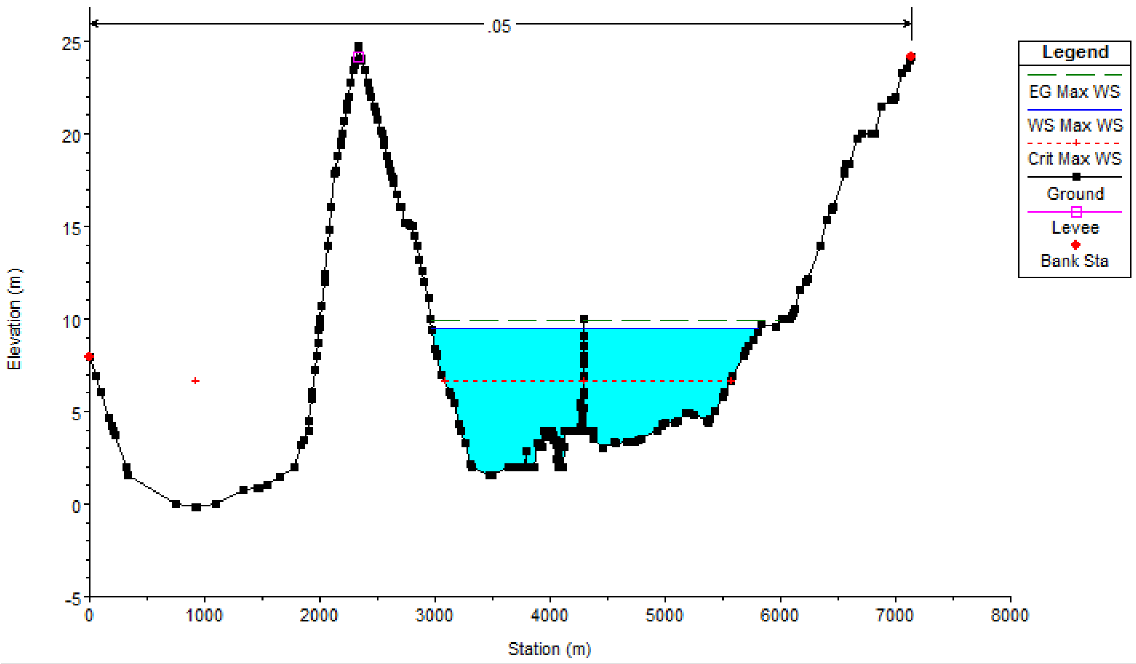


Figure 4-2 (a) Hydrograph at station Sea Outlet, (b) Cross Section at station Sea Outlet





Floodplain Prior To Dam Breach

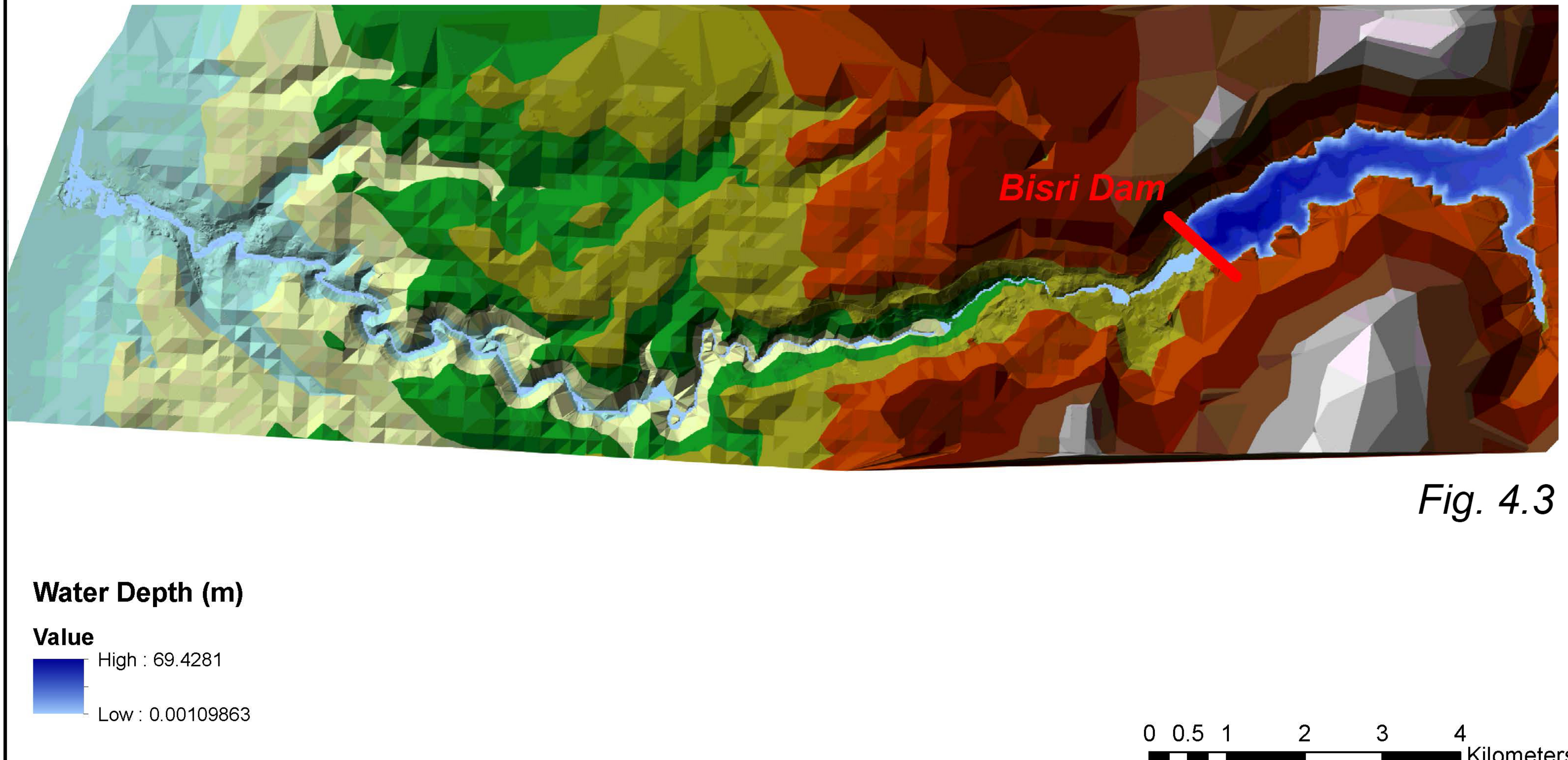


Fig. 4.3

Floodplain 10 Minutes After Start of Dam Breach

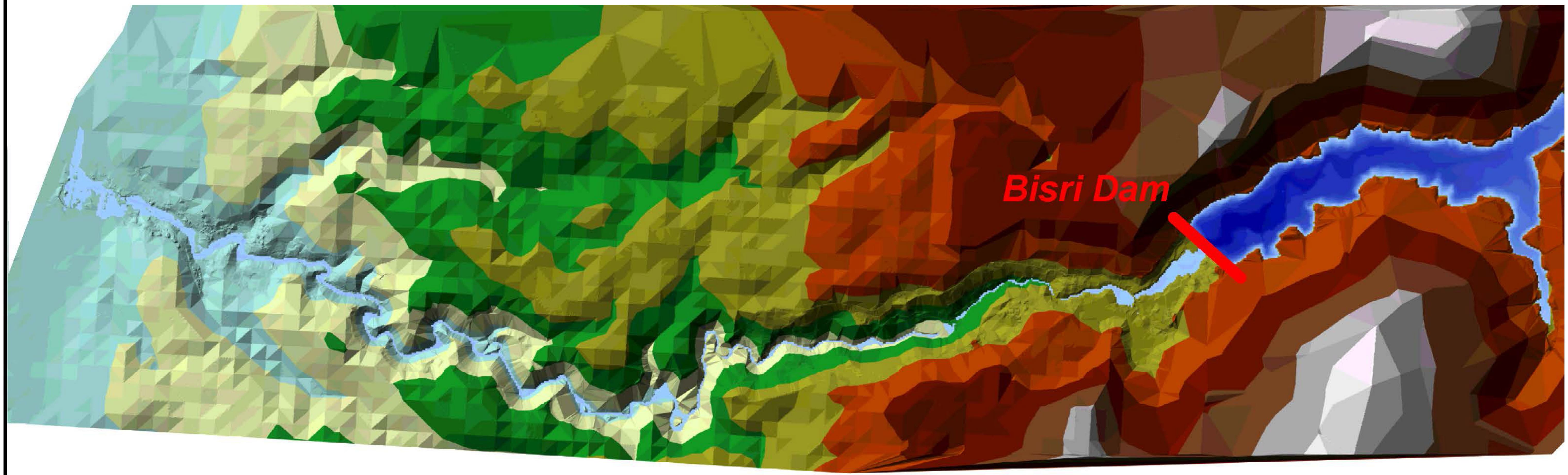


Fig. 4.4

Water Depth (m)

Value

High : 69.3613

Low : 0.0016098

0 0.5 1 2 3 4 Kilometers

Floodplain 20 Minutes After Start of Dam Breach

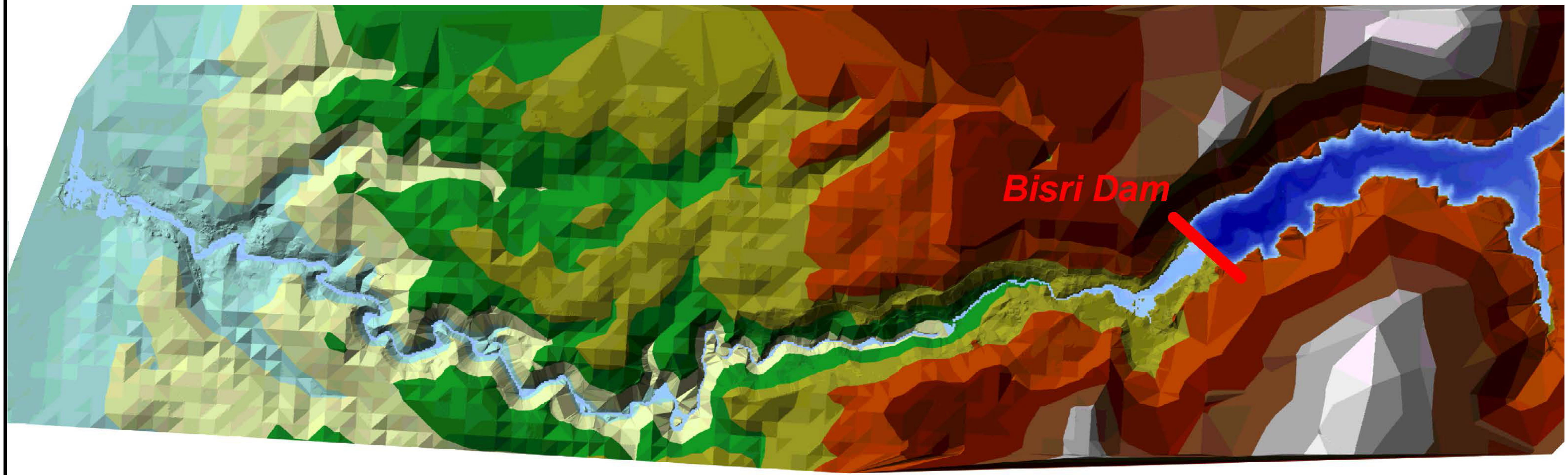


Fig. 4.5

Floodplain 30 Minutes After Start of Dam Breach

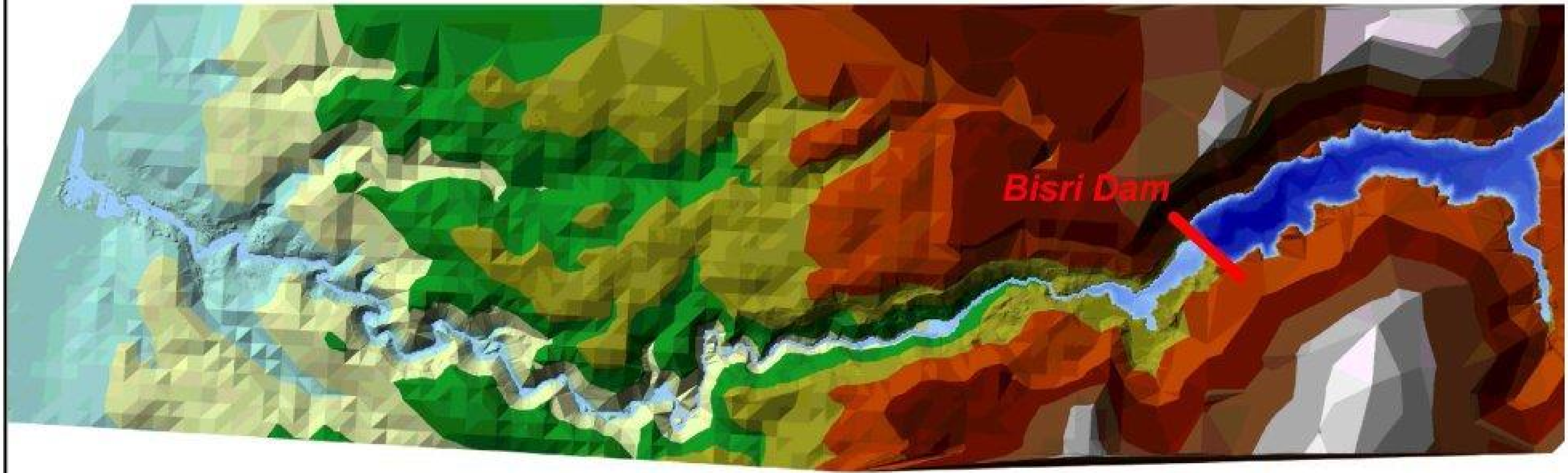


Fig. 4.6

Water Depth (m)

Value

High : 67.5363

Low : 0.000610352

0 0.5 1 2 3 4 Kilometers

Floodplain 40 Minutes After Start of Dam Breach

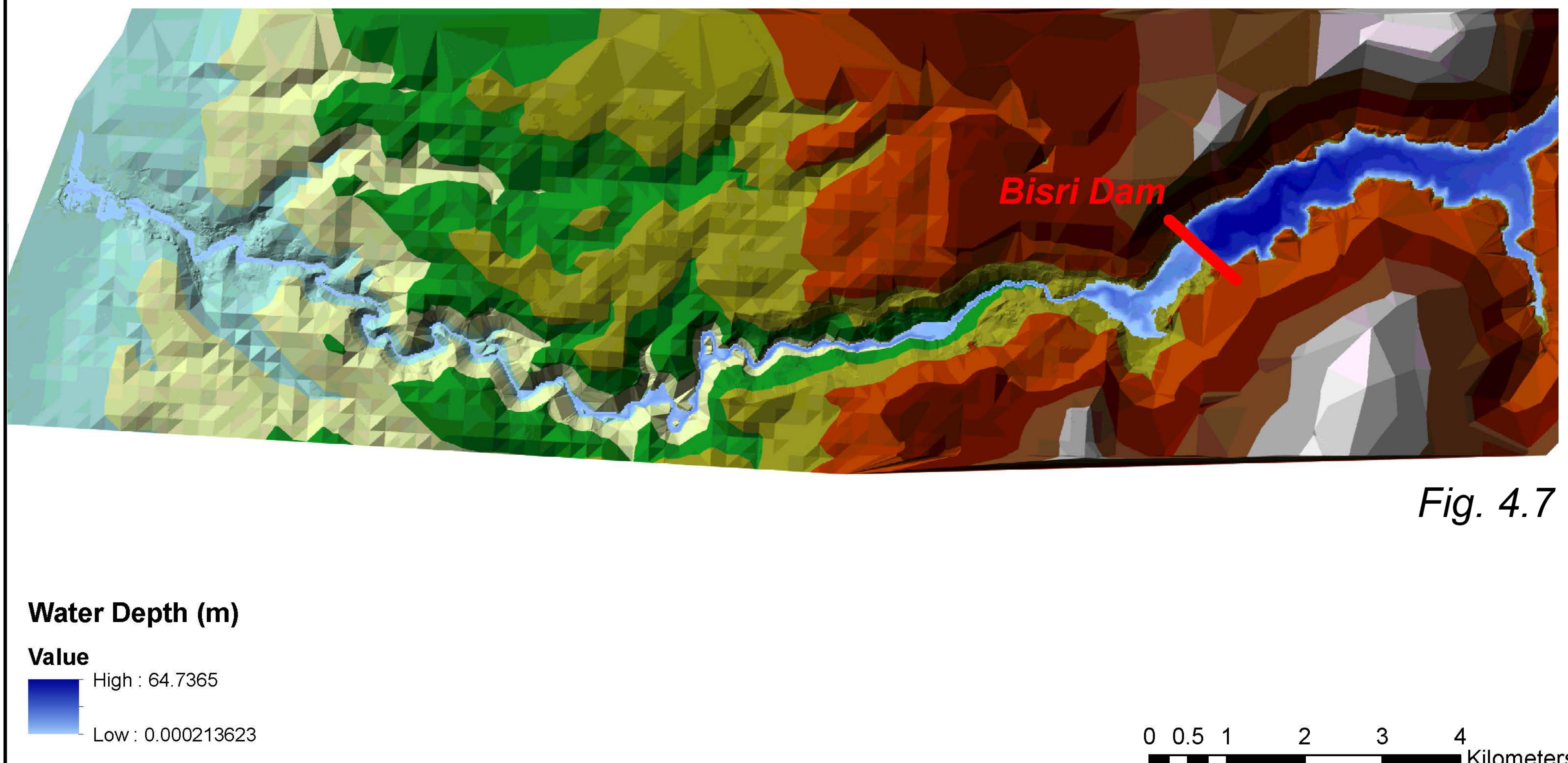


Fig. 4.7

Floodplain 50 Minutes After Start of Dam Breach

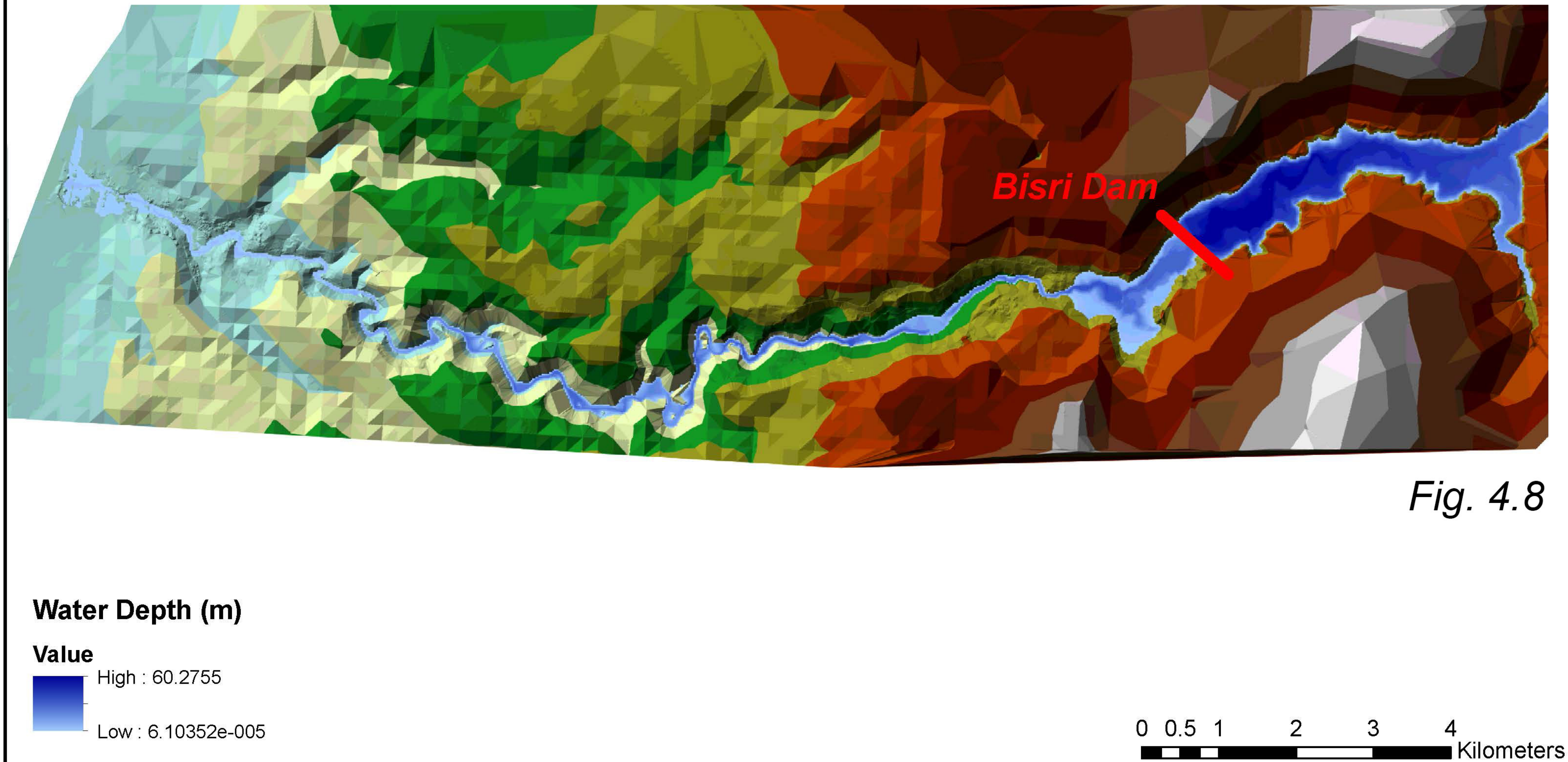


Fig. 4.8

Floodplain 60 Minutes After Start of Dam Breach

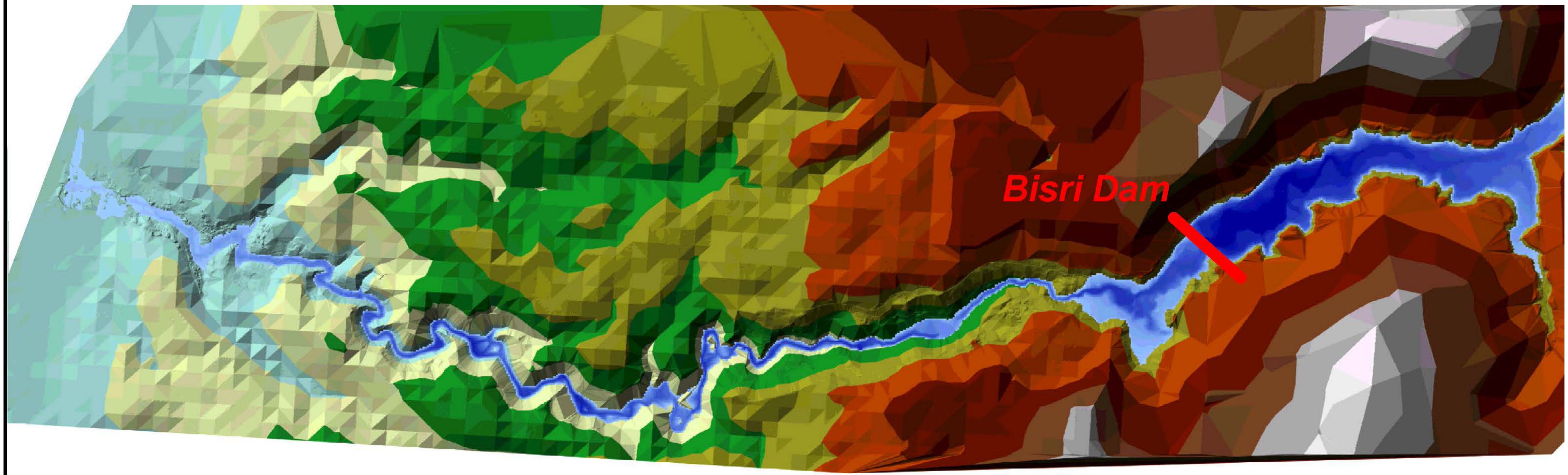


Fig. 4.9

Floodplain 70 Minutes After Start of Dam Breach

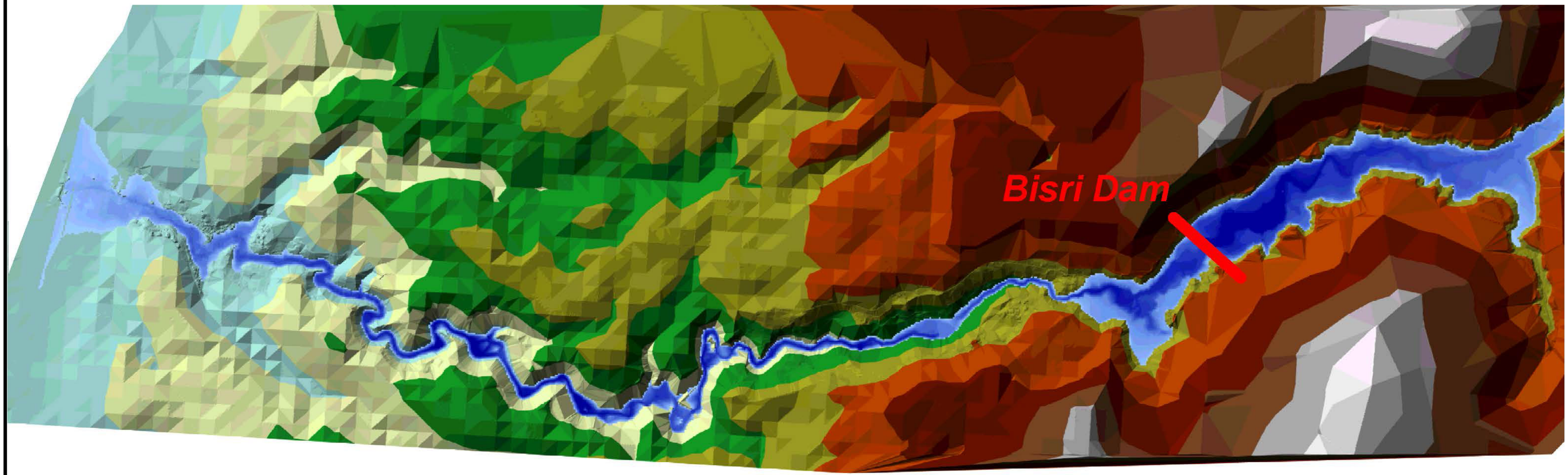


Fig. 4.10

Water Depth (m)

Value

High : 46.3948

Low : 0.00292587

0 0.5 1 2 3 4 Kilometers

Floodplain 80 Minutes After Start of Dam Breach

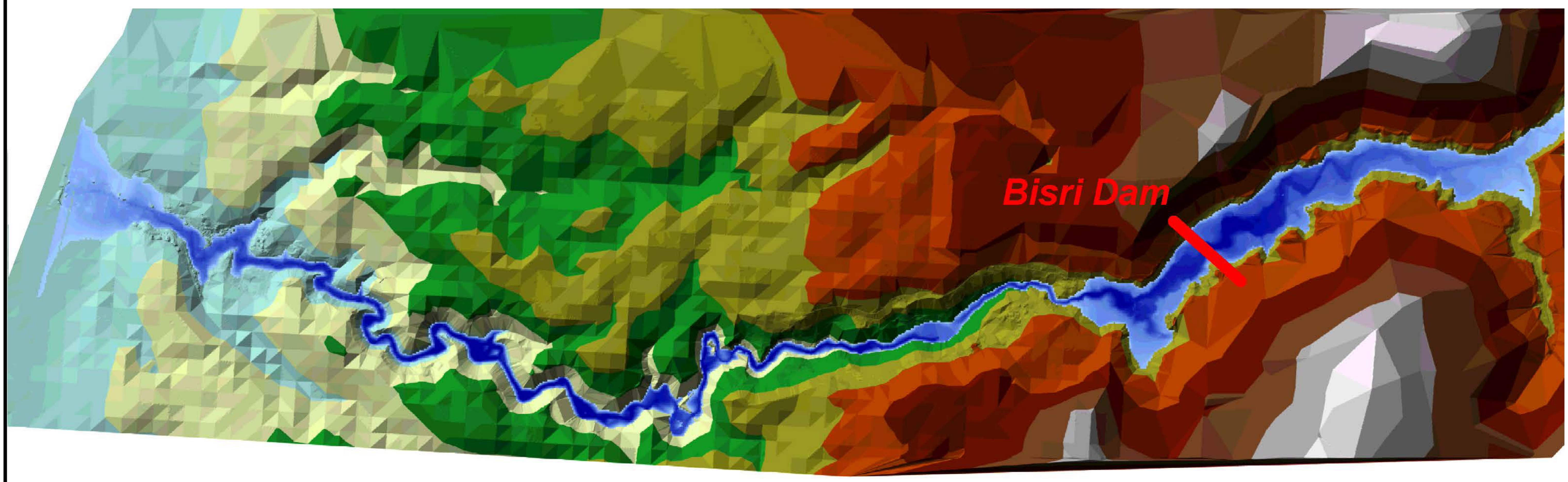


Fig. 4.11

Floodplain 90 Minutes After Start of Dam Breach

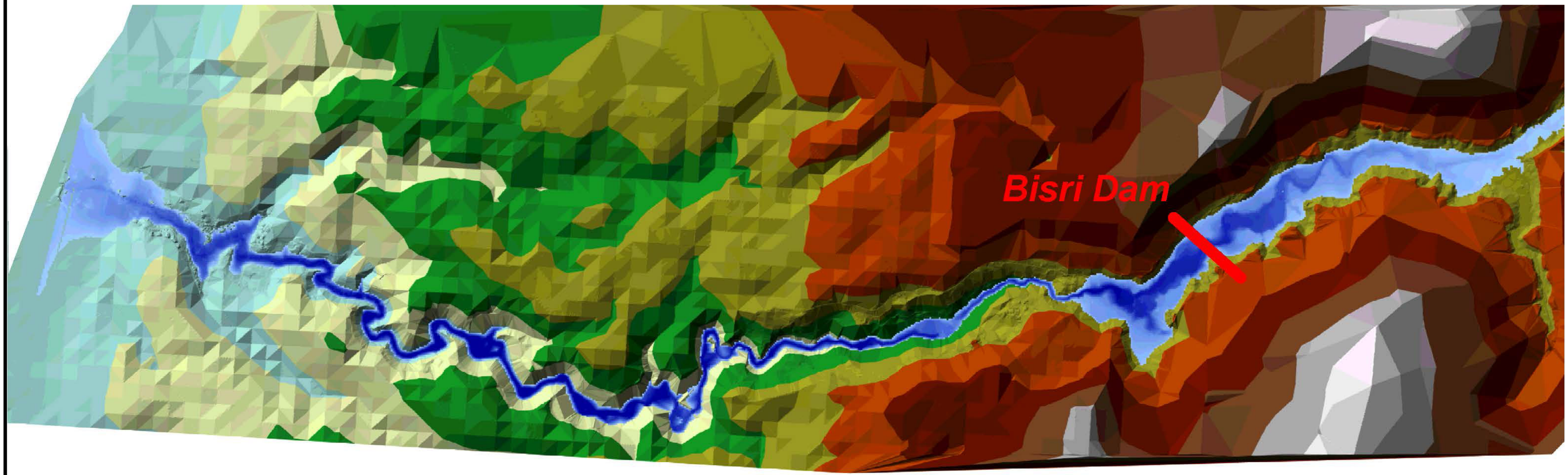


Fig. 4.12

Water Depth (m)

Value

High : 52.6679

Low : 0.000152588

0 0.5 1 2 3 4 Kilometers

Floodplain 100 Minutes After Start of Dam Breach

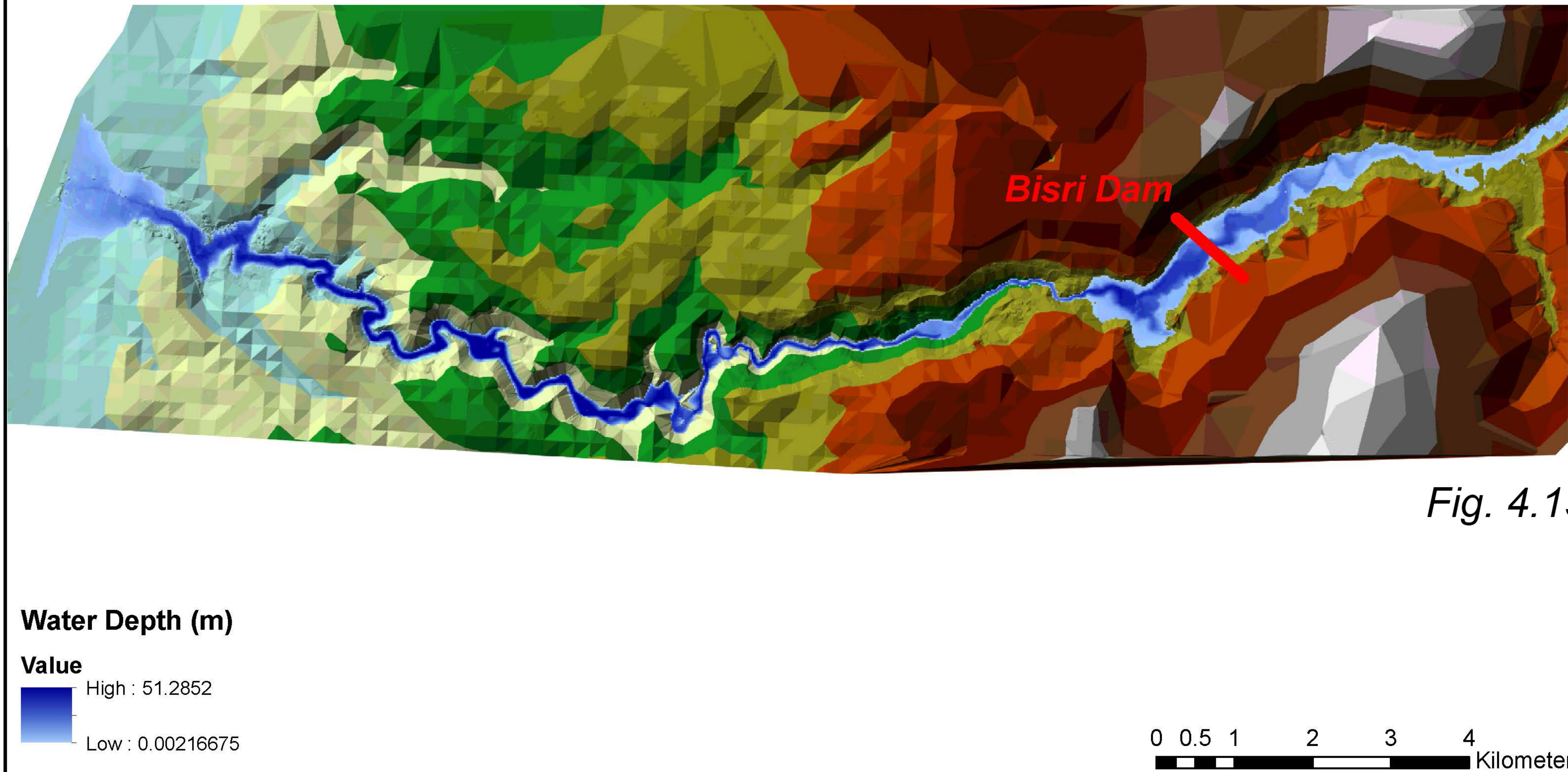


Fig. 4.13

Floodplain 110 Minutes After Start of Dam Breach

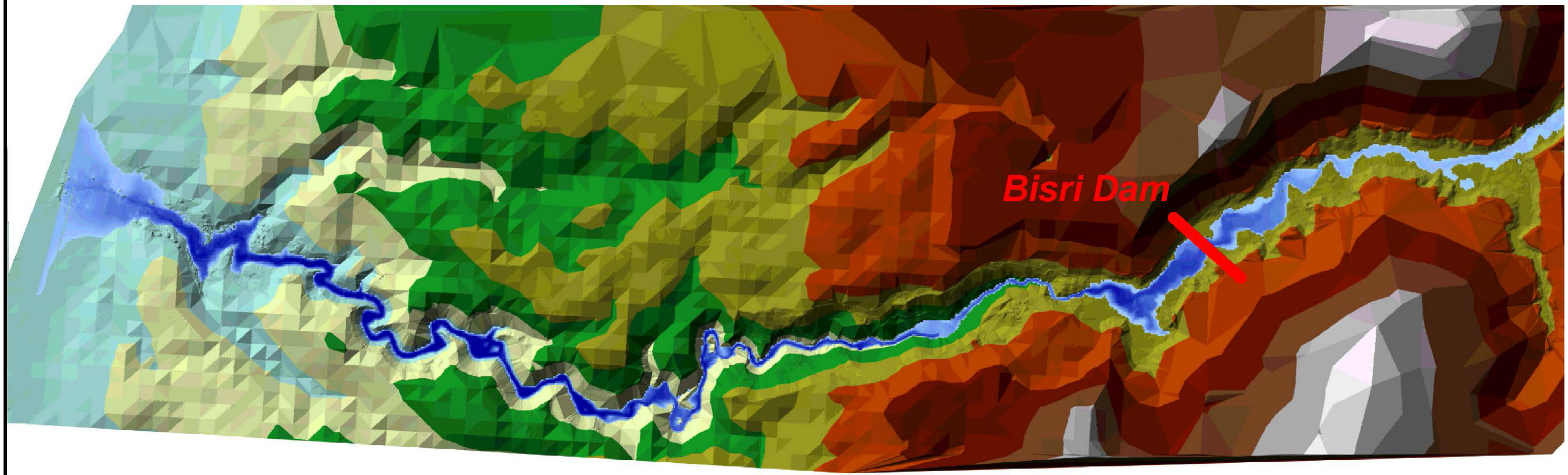


Fig. 4.14

Water Depth (m)

Value

High : 42.6821

Low : 0.00128174

0 0.5 1 2 3 4 Kilometers

Floodplain 120 Minutes After Start of Dam Breach

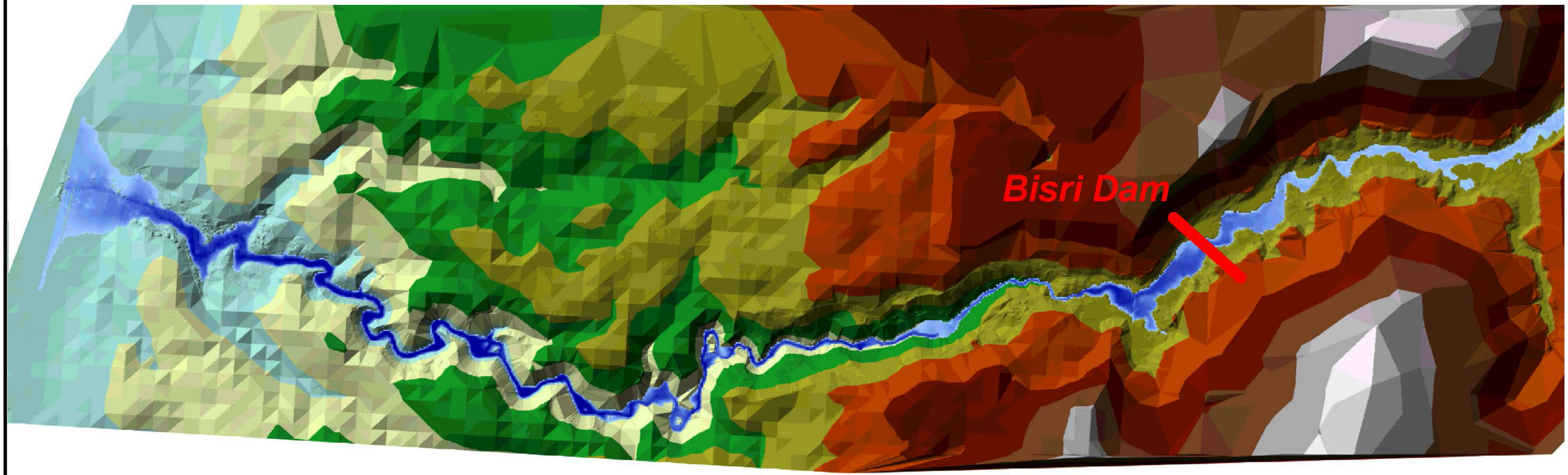


Fig. 4.15

Floodplain 130 Minutes After Start of Dam Breach

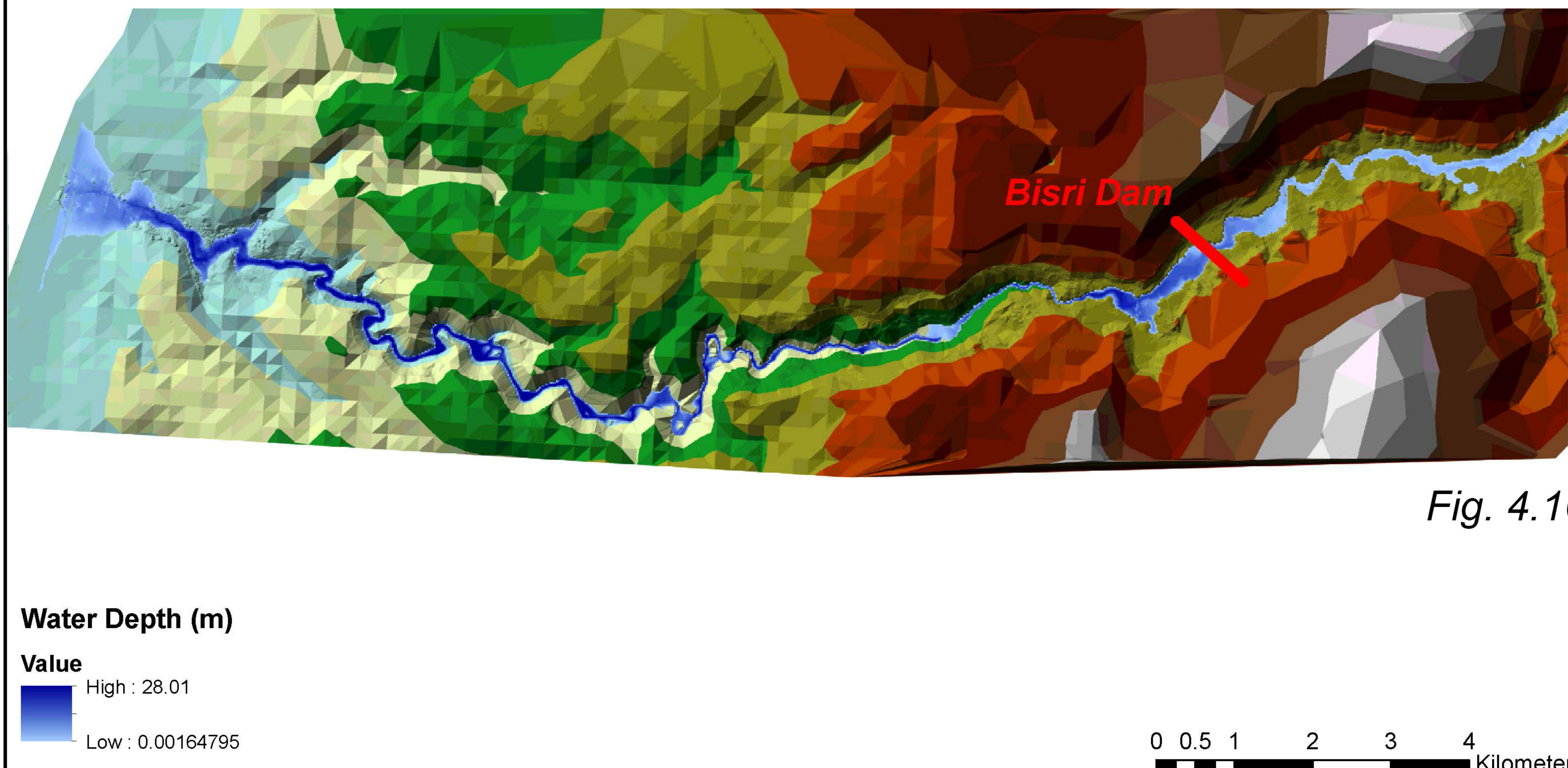


Fig. 4.16

Floodplain 140 Minutes After Start of Dam Breach

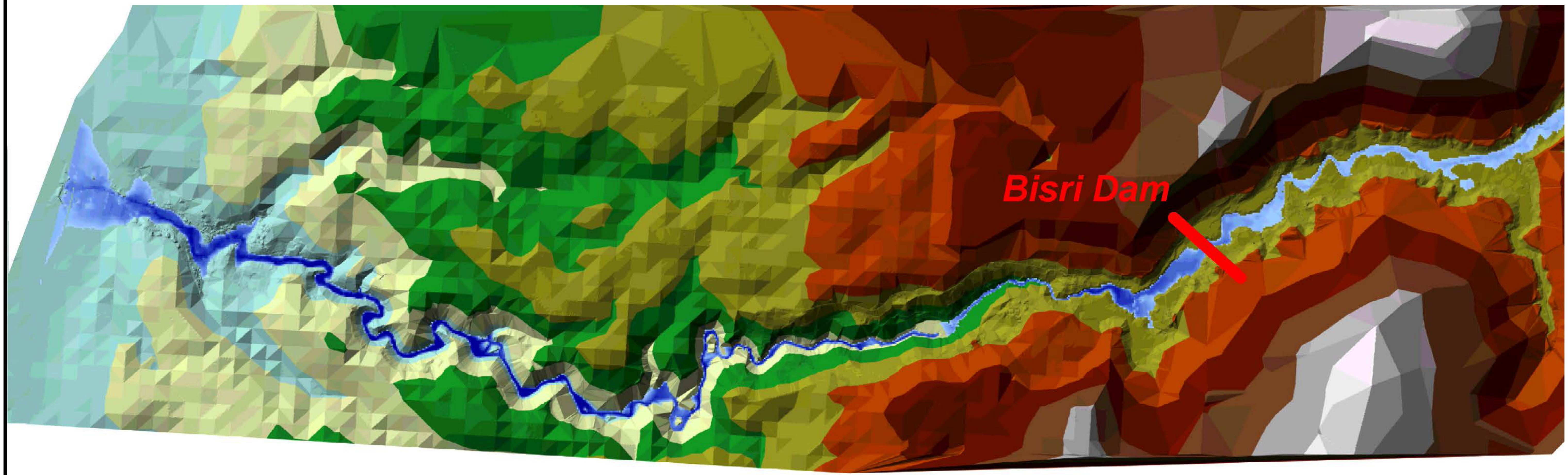


Fig. 4.17

Water Depth (m)

Value

High : 23.5739

Low : 0.00164795

0 0.5 1 2 3 4 Kilometers

Floodplain 150 Minutes After Start of Dam Breach

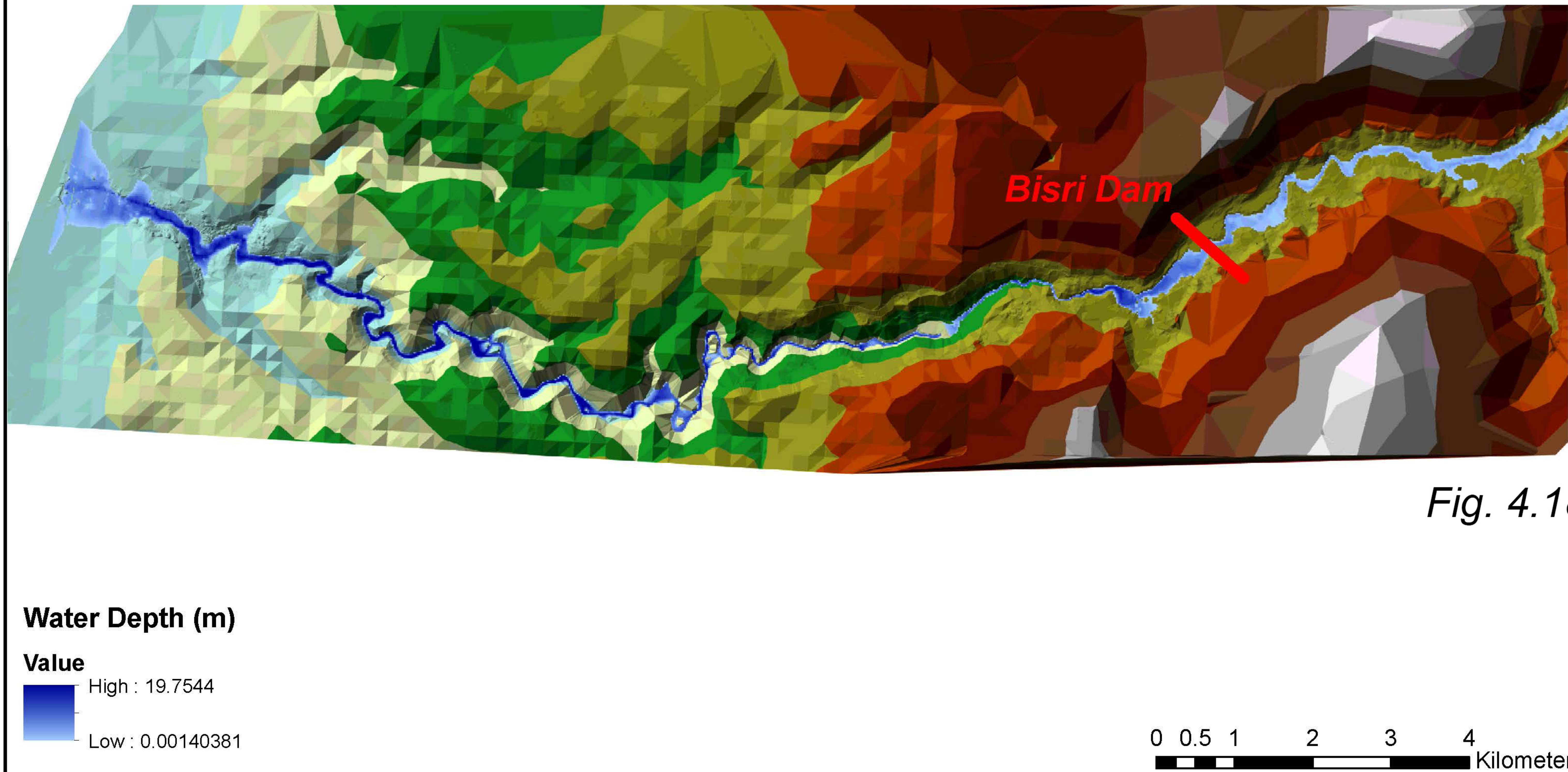


Fig. 4.18

Maximum Floodplain

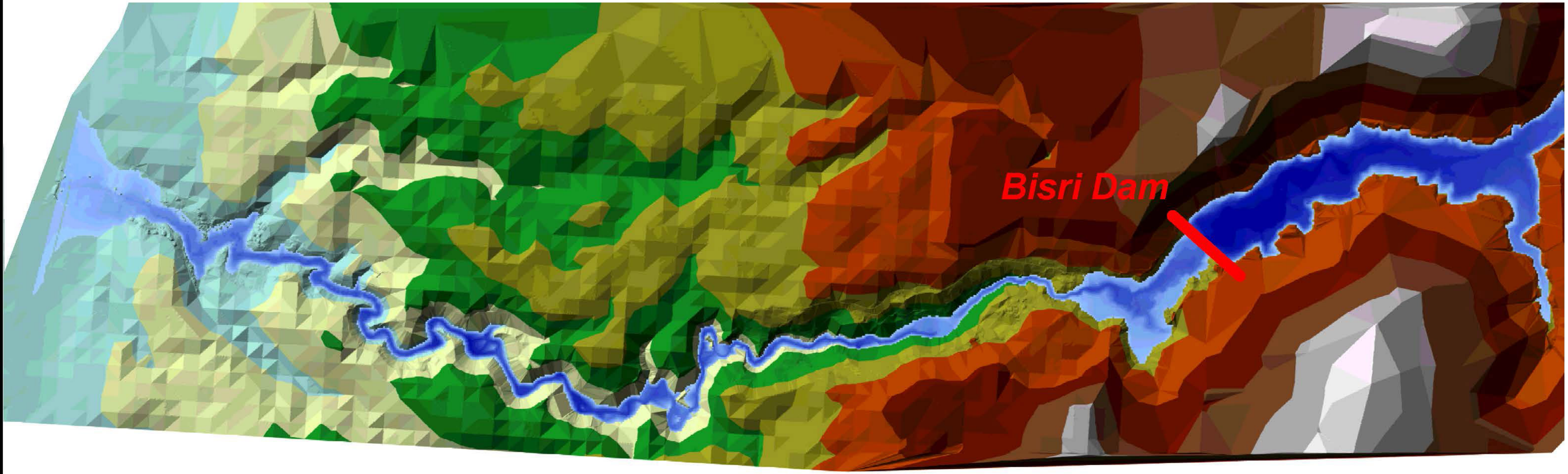


Fig. 4.19

Water Depth (m)

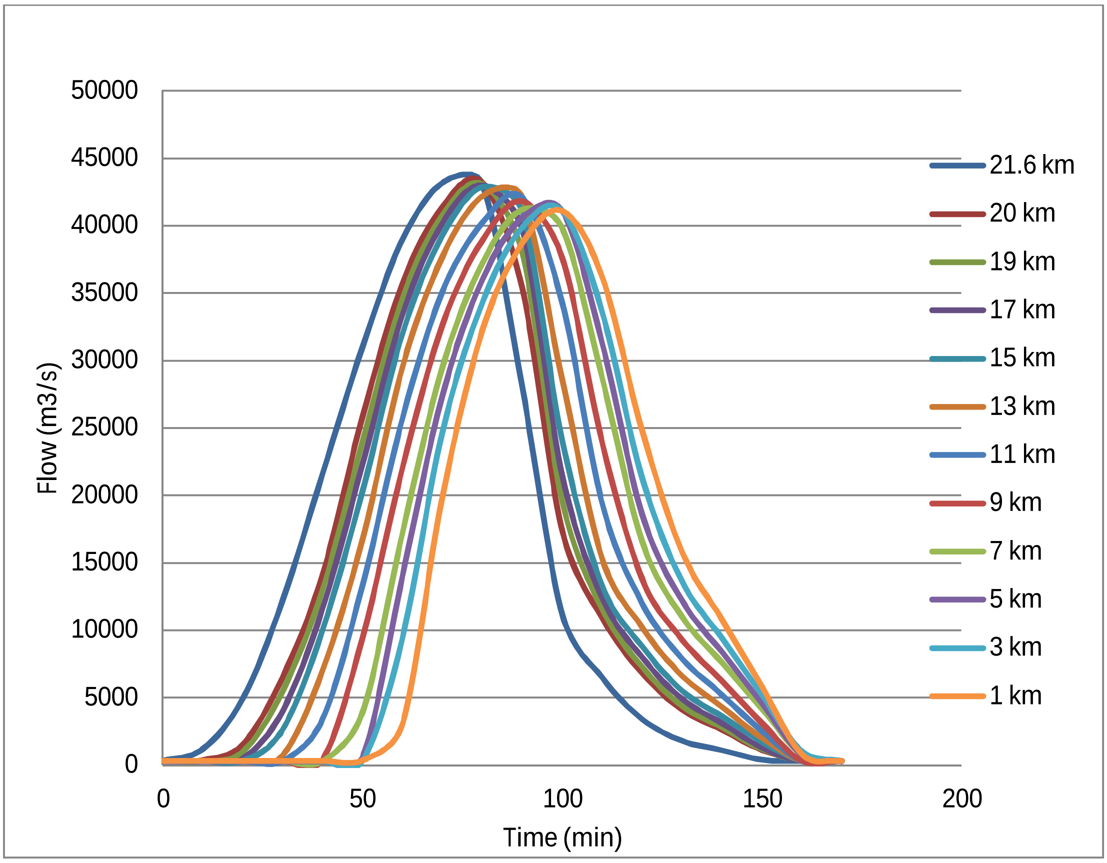
Value

High : 69.4302

Low : 0.00124741

0 0.5 1 2 3 4 Kilometers

Figure 4-20 Flood Hydrographs at different locations throughout the Bisri River



4.2 Sensitivity Analysis of Dam Breach Time

Table 4.2 lists the results for a breaching time of 2 hours. For the dam and the outlet stations the table lists the height of the flood wave passing the section; the time of the peak of the flood, and the peak follow of the flood. The flood wave is between 9m and 28m in height. These results show a flood of lower magnitude than for a 1.5-hour breaching time.

Table 4-2 Maximum stage, flow and time of peak flow for selected Bisri River stations below Bisri Dam with a 2.0 hour breach formation time

Cross-section (distance in km from sea outlet)	Initial Rise Time *	Peak Time *	Peak Flow	Flood Height
	hr:min	hr:min	m^3/sec	m
21.6 (dam)	0:00	1:30	34000	25
Sea outlet	1:10	2:00	33000	9

Table 4.3 shows the results for a breaching time of 3 hours. For the dam and the outlet stations the table lists the height of the flood wave passing the section; the time of the peak of the flood, and the peak follow of the flood. The flood wave is between 8m and 23m in height. These results also show a flood of lower magnitude than for a 1.5-hour breaching time.

Table 4-3 Maximum stage, flow and time of peak flow for selected Bisri River stations below Bisri Dam with a 3 hour breach formation time

Cross-section (distance in km from sea outlet)	Initial Rise Time *	Peak Time *	Peak Flow	Flood Height
	hr:min	hr:min	m^3/sec	m
21.6 (dam)	0:00	2:00	24000	23
Sea outlet	1:20	2:30	23000	8

4.3 Sensitivity Analysis of Breach Side Slopes

In the results reported above the side slope of the breach formed in the dam is specified as 1:1. The time for the dam to breach is 1 hours and 30 minutes, the peak of the outflow from the dam occurs 30 minutes after the beginning of the breaching process. The maximum flow rate from the dam is 43,000 m^3/sec. In order to understand the impact of the breach slope on the resulting flood characteristics, a breach slope of 2:1 was simulated.

Table 4.4 lists the results for a breach slope of 2:1. These results are almost the same as the results for a breach slope of 1:1, indicating slopes beyond the 1:1 do not have much impact on the flood formation, since the flow from the breach occurs before the water has a chance to further widen the breach beyond the 1:1 slope.

Table 4-4 Maximum stage, flow and time of peak flow for selected Bisri River stations below Bisri Dam with a 1.5 hour breach formation time and side slopes of 2:1 instead of 1:1

Cross-section (distance in km from sea outlet)	Initial Rise Time *	Peak Time *	Peak Flow	Flood Height
	hr:min	hr:min	m^3/sec	m
21.6 (dam)	0:00	1:10	43000	28
Sea outlet	1:00	1:40	41000	10

5 VALIDATION USING A 3D MODEL

5.1 Introduction

The dynamics of the dam-break wave propagation is quite complex and its behavior does not comply with the common assumptions of conventional steady and gradually-varied open channel flows. Dam break flows are highly unsteady and rapidly varied, typically with mixed subcritical and supercritical flow regimes.

In most practical dam-break applications, one dimensional numerical modeling is commonly used to simulate the flood wave propagation downstream from the dam. However, in certain cases the simplifications assumed in one dimensional models may be too restrictive to accurately reproduce the flood wave dynamics such as when the flow is not confined to a single channel or the channel has sharp bends. Such special cases require the application of a full three dimensional flow model. Accordingly, a three dimensional Computational Fluid Dynamics (CFD) model was performed.

5.2 Objective

The work aims to validate the HEC-RAS model by using a three dimensional CFD mathematical model of commercial use "Flow-3D" for the representation and verification of the inundation modeling and wave propagation from the flow originated by the breaching of Bisri dam.

5.3 Methodology

5.3.1 Software

Flow-3D was developed by Flow Science Inc. in the United States and it is a code that simulates fluid dynamics based on the numerical solution of the Navier-Stokes equations and continuity. It computes the three velocity components and pressure at the nodes of orthogonal Finite Difference Grid, using different turbulence models (Κ-ε, RNG, LES). Among the general-purpose CFD programs commercially available in the market, Flow 3D stands out for its capabilities intended for hydraulic engineering applications. The free surface in Flow-3D is tracked by means of the VOF method (Volume of Fluid) and the model uses FAVOR method to determine the solid boundaries.

5.3.2 CFD Model

5.3.2.1 Geometry and Boundary Conditions

For the simulation of Bisri dam breach three linked meshes were used and all of them had cubic cells of 10 meters size. Figure 5.1 and Table 5.1 show the location and boundary conditions of each mesh.

Table 5-1 Characteristics of Meshes

Mesh Number	Coordinates						Boundary Condition
	$X_{minimum}$	$X_{maximum}$	$Y_{minimum}$	$Y_{maximum}$	$Z_{minimum}$	$Z_{maximum}$	
Mesh 1	-338000	-334785	-64400	-61500	50	600	Flow rate equals 43,412 m^3/s obtained from HEC-RAS
Mesh 2	-342000	-338000	-65000	-62400	50	500	Continuity of flow
Mesh 3	-347900	-342000	-65000	-60700	-5	300	Outflow conditions

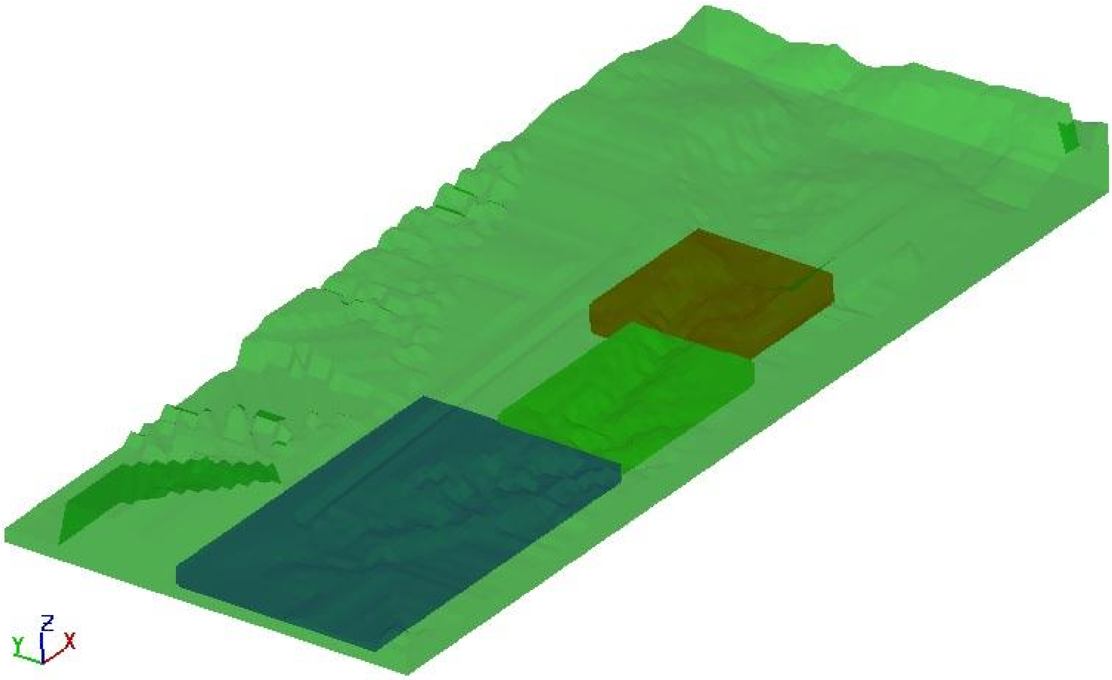


Figure 5-1 Meshes used in the modeling

5.3.2.2 *Physical Models*

The fluid was considered monophasic and incompressible, at a temperature of 20°C. The physical models activated were gravity and turbulence. The gravity acceleration was set to 9.81m/s2 and the turbulence model used is the standard K-ε model.

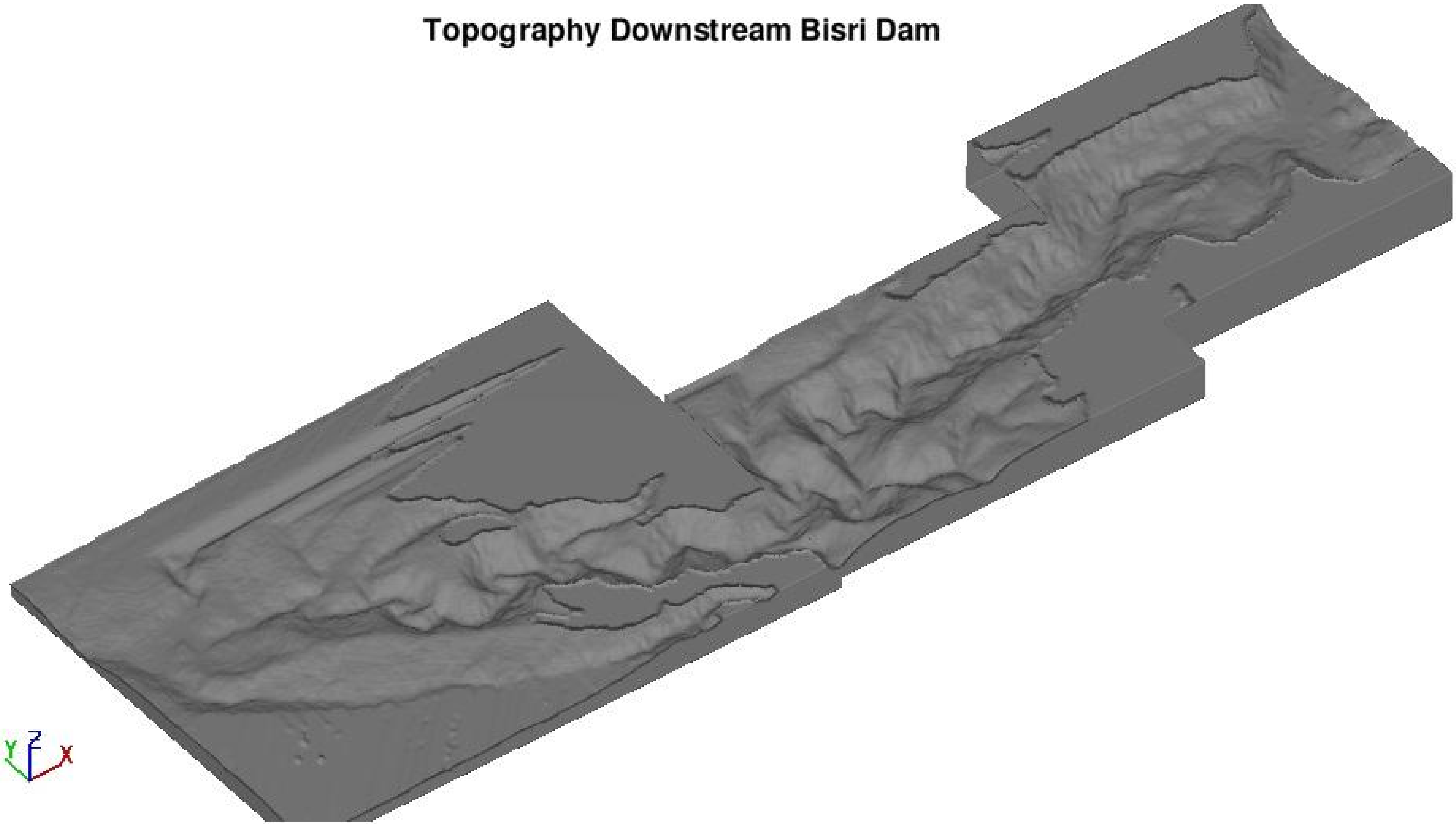


Figure 5-2 3D View of topography after meshing for area downstream Bisri dam

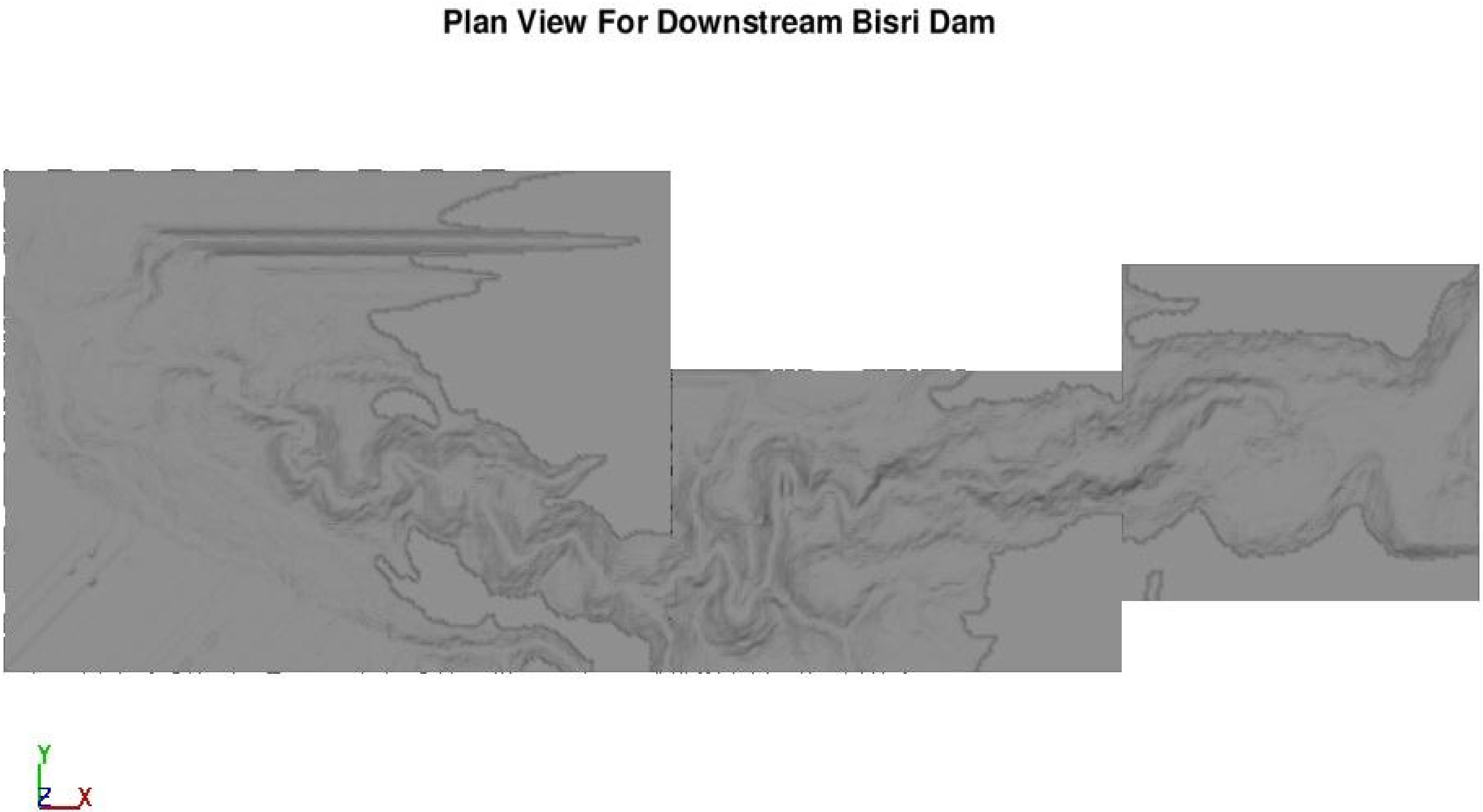


Figure 5-3 Plan View of topography after meshing for area downstream Bisri dam

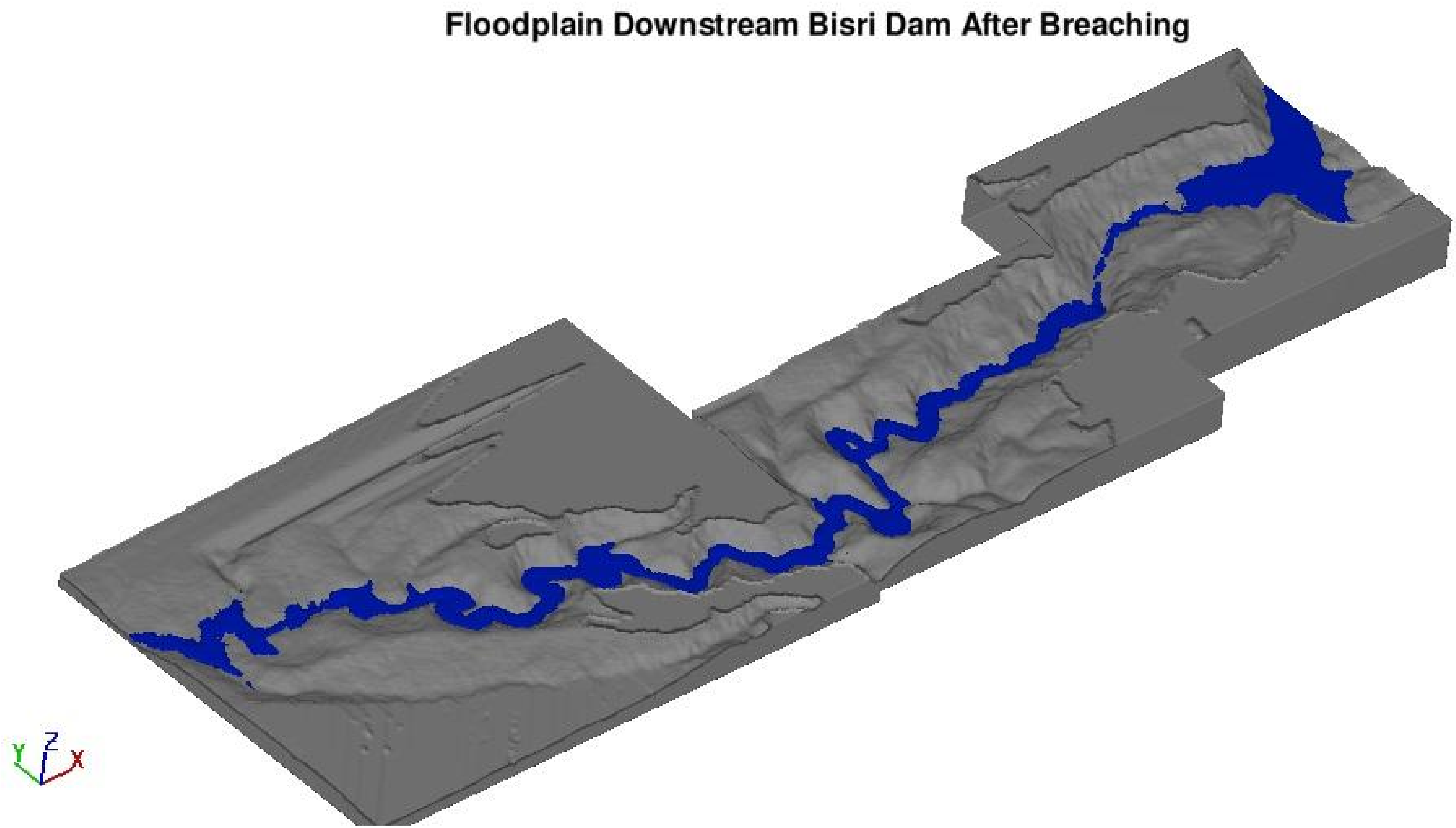


Figure 5-4 3D view for maximum floodplain downstream Bisri dam

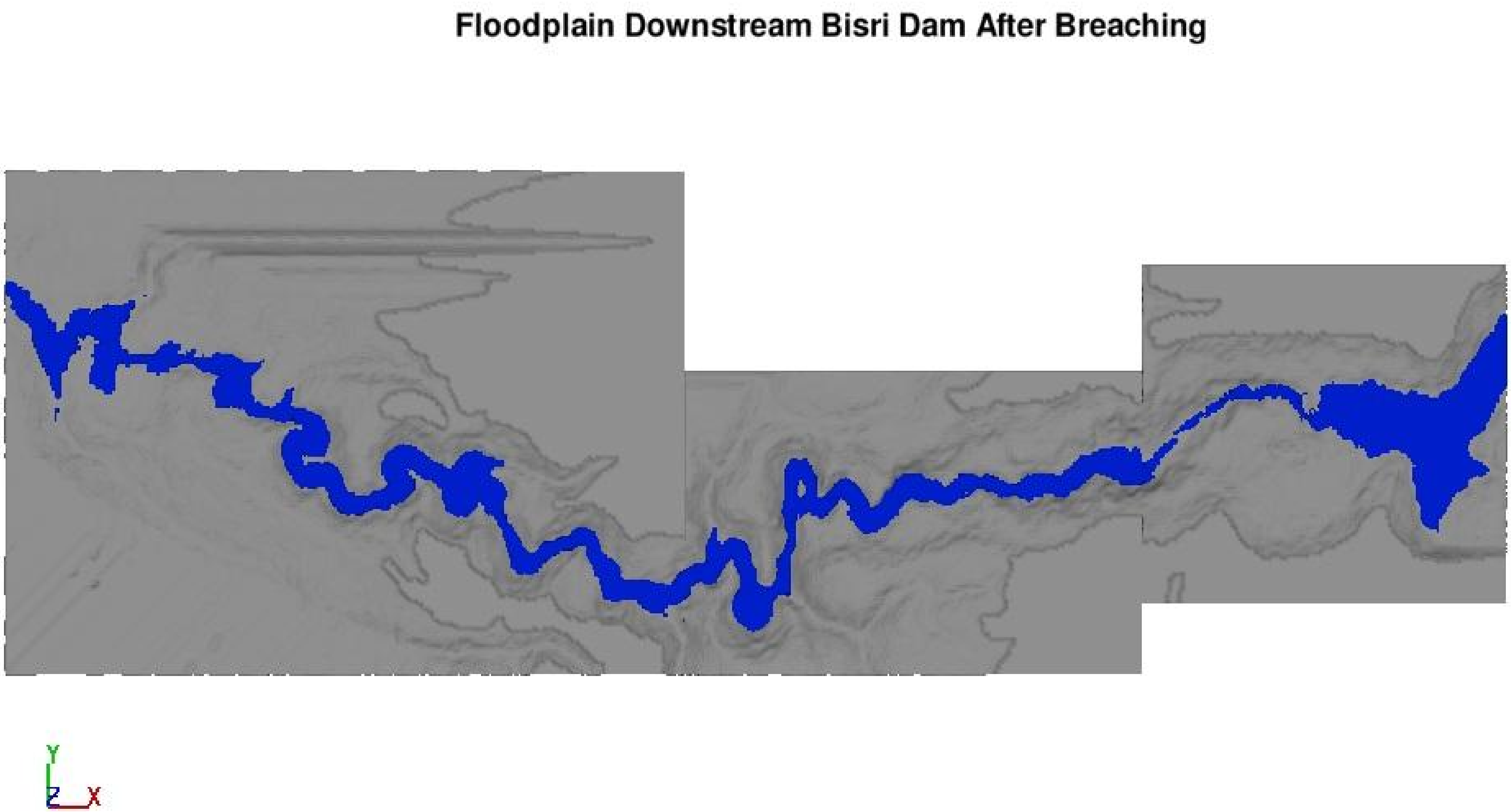


Figure 5-5 2D view for maximum floodplain downstream Bisri dam

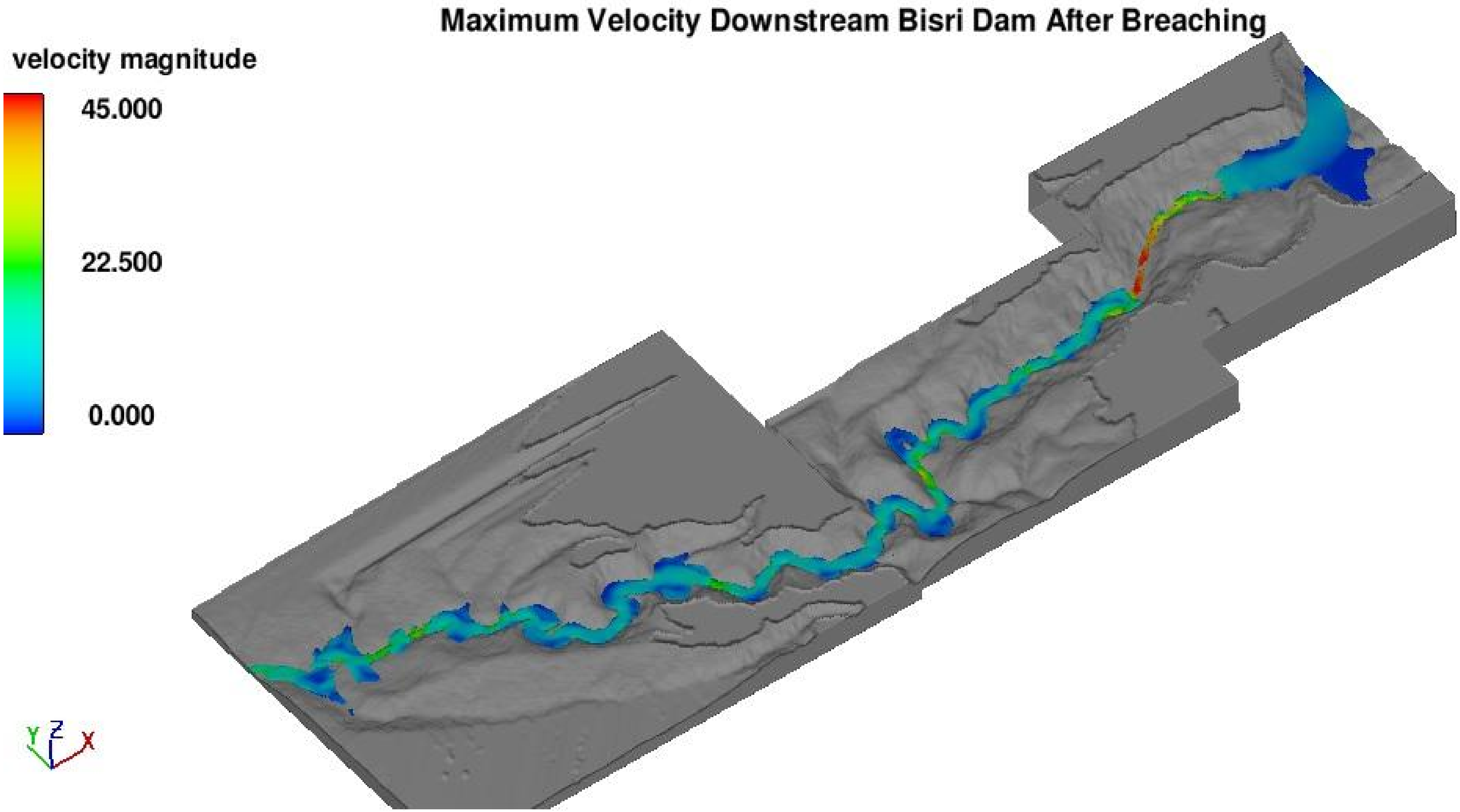


Figure 5-6 3D view for maximum flow velocities downstream Bisri dam after breaching

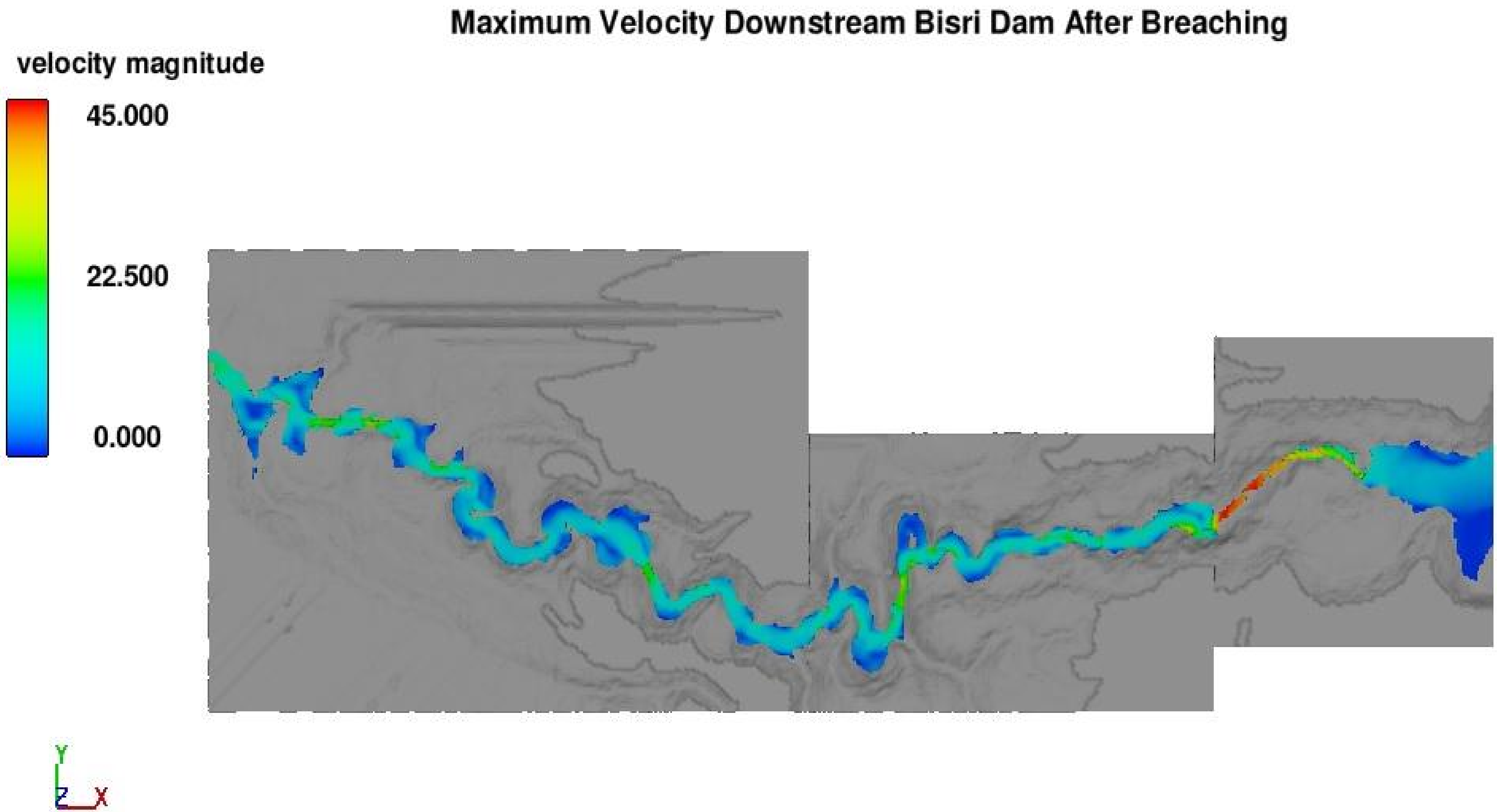


Figure 5-7 2D view for maximum flow velocities downstream Bisri dam after breaching

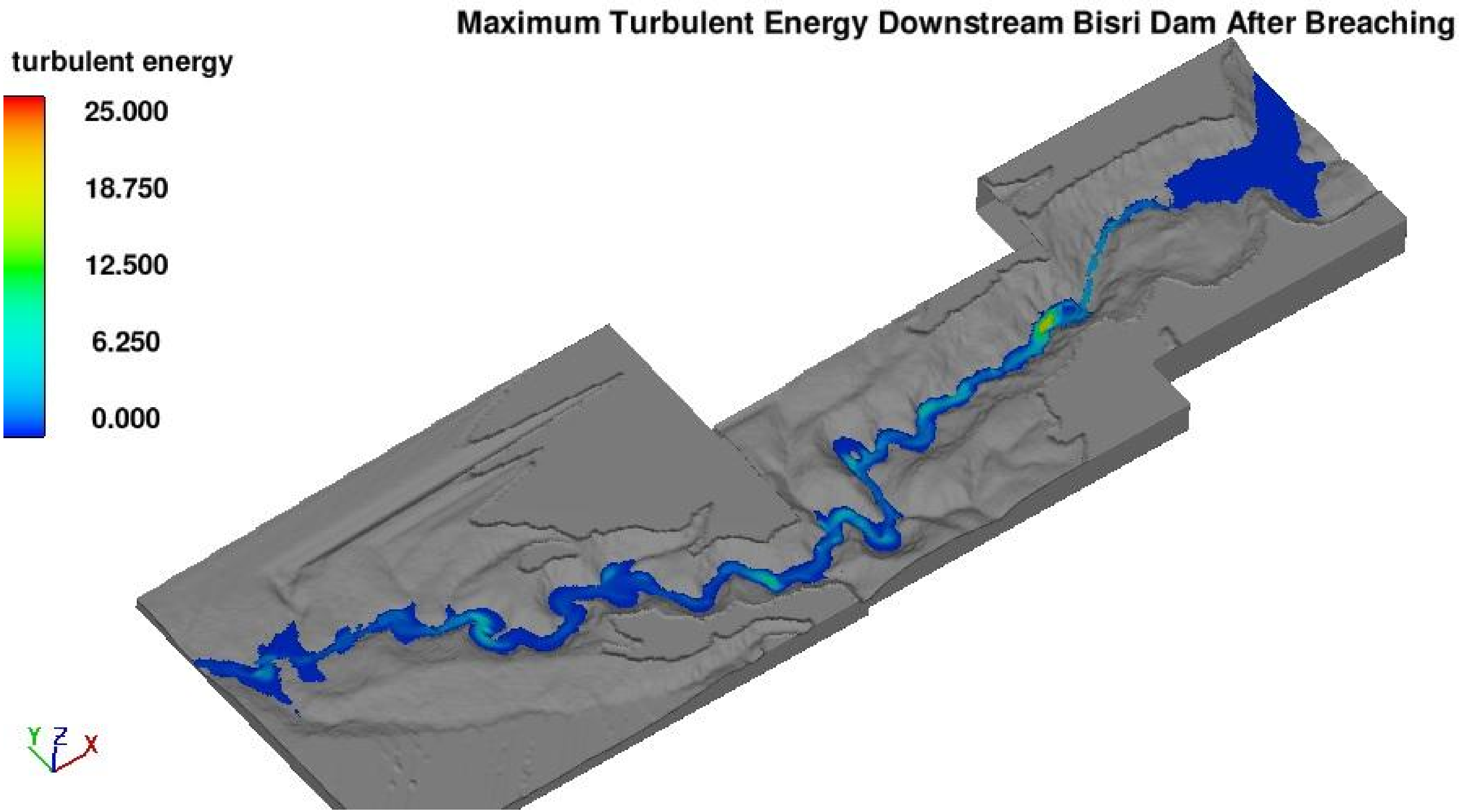


Figure 5-8 3D view for maximum flow turbulent energy downstream Bisri dam after breaching

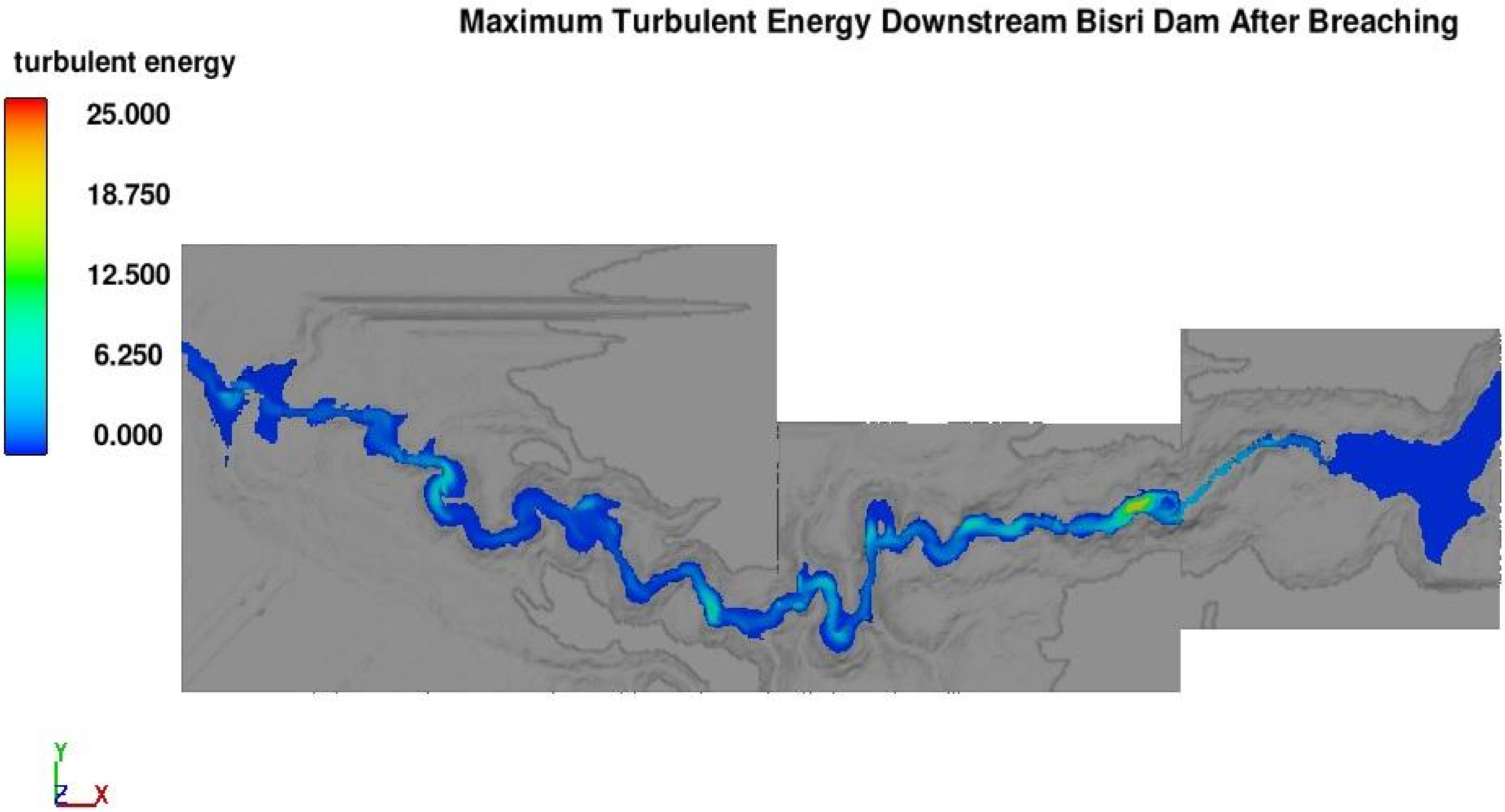
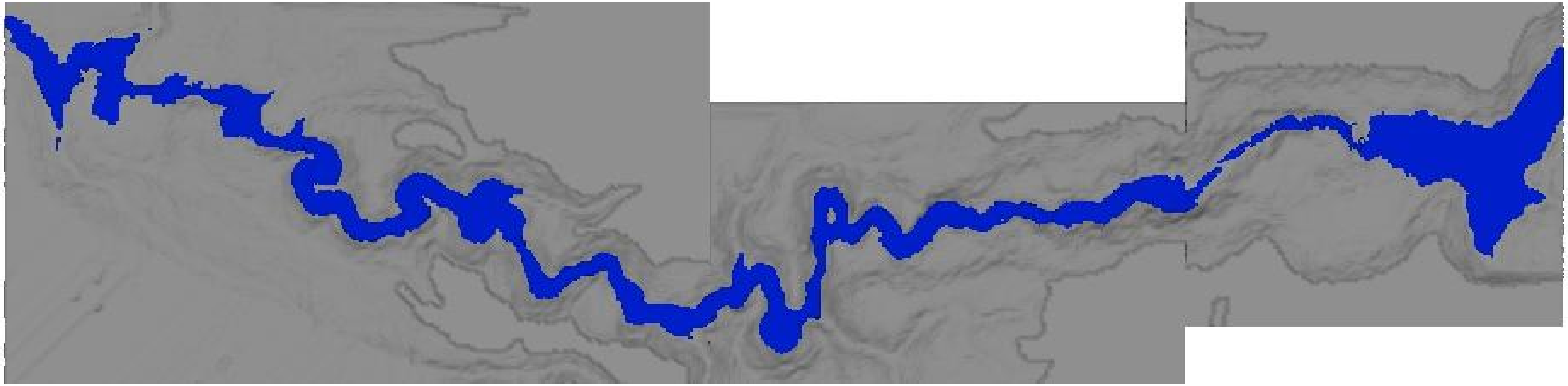
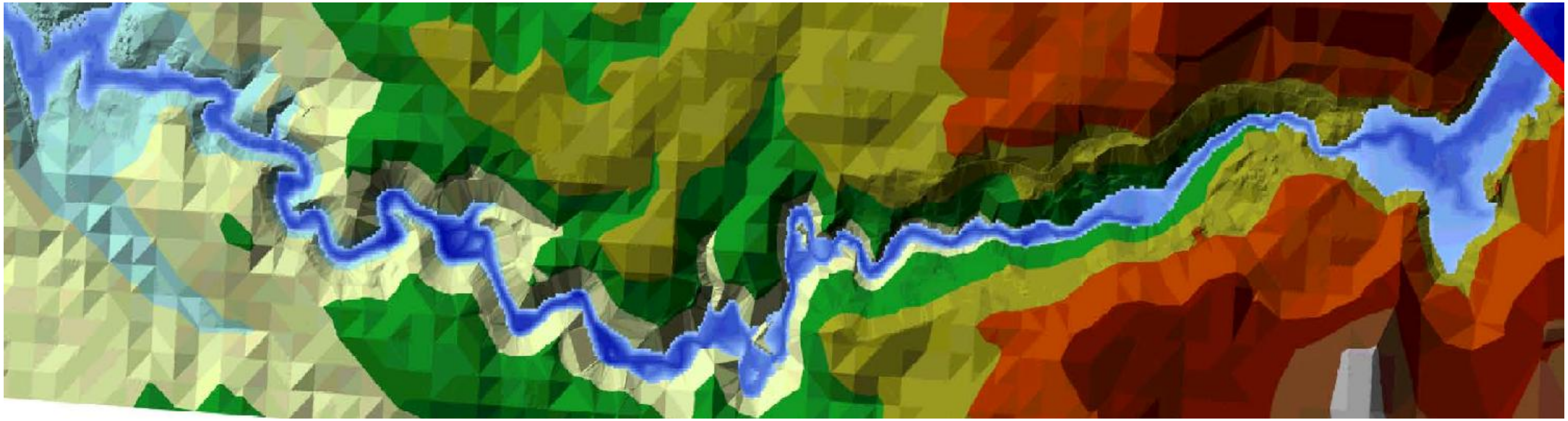


Figure 5-9 3D view for maximum flow turbulent energy downstream Bisri dam after breaching



(a)



(b)

Figure 5-10 Floodplain results of Flow-3D (a) and HEC-RAS (b)

5.4 Conclusion

Based on the comparison between one dimensional modeling (HEC-RAS) and three dimensional CFD modeling (Flow-3D) no significant differences were found. However, the inundation mapping downstream the dam considers the envelope of both models.

6 DAM BREAK DAMAGE ASSESSMENT

6.1 Introduction

Damages due to Dam Break impact different types of structures or activities (stakes) and can be direct (physical damage due to submersion and water flows) or indirect (disruption of human and notably economic activities).

The table below is commonly used to categorize flood damages per stake and type of impacts.

Types of damage	Direct		Indirect	
Stakes	Examples	Cost evaluation	Examples	Cost evaluation
Residential houses	Destruction or degradation	Reconstruction, repair or cleaning costs	Alternative housing during reconstruction/repair Decrease in house value	Cost of alternative housing
Factories and private sector facilities	Destruction or degradation	Reconstruction, repair or cleaning costs	Interruption of production, loss of clients, loss of jobs, bankrupcy	Production decrease and economic losses, impacts from long-term job losses?
Farms	Destruction or degradation of crops	Areas impacted and estimated yield decreases	Decrease in land value Bankrupcy, loss of jobs	Production decrease and economic losses, impacts from long-term job losses?
Public infrastructure (hospitals, schools, administrative buildings, etc.)	Destruction or degradation	Reconstruction, repair or cleaning costs	Service interruption	Cost of delays or of alternative service sources
Road infrastructure	Destruction or degradation of roads and structures (e.g. bridges)	Reconstruction, repair costs	Road or bridge restriction or closure, increased travel times for users	Increased costs for transport companies Economic losses for factories, farms, etc.
Other transport infrastructure (ports, airports, railways, canals, etc.)	Destruction or degradation	Reconstruction, repair costs	Transport restriction or closure, increased travel times for users	Increased costs for transport companies Economic losses for factories, farms, etc.
Public services (water, electricity)	Destruction or degradation of infrastructure (networks, plants, etc.)	Reconstruction, repair costs	Service interruption	Production losses and economic losses for factories, farms, etc.

Types of damage	Direct		Indirect	
Stakes	Examples	Cost evaluation	Examples	Cost evaluation
Tourist infrastructure (hotels, restaurants, campings, etc.) & historic locations/buildings	Destruction or degradation	Reconstruction, repair costs	Decrease in tourism	Economic losses
Natural environment (rivers, wetlands, forests)	Destruction or degradation	Reconstruction, repair costs	Pollution	Pollution impacts Depollution costs

Dam Breaks can also claim lives of human beings. These are direct impacts that are not considered here because financially estimating the cost of life is always a difficult and controversial topic.

Assigning costs to direct impacts is not always easy as it may be more than just physical repairs (for example crop losses are difficult to “repair”). It is however becoming feasible as formulas and mechanisms are being developed in Europe and in the US. These formulas or standard values are mostly established by insurance companies.

Numerous surveys have also been carried out to assess the costs of flood damages and references exist. These references have been adapted here to Lebanon where such formulas or standard values do not exist yet.

Assigning costs to indirect impacts (which can go as far as including psychological impacts on populations) is much more difficult. Most of the associated economic losses are caused by the temporary or permanent unavailability of structures or equipment. Such losses can even lead to job losses and bankruptcies.

As the objective of this damage estimation study is simply to give an idea of the magnitude of the economic cost of a Dam Break in the Bisri River, only direct impacts will be calculated. Indirect impacts will be for now considered to be, at most, of an equivalent magnitude.”

6.2 Damage Assessment: Methodology and Results

The study area includes the region situated between Bisri Dam and the Sea Mouth.

Combined with information collected on land use and simulated flood depth, maps of the flooded areas provide information that can be used for flood damage assessment, urban and rural planning and validating flood simulation models. The concept of damage function is used when calculating flood damage.

In order to assess flood damage correctly, the impact parameters need to be incorporated in a method (Water depth, Duration of flooding, Flow velocity, Sediment concentration, Sediment size, Wave or wind action, Pollution load of flood water, Rate of water rise during flood onset). However, due to the difficulty in integrating such variables, damage is generally related to only water depth.

In the case of built-up areas, the land use class is expressed per unit area. The economic value of the land use class is estimated in order to calculate the damage. This value is based on the principle of replacement value: how much money it would cost to obtain the ‘identical’ object. The damage function has values included between 0 and 1, with the value 0 if there is no damage and the value 1 if there is maximum damage.

This analysis has the purpose to give an assessment of the damage of flood by using the damage functions which are available in the literature. The assumptions listed below had to be made to do the flood damage assessment:

- The damage function is a function only of inundation depth, although flood damage is determined by more factors, as explained before.
- The damage functions must be increasing functions, which means that as the inundation depth grows, also damage rises.
- During a flood event, some damage can be avoided by appropriate action from the people who live in the floodplain. Therefore cars are not taken into account of the damage assessment.
- An important question in damage calculation is which assumption has to be made with respect to the behavior of the people. This is caused by the fact that damage is a function of many physical and behavioral factors, like for example the content of the house and the preparation time. Hence, uncertainties in the damage functions are not dealt with in this analysis.
- The maximum damage values are here only indicative and are based on the average price per m^2 for a house or an apartment. This information is deducted from the local market prices.

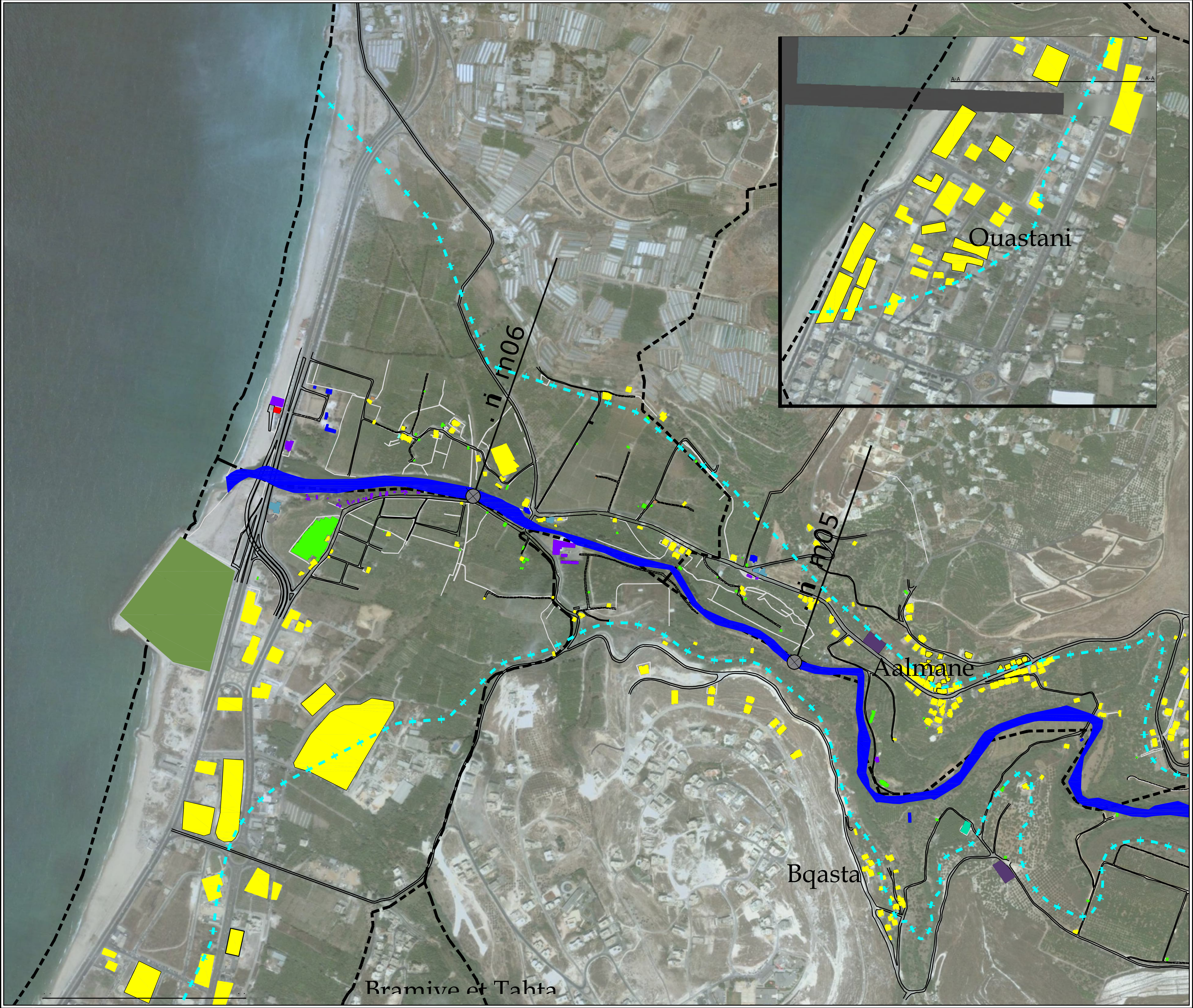
The damage function used in this study depends on several components: different land used classes, flood depth factors, economical value per square meter.

The flooded area was individuated and considered according to the map of the flooded area provided based on the Dam Break Model.

The flood damage depends on the land use type: in urban areas floods produce as a consequence much more damage than floods in a rural area. The land use classes, which are used to calculate the flood damage, correspond to:

- Vegetated and Agricultural areas
- Built-up area (Residential, Industrial and Commercial areas)
- Infrastructure

A satellite view showing the estimated delimitation of the flood and an estimation of land use based on the information collected during the field survey is illustrated in Figures 6.1 to 6.5.



Legend

- Flood Limit
- River
- Residential
- Hospitality & Restaurants
- Retail & Commercial
- Religion & Heritage
- Cemetery
- Government (Police , Hospital , Red Cross , Fire Station)
- Service Station
- Workshop & Quarry
- Sport
- Agricultural (Houses , Plastic Rooms , Stable & Warehouse)
- Electrical (Stations , Generator Room ,Column tension
- Reservoirs & Water
- Parking & Transport Station
- 60 Min

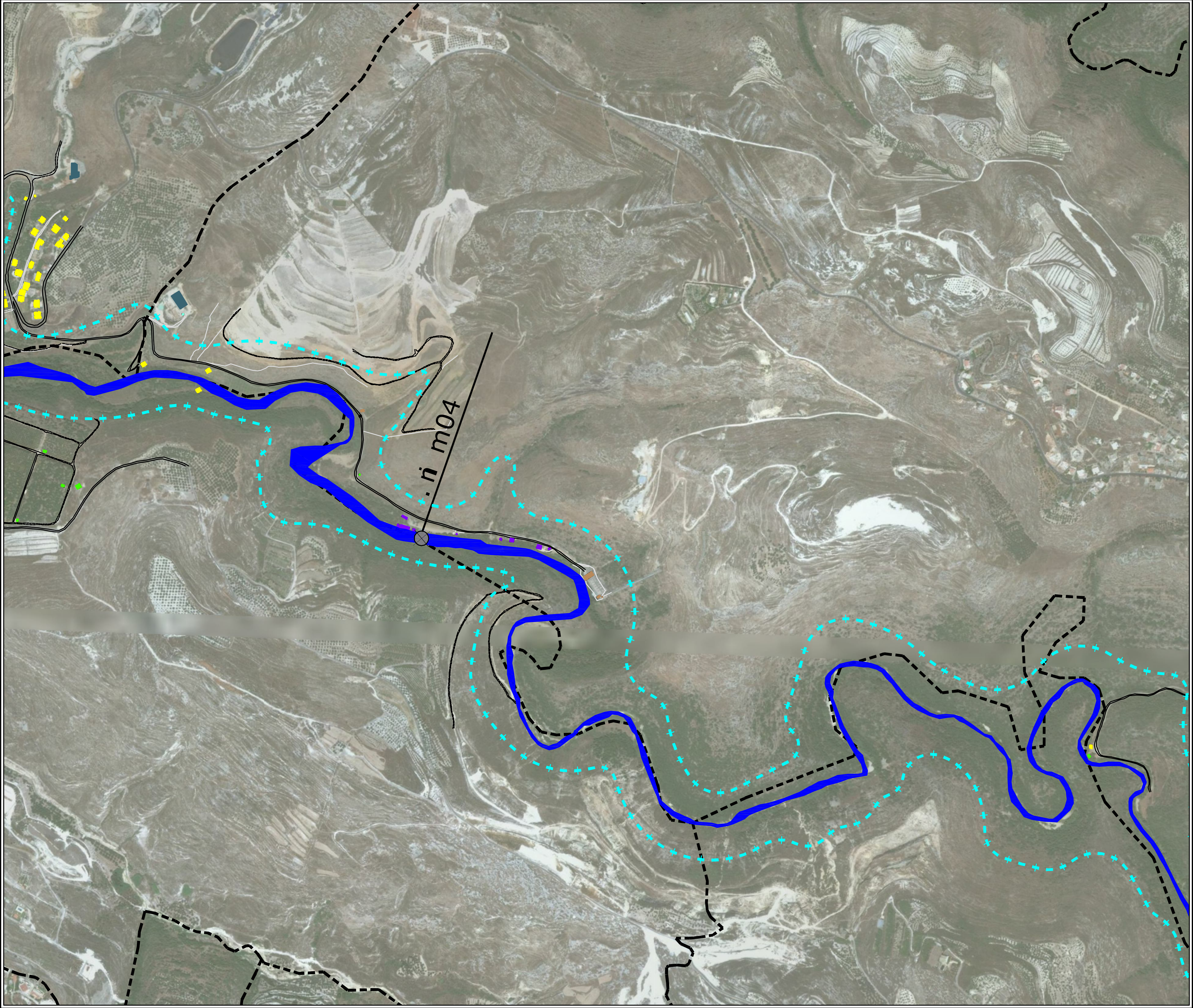
Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

0m 100m 250m

Fig. 6.1

LAND USE OF THE FLOODED AREA (5 / 5)

DAR AL HANDASAH NAZIH TALEB & PARTNERS



Legend

Flood Limit

River

Residential

Hospitality & Restaurants

Retail & Commercial

Religion & Heritage

Cemetery

Government (Police , Hospital , Red Cross , Fire Station)

Service Station

Workshop & Quarry

Sport

Agricultural (Houses , Plastic Rooms , Stable & Warehouse)

Electrical (Stations , Generator Room ,Column tension

Reservoirs & Water

Parking & Transport Station

60 Min

Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

0m 100m 250m

Scale $\frac{1}{10000}$ @ A3 Size

N

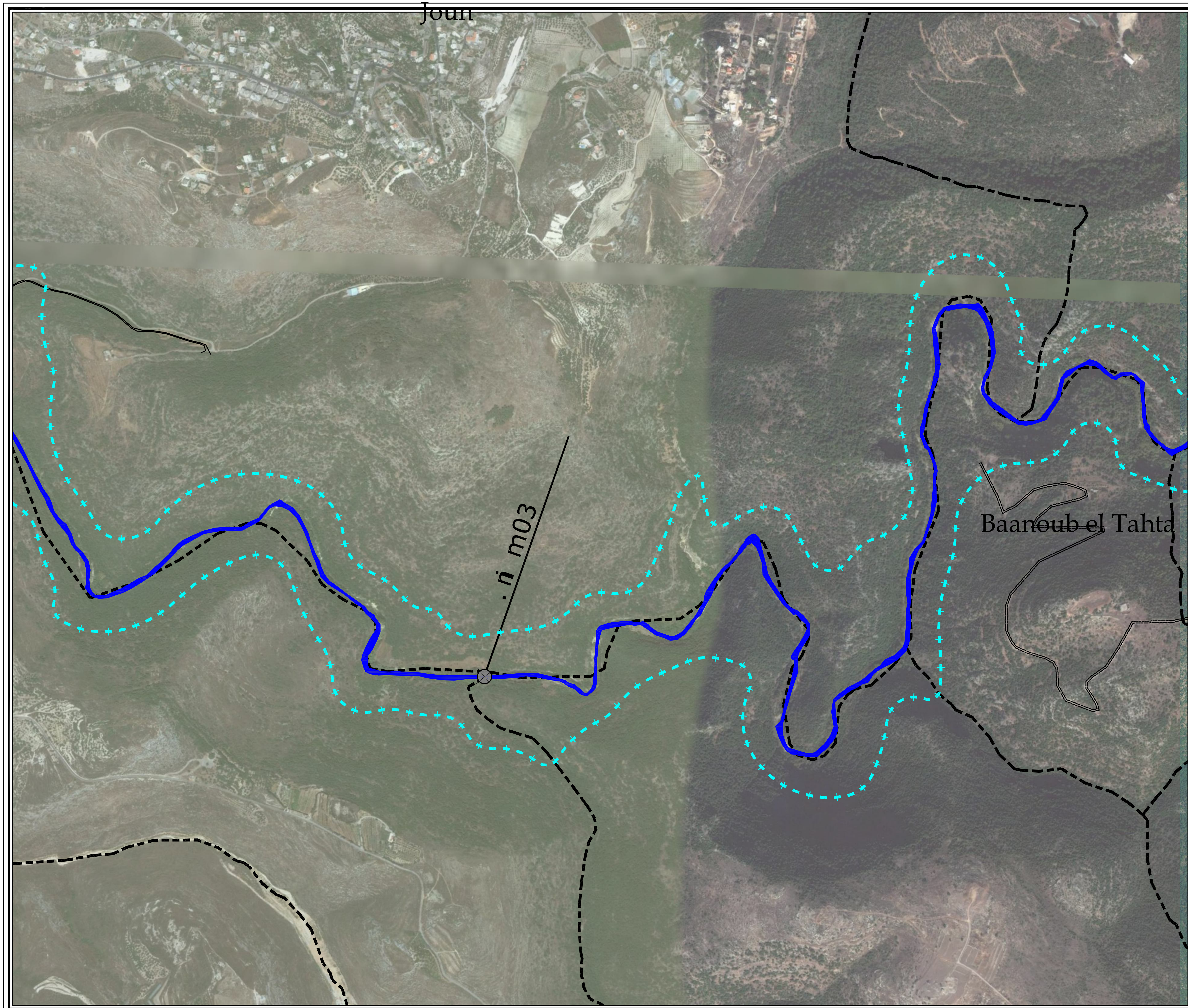
Fig. 6.2

LAND USE OF THE FLOODED AREA (5 / 5)

DAR AL HANDASAH NAZIH TALEB & PARTNERS

دار الهندسة نزيه طالب وشركاه

Founded 1956



Legend

- Flood Limit
- River
- Residential
- Hospitality & Restaurants
- Retail & Commercial
- Religion & Heritage
- Cemetery
- Government (Police , Hospital , Red Cross , Fire Station)
- Service Station
- Workshop & Quarry
- Sport
- Agricultural (Houses , Plastic Rooms , Stable & Warehouse)
- Electrical (Stations , Generator Room ,Column tension
- Reservoirs & Water
- Parking & Transport Station
- 60 Min

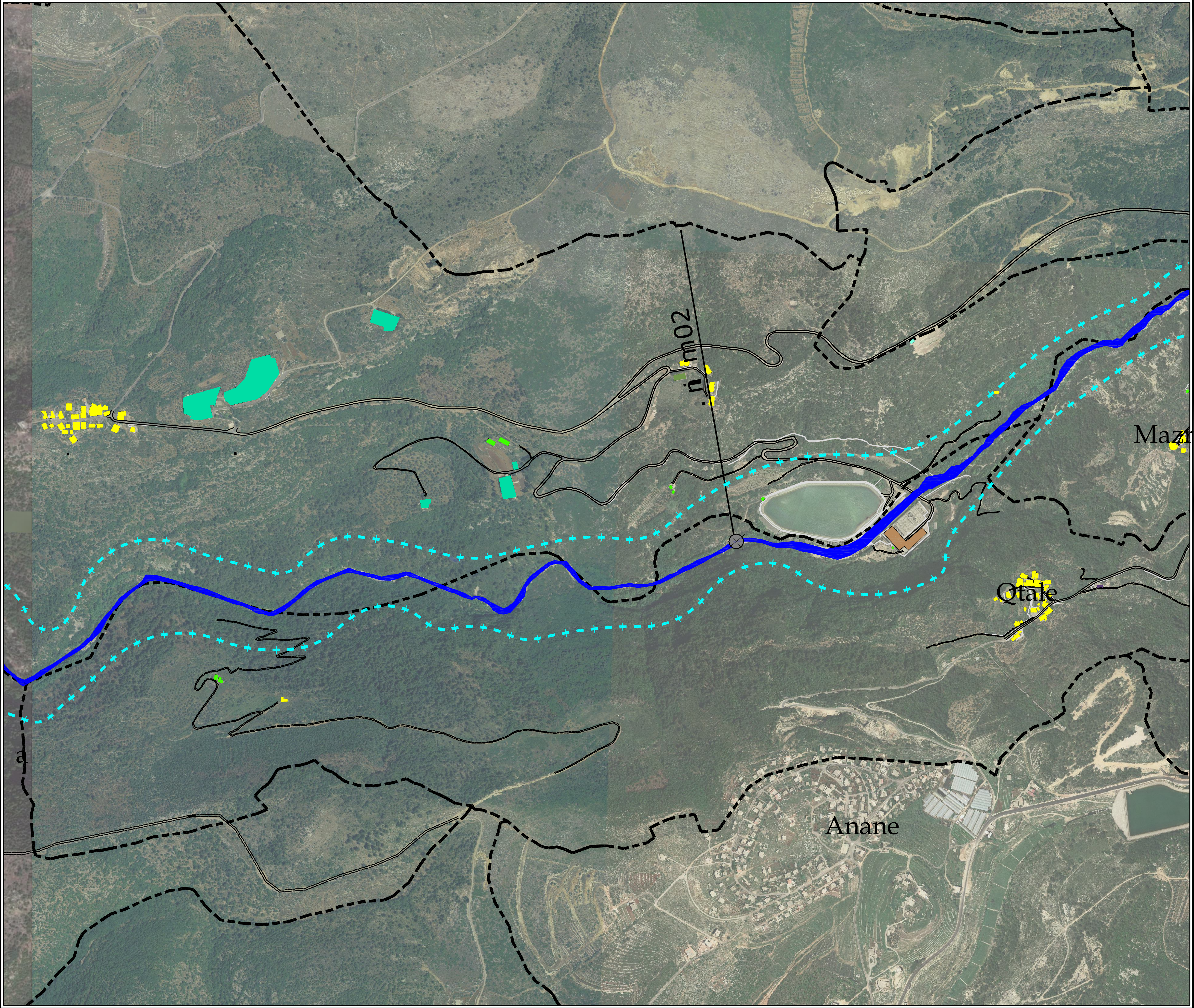
Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

0m 100m 250m

Fig. 6.3

LAND USE OF THE FLOODED AREA (5 / 5)

DAR AL HANDASAH NAZIH TALEB & PARTNERS



Legend

- Flood Limit
- River
- Residential
- Hospitality & Restaurants
- Retail & Commercial
- Religion & Heritage
- Cemetery
- Government (Police , Hospital , Red Cross , Fire Station)
- Service Station
- Workshop & Quarry
- Sport
- Agricultural (Houses , Plastic Rooms , Stable & Warehouse)
- Electrical (Stations , Generator Room ,Column tension
- Reservoirs & Water
- Parking & Transport Station
- 60 Min

Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

0m 100m 250m

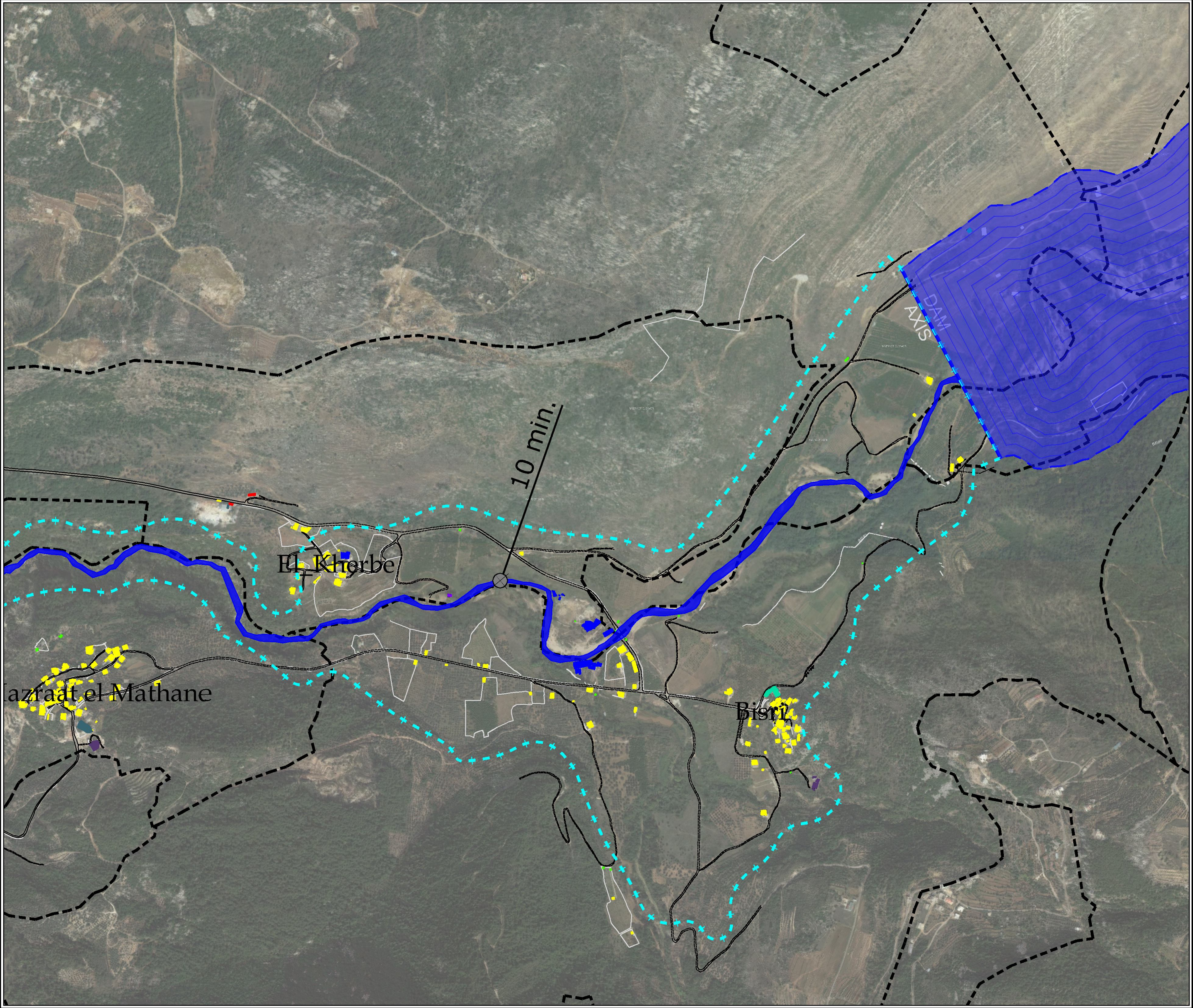
Scale $\frac{1}{10000}$ @ A3 Size

N

Fig. 6.4

LAND USE OF THE FLOODED AREA (5 / 5)

DAR AL HANDASAH NAZIH TALEB & PARTNERS
دار الهندسة نزيه طالب وشركاه
Founded 1956



Legend

- Flood Limit
- River
- Residential
- Hospitality & Restaurants
- Retail & Commercial
- Religion & Heritage
- Cemetery
- Government (Police , Hospital , Red Cross , Fire Station)
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- Sport
- Agricultural (Houses , Plastic Rooms , Stable & Warehouse)
- Electrical (Stations , Generator Room ,Column tension
- Reservoirs & Water
- Parking & Transport Station
- 60 Min

Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

0m 100m 250m

Scale @ A3 Size

N

Fig. 6.5

LAND USE OF THE FLOODED AREA (5 / 5)

DAR AL HANDASAH NAZIH TALEB & PARTNERS
دار الهندسة نزيه طالب وشركاه

6.2.1 Vegetated Areas

The damage in vegetated and agricultural areas composed of agricultural lands and trees does not depend on the inundation depth.

The overall vegetated and agricultural area that will be damaged directly from the Dam Break Flood is estimated to 550 ha.

An estimation of the agricultural revenues and cost of trees gives a value of 0.5 to 1.0 US$/$m^2$ of cultivated or vegetated land.

The evaluation of the damage caused by the flood in agricultural areas is estimated to 3 to 5 Millions of US$.

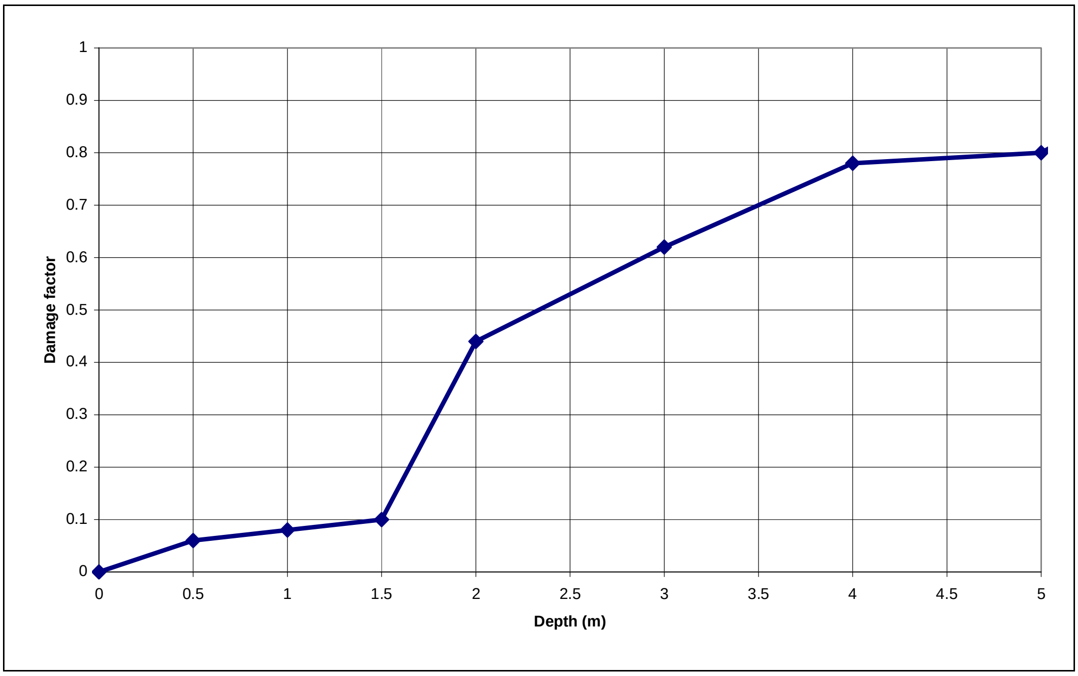
6.2.2 Residential Areas

Flood damage in residential areas is calculated per hectare. The applied flood damage function is based on damage data of the Commissie Watersnood Maas provided for assessing damage in the floodplain of the Meuse River. Damage to cars is not taken into account because there is usually enough time to move these cars onto the higher parts of the area.

A hazard map where the hazard levels correspond to different water depth was considered to obtain the hazard flood depth.

Linear interpolation is used to obtain the complete function of damage factor for the house and its content that is presented in Figure 6.6.

Figure 6-6 Proposed damage function for houses (property and content)



According to known market prices, the average price per m2 for built up area in the region in 2013 is estimated to 500 US$. For the purpose of the damage evaluation method herein proposed, these figures should be considered like a reconstruction cost, namely the costs for rebuilding to a standard responding to local conditions.

All the necessary data are available to propose an assessment for the different residential categories of land use which is considered representing 90% of built-up area (total built-up area is 20 ha).

In order to estimate damage cost for the residential built-up area, the generic formula below was applied:

Damage Cost = A * H * V

- A= area (m2)
- H= water depth damage factor
- V= average price for m^2 for an apartment.

The results are illustrated in Table 6.1.

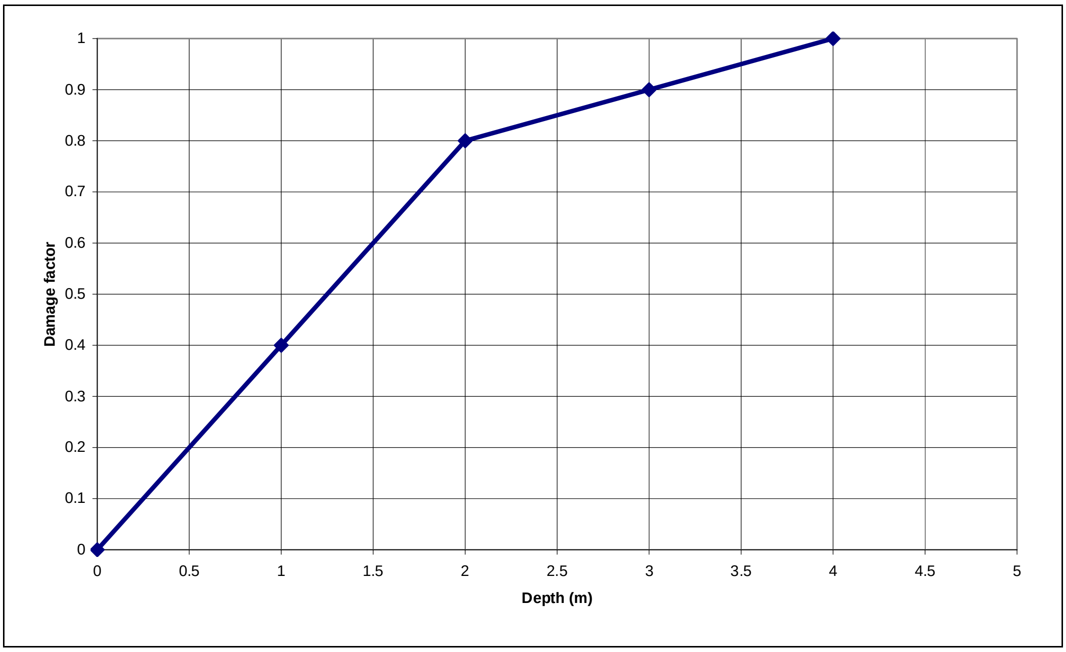
Table 6-1 Residential areas damage cost

Area (m^2)	Water Depth	Water Depth Damage Factor	Damage Cost (US$)
40,000	Below 5m	70%	≈ 15,000,000
140,000	Above 5m	100%	≈ 70,000,000

6.2.3 Industrial, Commercial and Service Areas

The most suitable method is to evaluate flood damage in industrial, commercial and service areas according to water depth. The maximum damage cost of industry is assessed per m2. The damage function adopted in our study is illustrated in Figure 6.7.

Figure 6-7 Proposed Damage Function for Commercial and Industrial Areas



All the necessary data are available to propose an assessment for the different commercial and industrial categories of land use which is considered representing 10% of built-up area. The results are illustrated in Table 6.2.

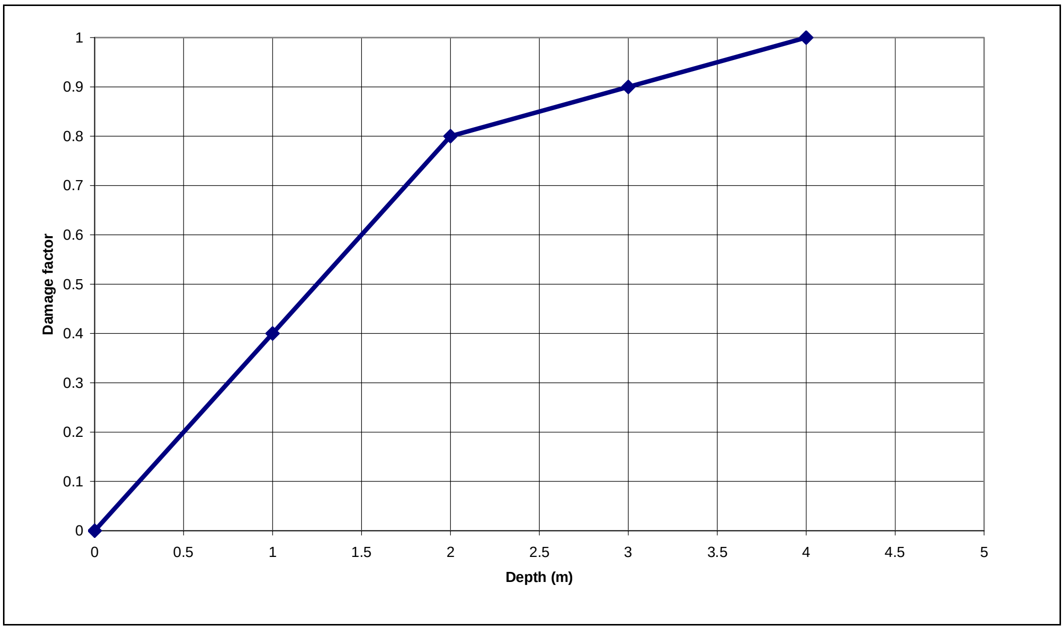
Table 6-2 Residential Areas Damage Cost

Area (m^2)	Water Depth	Water Depth Damage Factor	Damage Cost (US$)
4,000	Below 4m	65%	≈ 4,000,000
14,000	Above 4m	100%	≈ 21,000,000

6.2.4 Infrastructure

The damage is calculated per unit length rather than per unit area. The maximum damage values vary depending on the type of road. In the flooded area there are 90 km of mainly roads and rails. The used damage function is illustrated in Figure 6.8.

Figure 6-8 Proposed Damage Function for Infrastructure



Considering an average water depth varying between 0m and 30m for all roads and an average price of 200 US$ for the construction of one linear meter of road, the damage cost of infrastructure is estimated between 10 to 15 Million US$.

6.3 Conclusion

The results listed above, provide an average estimate and should not be considered as a detailed cost assessment of the damage, since they are strongly depending on the quality of the damage functions and the availability of detailed datasets.

The quality of the damage assessment also depends on the quality of the classification which was made considering satellite views, previous studies data and the field survey collected information.

The total damage cost estimation based on the above functions and assumption is approximated to 110 to 130 Millions US$.

7 EMERGENCY ACTION PLAN

7.1 Introduction

The Bisri Dam and Reservoir will be owned and operated by the Litani River Authority (LRA).

According to the Bisri Dam Breach Analysis, if a breach of the dam were to occur, a 100m opening could form in as little as 90 minutes. The subsequent flood wave would flow downstream through the floodplain with significant effects on the Bisri and Awali river. A breach of the dam has the potential to result in the loss of human life and loss of property.

7.1.1 Authority

The development and implementation of an Emergency Action Plan (EAP) is a positive step dam owners can take to accomplish dam-safety objectives, to protect their investment, and to reduce the potential liability associated with a dam failure.

As stipulated in ministerial decision No 93/30, issued on August 2nd, 1993, the High Relief Commission is presided by the Prime Minister and made up of members in the persons of the Ministers of Defense, Health, Social Affairs, Interior, Finance, Public Works, Energy and Housing. The High Relief Commission's members also include the Director Generals of Social Affairs, Council of the South, and the Fund for the Displaced, and representatives from the ISF and the Lebanese Army. The High Relief Commission is managed by its Secretary General, General Ibrahim Yehya.

The High Relief Commission has the authority to direct the LRA to take immediate and appropriate action to remedy situations posing serious threat to human life or health, or risk of property damage.

7.1.2 Purpose

The purpose of this Emergency Action Plan is to identify emergency situations that could threaten the Bisri Dam, and to plan for an expedited, effective response to prevent failure of the dam. This plan defines the notification procedures to be followed in the event of a potentially hazardous situation or the potential failure of the dam. The procedures are intended to protect lives and prevent property damage from an uncontrolled release of water from the reservoir.

7.2 Responsibilities

7.2.1 Emergency-Response Procedures

When conditions at the dam have caused the declaration of an emergency, actions are to begin immediately with the notification of the Emergency planning Manager (TBD). An Emergency Operations Center will be set up in the Dam Administration Building to monitor the progression of the situation and to coordinate remediation activities. Alternate phone numbers should be available. Provisions for light may be necessary due to darkness, and alternate access to the dam from both sides should be available.

Immediately upon determination of a "watch" or more serious condition, this Emergency Action Plan will be implemented. Surveillance of the problem will be maintained on a 24-hour basis. The prime minister (High Relief Commission), the South-Lebanon Governate, Saida municipality, Er Rmaile municipality, Karkha municipality, Joun municipality and the LRA will be notified according to the Notification Flowchart (Figure 7.6) by the Emergency planning Manager. The following are possible actions at the dam to prevent or delay failure after an emergency is first discovered:

Seepage Failure

1. Plug the flow with whatever material is available (clay, bentonite, or plastic) if the entrance is in the reservoir.
2. Lower the water level in the reservoir by using the low-flow outlet and pumping if necessary, until the flow decreases to a non-erosive velocity or until it stops. Place an inverted filter (a protective layer of sand and gravel) on the exit area to hold the material in place.
3. Continue operating at a lower level until a repair is made.

Embankment or Foundation Sliding

1. Lower the water level in the reservoir by pumping if necessary at a rate and to an elevation considered safe, given the slide condition.
2. Stabilize the slide, if on the downstream slope, by weighting the toe area below the slide with soil, rock, or gravel.
3. Continue operating at a lower level until a repair is made.

Structural Failure

1. Implement temporary measures to protect the damaged structure, such as placing rock riprap in the damaged area.
2. Lower the water level to a safe elevation through the low-flow release valve and by pumping if necessary.

Preventive measures can be taken in an emergency to prevent the catastrophic failure of the dam, but such repairs should be undertaken with extreme caution. The repairs are only temporary, and a permanent repair should be designed by an engineer as soon as possible.

7.2.2 Responsibilities for Notification

The Emergency planning Manager shall make all initial notifications. Technical advice shall be sought when time allows. However, for rapidly developing situations, immediate notification of the prime minister (High Relief Commission), the South-Lebanon Governate, Saida municipality, Er Rmaile municipality, Karkha municipality, Joun municipality and the LRA may be necessary for quick action. The South-Lebanon Governate officials will in turn notify the internal security forces, army personnel and the Fire Department for appropriate action. The LRA's public-affairs representative will issue news releases.

7.2.3 Responsibilities for Evacuation

The internal security forces, army personnel and the Fire Department shall be responsible for evacuating residents in the event of a dam emergency. After notification by the Emergency planning Manager through the prime minister (High Relief Commission), the South-Lebanon Governate, Saida municipality, Er Rmaile municipality, Karkha municipality, Joun municipality and the LRA officials, the internal security forces, army personnel and the Fire Department will be responsible for the warning and evacuation of people in the threatened areas.

7.2.4 Responsibilities for Duration, Security, Termination, and Follow-up

The Emergency planning Manager or his or her designated representative will be responsible for on-site monitoring of the situation and for keeping local authorities informed of developing conditions at the dam from the time that an emergency starts until it ends. The internal security and army shall maintain security at the dam. The Emergency planning Manager shall be responsible for declaring the situation terminated and for a follow-up evaluation of the emergency.

7.2.5 Plan Coordinator

The Emergency planning Manager who takes care of the day-to-day operations of the dam is responsible and has the authority to implement and carry out all procedures and surveillance found in this Plan. He shall be responsible for initiating the notification procedures when signs of distress or failure are noted. All participating parties should be familiar with this plan and their responsibilities during an emergency. Precautionary measures shall be taken to prevent the uncontrolled release of water from the reservoir. In the event that a failure is imminent, proper notification of persons in the downstream area shall be made. Any resources available to the Emergency planning Manager shall be used to minimize uncontrolled releases. The Emergency planning Manager alternates listed on the Notification Flowchart shall implement and carry out these procedures in his absence.

7.2.6 Emergency Operations Center

In the event of a “watch” or more serious condition, the Emergency planning Manager shall activate the Emergency Operations Center for the overall direction and response activities. The Emergency Operations Center shall be established at the Dam Administration Building. The Emergency planning Manager will be responsible for initiating actions from this location.

7.2.7 Communications

Local officials and downstream residents will be notified by landline telephone or internet if available; otherwise via cell phones or emergency personnel (in person or using their radios). The various radio networks for emergency use include the informal ham-radio network, and networks belonging to:

- The South-Lebanon Governate office
- Saida Municipality office
- Er Rmaile municipality office
- Karkha municipality office
- Joun municipality office
- The Lebanese Army
- The Internal Security
- The Fire Department

Verification or authentication of the situation can be made by contacting the prime minister (High Relief Commission), the South-Lebanon Governate, Saida municipality, Er Rmaile municipality, Karkha municipality, Joun municipality and the LRA officials. Television and radio can be used as much as possible to notify area residents of the possible dangers. News releases are to be issued by the LRA's public-affairs officer. The following summarizes the notification procedures for different levels of alert:

"Abnormal" Condition

1. The Emergency planning Manager will be notified.
2. The Emergency planning Manager will notify officials at LRA's headquarters.
3. LRA will contact its Technical Team to inspect the situation.

"Watch" Condition

1. The Emergency planning Manager will notify officials at LRA's headquarters.
2. LRA will contact its Technical Team to inspect the situation.
3. A "watch" message will be issued by local emergency management officials to downstream contacts, if so directed by LRA's officials.

Possible Dam Failure

1. The Emergency planning Manager will notify the prime minister (High Relief Commission), the South-Lebanon Governate, Saida municipality, Er Rmaile municipality, Karkha municipality, Joun municipality and the LRA officials.
2. LRA will contact its Technical Engineering Team.
3. Local emergency-management officials will send a "possible dam failure" warning message to downstream residents, if so directed by LRA's officials.

Imminent Dam Failure

1. The Emergency planning Manager will notify the prime minister (High Relief Commission), the South-Lebanon Governate, Saida municipality, Er Rmaile municipality, Karkha municipality, Joun municipality and the LRA officials.
2. LRA will contact its Technical Engineering Team.
3. Local emergency-management officials will issue a "failure" message to downstream residents and evacuation programs shall begin.

The Emergency planning Manager shall ensure notification of personnel in the event of an emergency at the dam, and may delegate contacting some personnel to other LRA's personnel. The delegation of contacts should be very specific as to which ones are to be made. The Notification Flowchart should contain contact information for LRA staff, as well as the other officials which may be involved in the event of a situation at the dam.

7.3 Possible Emergency Conditions

7.3.1 Situations

Many dam conditions can lead to emergency situations, not all of which will necessitate the implementation of the Emergency Action Plan; however, if any of them occur, the appropriate action must be taken.

- Severe storms: Although generally not in themselves a threat to the dam, severe storms can contribute to an existing problem and hinder any remediation efforts. Severe storms also cause the uncontrolled release of floodwater, and increase flow in already rain-swollen areas.
- Earthquakes: The Bisri Dam is located in a seismic zone with high activity. An earthquake is a possibility, and appropriate post-earthquake inspections should be performed.

- Sabotage: Threats to damage the dam are very probable in the dam region. Appropriate actions must be taken to protect the dam.

7.3.2 Signs of Failure

The following sections describe some of the different types of failure which could lead to a dam breach. The impacts of a dam breach have been evaluated and the results are included in this report.

- Seepage Failure: Although all earthen embankments allow some minor seepage through the dam or the foundation, excessive, uncontrolled seepage can result in piping (or the movement of embankment material in the seepage flow) and lead to failure. Piping can occur for years at a slow rate. If the piping has progressed to a dangerous level, it will be evident by increased flow or the discharge of muddy water (or both). At that stage, immediate action to stop the piping is needed. Fully developed piping is difficult to control and is very likely to result in failure. A whirlpool in the reservoir is a sign of uncontrollable piping and necessitates immediate emergency action.
- Embankment or Foundation Sliding: Sliding is usually first apparent when cracks or bulges in the embankment appear. Slides with progressive movement can cause failure of the embankment.
- Structural Failure: The structural failure or collapse of any portion of the service spillway or spillway gates could result in loss of the reservoir. A structural failure of a portion of the spillway could cause piping and possibly embankment failure.
- Overtopping Failure: Overtopping of the embankment results in erosion of the dam crest. Once erosion begins, it is very difficult to stop.

7.3.3 Emergency Identification

A. Signs of Failure

In an emergency, the *Emergency planning Manager* is responsible for the dam's operation, maintenance and inspection. The early identification of potentially dangerous conditions can allow time for the implementation of emergency action plans. It is important to understand how distress can develop into failure. With appropriate action, distress need not lead to a catastrophic failure of the dam. Early identification, close monitoring, planned action and remedial measures will help alleviate a potentially dangerous situation. The following sections describe some of the different levels of distress which could lead to a dam breach.

B. "Abnormal" Conditions

The conditions listed below are not normal occurrences. When these conditions are present, they should be noted, and action should be taken to prevent the possible failure of the dam.

- piping or boils in the area of any structure such as the embankment, spillway, or in the vicinity of the toe of the embankment, as evidenced by muddy water
- slides or sloughs in the embankment, discharge channel or abutments
- a significant increase in seepage quantities through or under the embankment, abutments or emergency spillway

- unusual vertical or horizontal movement or cracking of the embankment or abutments
- small sinkholes or subsidence within 150m of the embankment or spillway
- excessive displacement of the rip-rap on the embankment slope
- an earthquake
- a severe storm
- threat of sabotage

In the event that any of these items are observed, the LRA Technical Team should be contacted to inspect the dam to document the distress and determine whether remedial action is necessary. Notification of local authorities is not necessary for "abnormal" conditions.

C. "Watch" Conditions

A "watch" indicates that a significant problem that may potentially progress to a dangerous situation has been detected, but that a breach is considered unlikely and no flooding is imminent. This situation will require monitoring and repair or correction as soon as possible. Upon detection, the notification procedures must be implemented. The *Emergency planning Manager* shall institute all practicable measures to mobilize personnel to control the situation. The following is a list of conditions which constitute "watch" conditions:

- small boils if conditions are muddy, on the downstream slope of the embankment or downstream from the toe, or if there is flowing muddy water downstream from the embankment
- large sinkholes with corresponding seepage anywhere on the embankment or downstream from the toe
- any slide that degrades the crest of the embankment or that is progressively increasing in size
- significantly increasing seepage or flow
- cracking or movement of any concrete structure

D. Possible Dam Failure

A "possible dam failure" warning is issued when a "watch" condition is becoming progressively worse, and a dam failure is considered possible. The *Emergency planning Manager* will immediately notify the prime minister (High Relief Commission), the South-Lebanon Governate, Saida municipality, Er Rmaile municipality, Karkha municipality, Joun municipality and the LRA officials and others in accordance with the Notification Flowchart. He or she will continue all practicable measures to correct the problem, including lowering the reservoir level if appropriate. The existence of any of the following conditions constitutes possible dam failure:

- large boils, increasing in size and flow rate, especially if there is flowing muddy water
- significantly increasing seepage, especially flowing muddy water
- slides involving a large mass of material that impairs the crest of the dam and is continuing to move

- sinkholes with seepage flowing muddy water
- large cracks, movement or failure of a portion of any major concrete structure that forms an integral part of the dam
- an increase in the reservoir level to near the top of the dam

E. Imminent Dam Failure

"Imminent failure" is the determination that a "warning" condition will most likely progress to a failure of the dam and the reservoir will be uncontrollably released, regardless of the actions taken. When this determination is made, immediate notification and warning of downstream areas becomes the primary concern. The existence of any of the following conditions constitutes imminent failure:

- rapidly increasing boils or the presence of new, significantly flowing boils, particularly muddy ones near previously identified ones
- rapidly increasing seepage, especially flowing muddy water
- slides involving a large mass of material or which have degraded the crest of the embankment to a level that approaches the water surface level, or if significant seepage is observed through the slide area
- settlement that is predicted to degrade to the reservoir level
- cracks that extend to the reservoir level
- significant movement or failure of any major concrete structure that forms an integral part of the dam
- overtopping of the dam

7.4 Preventive Actions

This section lists the conditions and actions which may be used to classify the level of emergency response, as a guide for LRA's personnel.

7.4.1 Abnormal Condition

Periodic inspections of the dam will evaluate its structural safety, stability, and operational adequacy. If *LRA's* personnel who visit the dam site notice visual evidence of distress, the structure should be inspected by a consultant engineer specializing in dam design and construction. In the event of an abnormal occurrence, such as earthquake, or unusually heavy rainfall, special inspections by an engineer of the embankment and spillway are warranted. An abnormal condition can generally be repaired or corrected in the next few months with no immediate action necessary.

7.4.2 "Watch" Condition

If a problem has been detected at the dam which requires constant monitoring or immediate action to repair and the condition is manageable by LRA's staff, a "Watch" condition exists. A "watch" will continue until the problem is corrected or a "possible dam failure" warning is issued. The Emergency planning Manager should notify the officials at LRA's headquarters.

7.4.3 Possible Dam Failure

A "watch" condition that is progressively getting worse is considered a possible dam failure. Efforts to correct the situation will continue, and—although there is no imminent danger—if conditions continue to deteriorate, a dam failure could occur. A "possible dam failure" condition generally has already involved extensive efforts by *LRA's* personnel and potentially other contractors. A "possible dam failure" condition will continue until the problem is corrected, or until an "imminent dam failure" warning is issued. Notifications have been issued and the internal security and army personnel are ready to begin evacuation of threatened areas.

7.4.4 Imminent Dam Failure

If the Emergency planning Manager has determined that the condition at the dam will continue to progress to failure and result in the uncontrolled release of water, an "imminent dam failure" condition exists. Dam failure will most likely occur regardless of what actions are taken. Numerous forces are involved in trying to correct the situation. Evacuation has begun and will continue until the situation is stabilized.

7.4.5 Dam Failure

A dam failure has occurred and a flood wave is moving downstream. Flooding will occur immediately and will continue to move downstream until water levels in the reservoir are stabilized. Considerable destruction can be expected, and evacuation of low-lying areas should continue.

7.4.6 Other Considerations

Alternate Access

Alternate access routes should be planned in the event of an emergency at the dam. The access road which runs along the crest of the dam should be reachable from Mazraat Ed Dahr on the north and from Deir Machmoucheh on the south.

Darkness

In a nighttime emergency, the Emergency planning Manager should arrange for access to generators and lights to adequately monitor the situation.

7.5 Supplies and Resources

7.5.1 Contracts

Should LRA's personnel and resources prove to be inadequate during an emergency, requests will be made for assistance from other local jurisdictions, other agencies, and industry, as needed. Such assistance may include equipment, supplies, or personnel. All agreements will be entered into by authorized officials and should be in writing whenever possible. The Emergency planning Manager shall have the authority to enter into agreements as deemed necessary to prevent the failure of the dam.

7.5.2 Equipment and Supplies

The following equipment and supplies may be necessary for use during emergencies: backhoes, dump trucks, portable welding equipment, generators, dozers, excavators, loaders, motor graders, crane, sandbags, rock riprap...

Contractors in the area may be needed. A list of possible Contractors should be available.

7.5.3 Reports

Technical Data

Periodic inspections of the dam will be made to evaluate its structural safety, stability, and operational adequacy. In the event of an abnormal occurrence, reference to these reports, particularly the photographs, can be beneficial in the evaluation of a potential problem.

Technical records such as drawings and inspection reports should be stored and carefully maintained at the LRA's Site offices (Dam Administration Building). Alternate personnel shall be familiar with the location of the documents in the event of an emergency situation.

Emergency Operations Center Activity Log

Any unusual or emergency condition should be documented, including the following:

- activation or deactivation of emergency facilities
- emergency notifications
- significant changes in the emergency
- major commitments of resources or requests for additional resources from external sources
- telephone calls should be recorded in chronological order
- issuance of protective action recommendations to the public
- evacuations
- casualties
- termination of the incident

Costs of the Emergency Operations Center

For major emergencies, the emergency operations center shall maintain detailed records of costs expended. These records may be used to recover costs from the responsible party or insurers, or as a basis for requesting financial assistance for certain allowable response and recovery costs from the government. Documented costs should include:

- personnel costs, especially overtime
- equipment operation
- equipment leasing and rental
- contract services to support emergency operations
- specialized supplies expended in emergency operations

7.6 Inundation Area

The impacts of a dam breach have been evaluated and the results are included in the Dam Breach Analysis. The inundation mapping resulting from the breach analysis is included in the figures 7.1 to 7.5. It illustrates the areas subject to flooding under a failure of the dam. Also included on these maps are the initial times to flood.

After examining the results of the breach analysis of the Bisri Dam, it has been determined that there were a significant number of structures that could be affected due to a sunny-day dam breach. The most important structures affected are the Anane lake and hydroelectric power plant and the Saida Municipality Stadium. Parts of the cities of Saida and Rmeileh can suffer a dramatic impact from a breach of the dam.

The Dam-Breach Analysis contains profiles of the peak flood levels expected, as well as an estimation of the time from the beginning of the breach to the peak flood elevations. A comparison of the areas that are likely to be flooded with the plots showing the times from the start of the breach to the flooding shows the areas of evacuation and the time constraints involved. Figures 7.1 to 7.5 of the Bisri Dam Breach Analysis include information on the estimated impact of flooding on the bridges along the Bisri River. These structures may suffer such impacts before the peak elevation of the flood wave.

7.6.1 Local Evacuation Plan

If imminent failure of the dam with uncontrolled downstream flooding is anticipated, local emergency-management , internal security forces, army personnel and the Fire Department should notify those downstream of evacuation in the most expedient manner possible. The organizations and personnel on the Notification Flowchart should be contacted immediately. The internal security and army officials, along with radio and television stations, can best spread the notice for evacuation. The immediate impact will be to rural areas along the Bisri River downstream of the dam. For sunny-day breaches, the following actions should be taken:

- Barricading all bridges that could possibly be flooded to prevent access to the affected area. These bridges include the bridge crossing of the littoral main highway. See the figures 7.1 to 7.5 to determine appropriate barricade locations and evacuation roads and directions of evacuation.
- Barricading all roads leading to the affected area and forbid any vehicle to enter this area.
- Municipalities officials are generally familiar with developed areas in their jurisdiction. Such knowledge make them the logical officials to be notified and to spread the warning message to all areas subject to flooding.

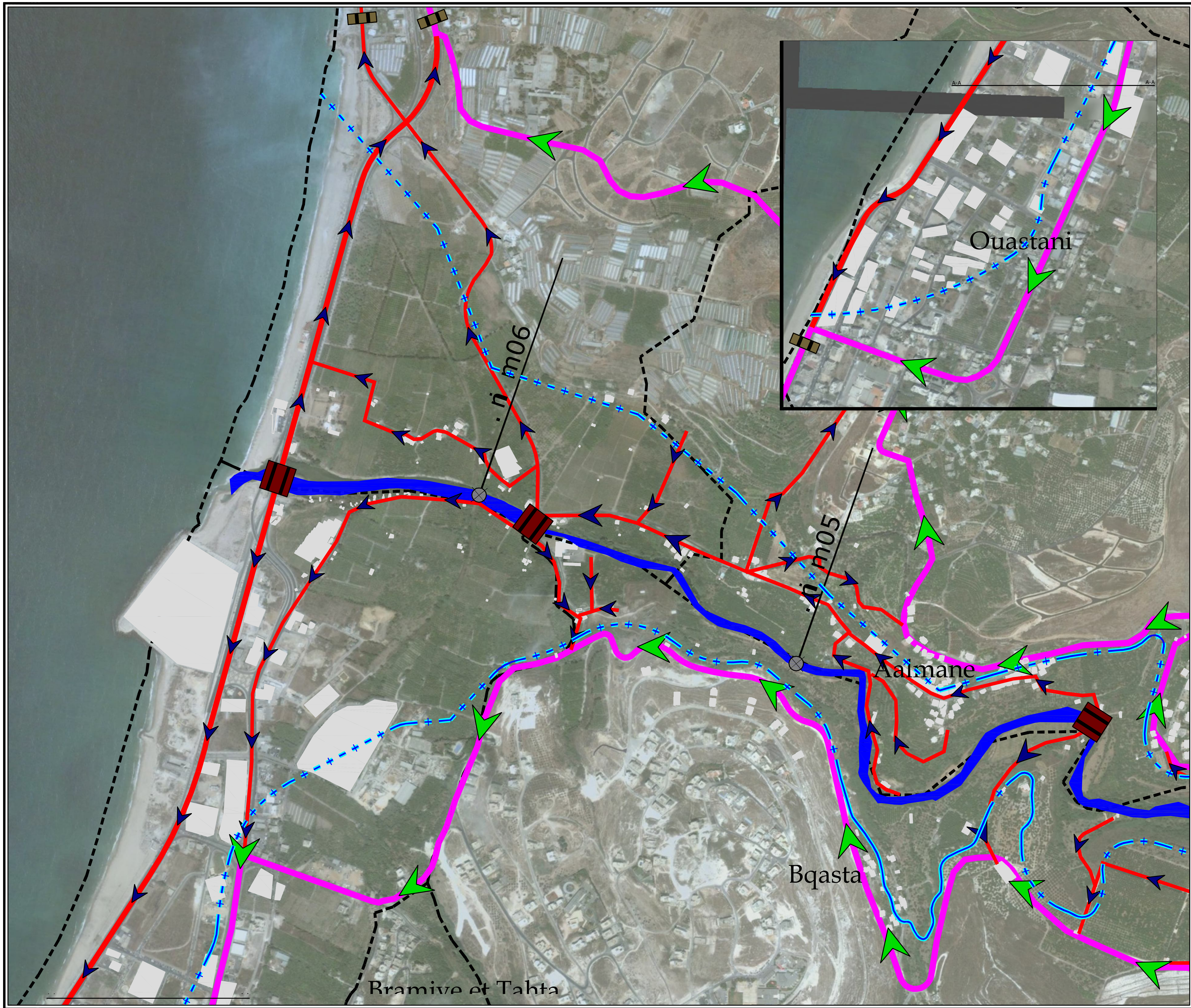
7.7 Implementation

7.7.1 Development

The present chapter constitute the draft Emergency Action Plan.

7.7.2 Testing

The draft Emergency Action Plan will be reviewed at the end of the construction of the dam in order to constitute the final emergency action plan and then annually for contacts and numbers and will be tested every five years using a tabletop exercise conducted under the direction of the Emergency planning Manager. The purpose of this exercise is to review the plan with key personnel. Any revisions to the plan will be implemented after the exercise. The timing and frequency of testing can be adjusted as needed by the Emergency planning Manager. The table top exercise should include emergency scenarios; notification of participants, including verification of all phone numbers and personnel; and notification of local officials. Area residents should not be included.



Legend

- Maximum Flood Limit
- Flooded Evacuation Road
- Safe Evacuation Road
- Bisri River
- Bisri River
- Barricade 1 Way
- Barricade 2 Way
- 60 Min

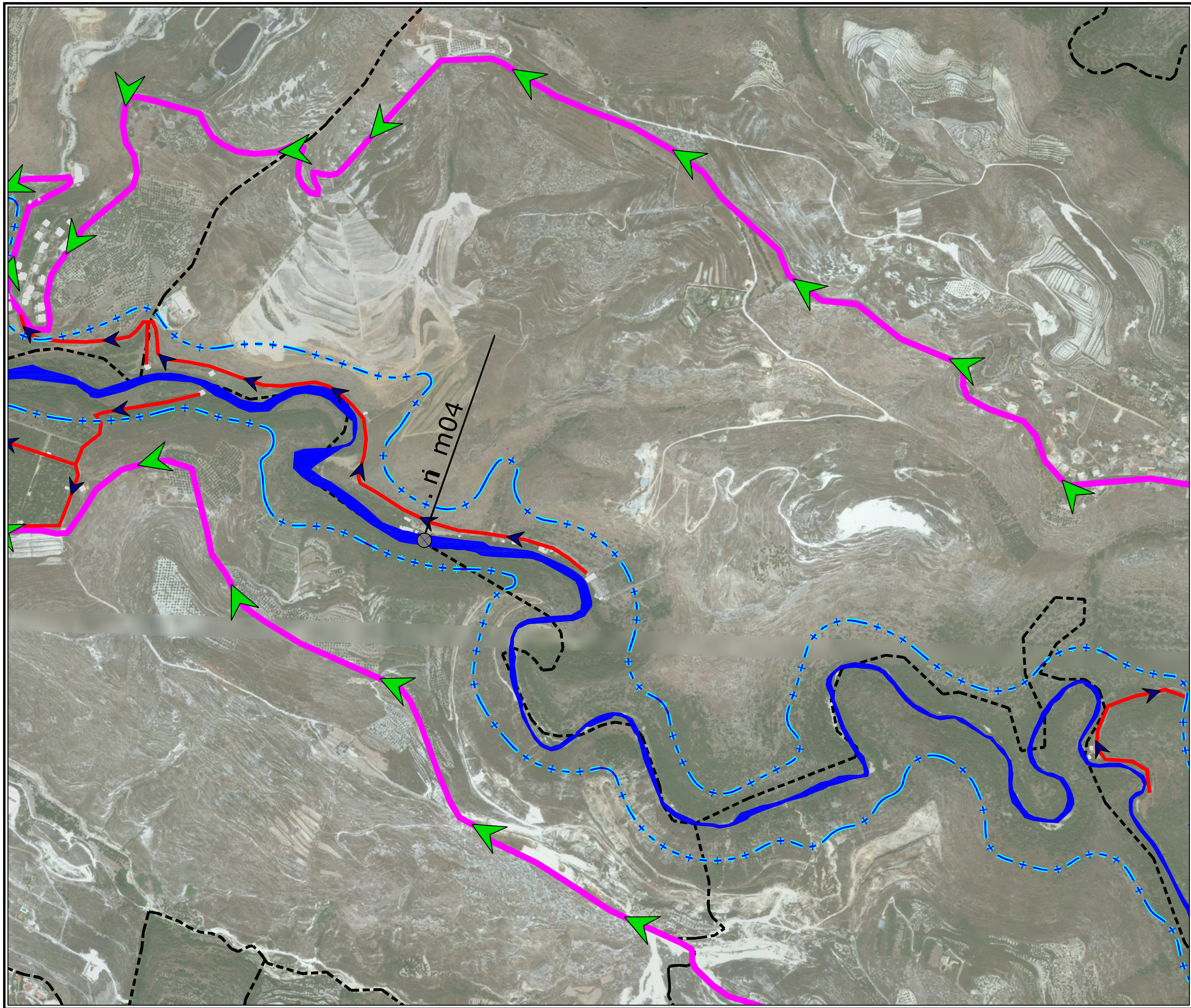
Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

0m 100m 250m

Fig. 7.1

INUNDATION AREA AND LOCAL EVACUATION PLAN

DAR AL HANDASAH NAZIH TALEB & PARTNERS



Legend

- Maximum Flood Limit
- Flooded Evacuation Road
- Safe Evacuation Road
- Bisri River
- Bisri River
- Barricade 1 Way
- Barricade 2 Way
- 60 Min

Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

0m 100m 250m

Scale $\frac{1}{10000}$ @ A3 Size

N

Fig. 7.2

INUNDATION AREA AND
LOCAL EVACUATION PLAN

DAR AL HANDASAH NAZIH TALEB & PARTNERS
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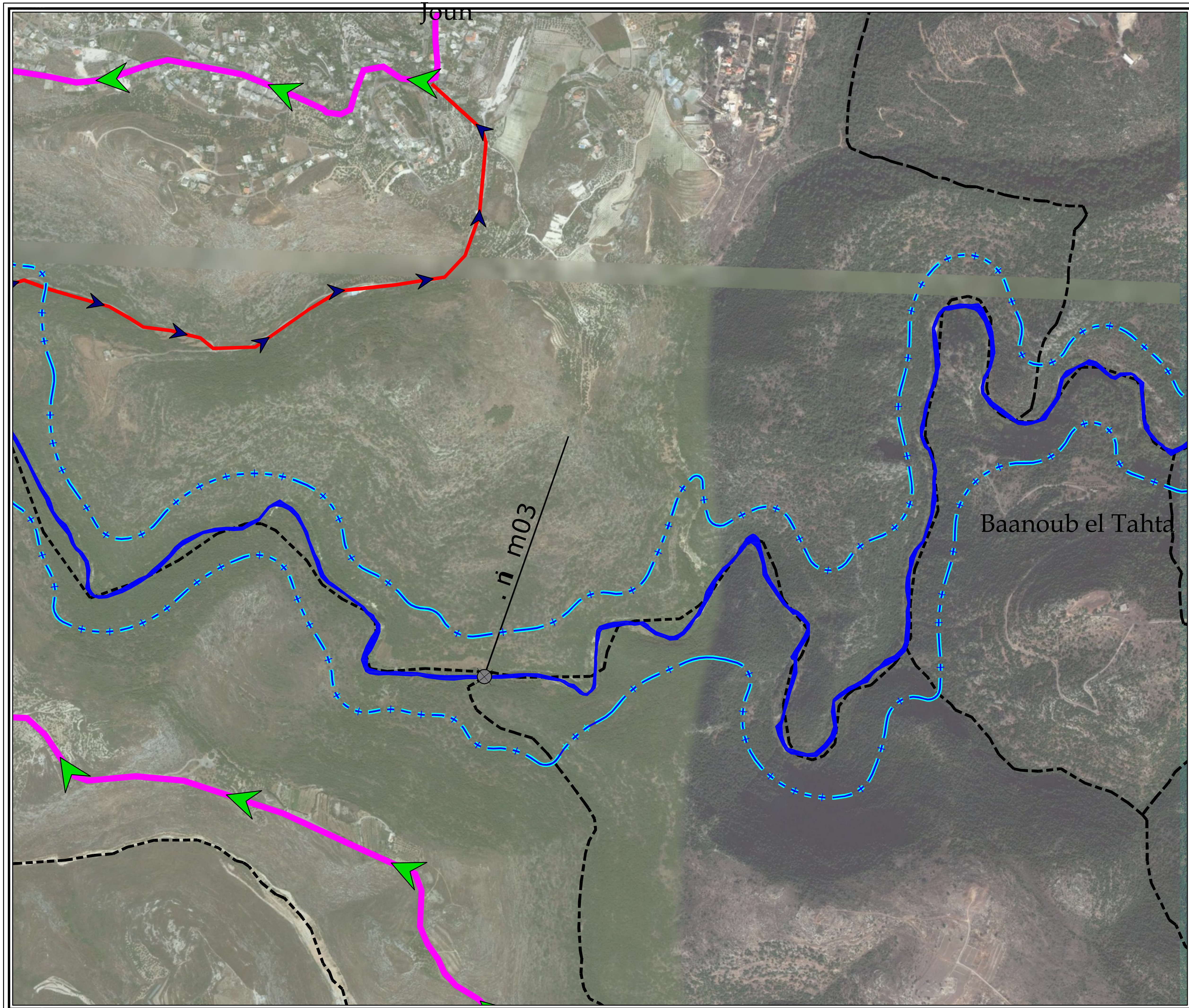
Founded 1956



Legend

- Maximum Flood Limit
- Flooded Evacuation Road
- Safe Evacuation Road
- Bisri River
- Bisri River
- Barricade 1 Way
- Barricade 2 Way
- 60 Min

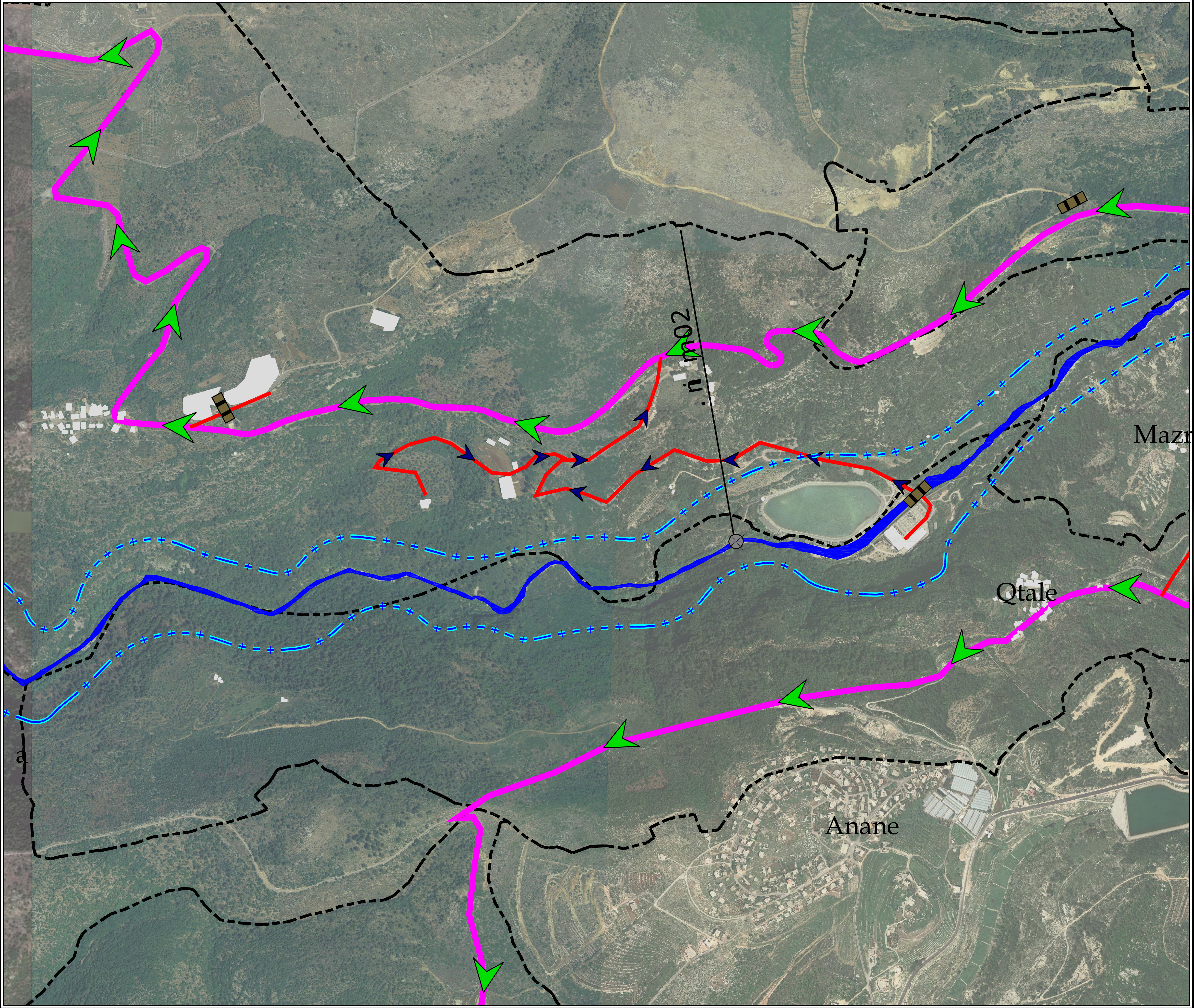
Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

0m 100m 250m

Fig. 7.3

INUNDATION AREA AND LOCAL EVACUATION PLAN

DAR AL HANDASAH NAZIH TALEB & PARTNERS



Legend

- Maximum Flood Limit
- Flooded Evacuation Road
- Safe Evacuation Road
- Bisri River
- Bisri River
- Barricade 1 Way
- Barricade 2 Way
- 60 Min

Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

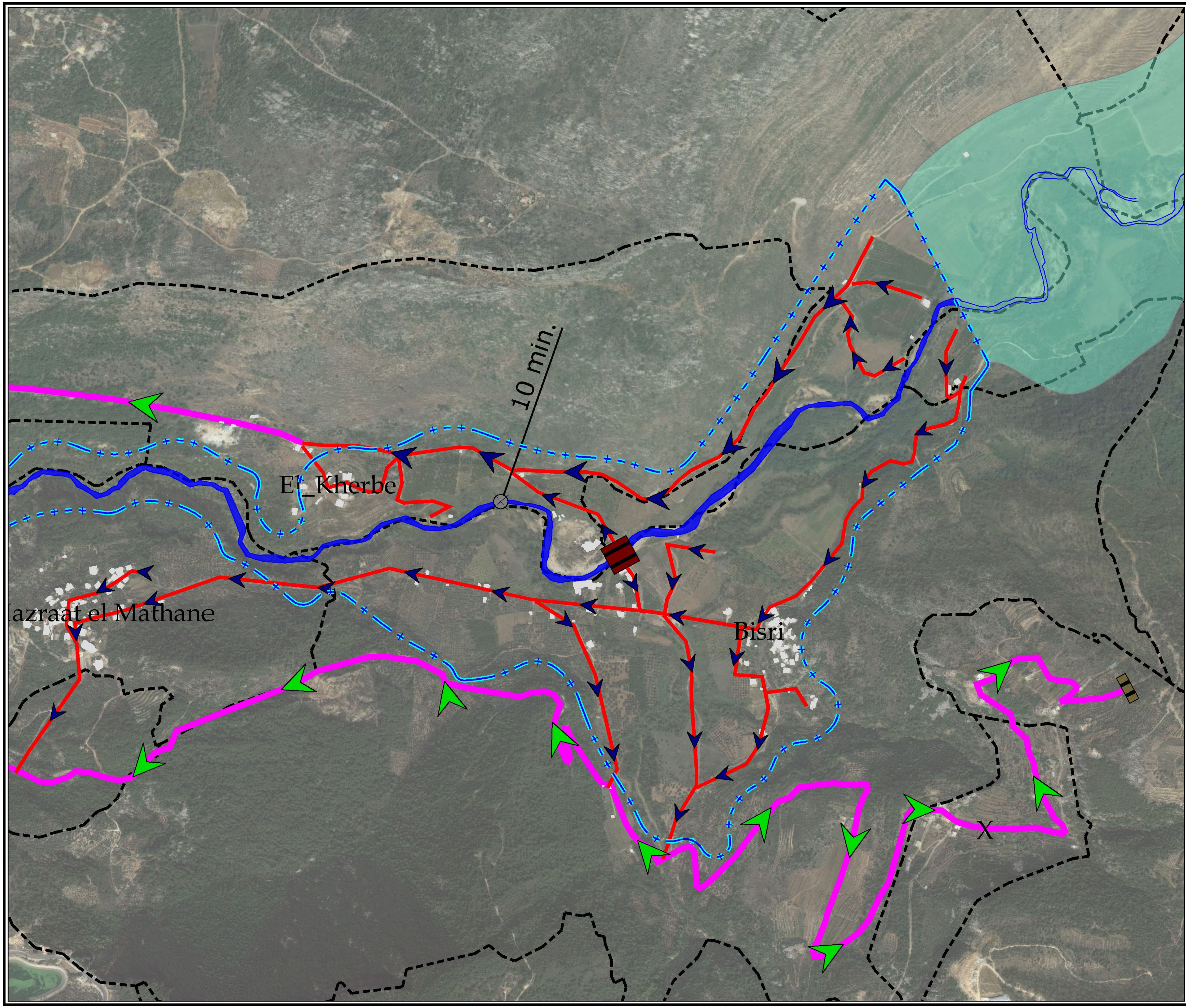
0m 100m 250m

Scale @ A3 Size

Fig. 7.4

INUNDATION AREA AND
LOCAL EVACUATION PLAN

DAR AL-HANDASAH NAZIH TALEB & PARTNERS



Legend

- Maximum Flood Limit
- Flooded Evacuation Road
- Safe Evacuation Road
- Bisri River
- Bisri River
- Barricade 1 Way
- Barricade 2 Way
- 60 Min

Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

0m 100m 250m

Scale $\frac{1}{10000}$ @ A3 Size

N

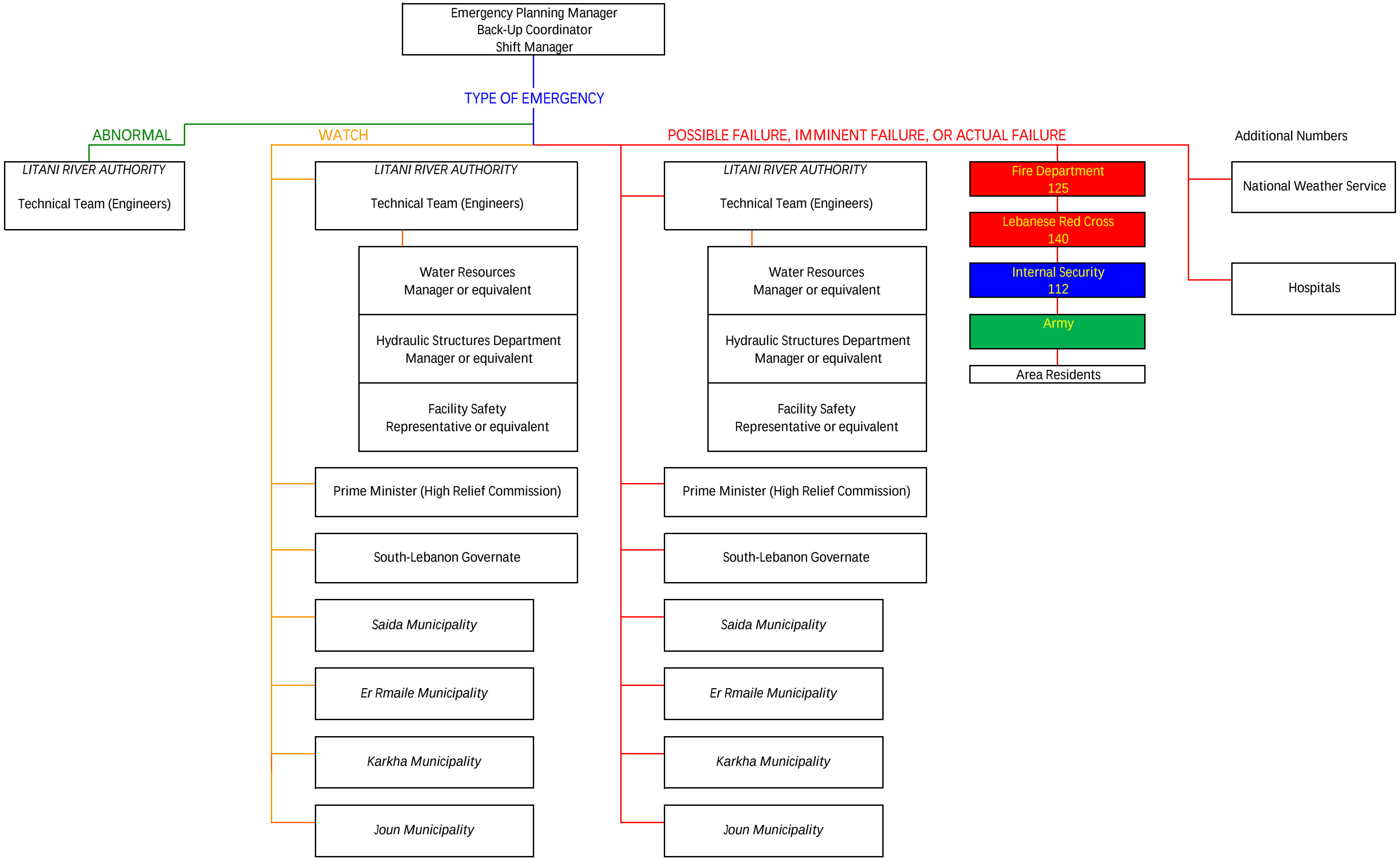
Fig. 7.5

INUNDATION AREA AND LOCAL EVACUATION PLAN

DAR AL HANDASAH NAZIH TALEB & PARTNERS

دار الهندسة نزيه طالب وشركاه

Figure 7-6 Notification Flowchart



8 LOSS OF HUMAN LIFE ESTIMATE

This chapter provides estimations of loss of human life in consequence to a breach of Bisri dam according to the new guidance of the USBR's empirically-based method for estimating consequences from dam failure in terms of loss of human life. The approach is similar to the approach that Reclamation has used since 1999 as the primary tool for estimating loss of life (DSO-99-06). DSO-99-06 provided suggested fatality rates to be applied to downstream populations subjected to dam breach flows, considering the warning time, flood severity, and flood severity understanding. This new graphical approach involves consideration of these same elements as well as other factors when selecting a fatality rate for a given exposed population, and features a graphical presentation of fatality rates versus warning time and flood severity. DSO-99-06 was based on the analysis of dam failures, flash floods and other floods located primarily in the United States. Additional case histories were investigated for the 2014 methodology.

USBR's approach to estimating life loss is primarily rooted in empirical interpretation of dam failure and flood case histories. The fatality rates are applied to the full population at risk (PAR). These rates reflect the impact of evacuations that occurred in the case histories, but do not explicitly quantify evacuation of downstream populations. The likely success of evacuations is something that should be considered when selecting ranges for fatality rates using the 2014 methodology.

8.1 Basis for Graphical Approach

8.1.1 Establishing a Relationship between Flood Severity and Fatality Rate

The graphical approach to estimating the fatality rate utilized is empirical and provides recommended ranges based on case history data and involves consideration of the case history database for making judgments about fatality rates.

Analysis of the case histories indicates all of these factors influence the fatality rate for a flood. However, the data available from the case history information varies and for a given historical event, it can be difficult to ascertain the category for each factor. In many cases the necessary data are limited, questionable, not consistent between sources, or non-existent. The paragraphs that follow provide a basis for establishing a relationship between flood severity and fatality rate as the foundation for the graphical approach. This relationship was established by studying the case history database and extracting what was judged to be the best available information.

Flood severity, measured in terms of DV, has a significant influence on fatality rate. Case history data indicate that the highest observed fatality rates are associated with the highest estimated DV values. When the flood severity is lower, there is a general trend of lower (or no) fatalities; however, there is greater scatter in the fatality rates for lower flood severity values. For this updated methodology, the numerical measure of flood severity, DV, was estimated for each case history event using available documentation and engineering judgment. The confidence level in the estimated DV varied depending on the amount and quality of the available information.

It is recognized that evacuation has a significant influence on the number of fatalities from a flood. Obviously, for cases where the maximum number of people were evacuated, the fatality rate with respect to the original PAR was lower - independent of the DV value. However, the case history data do not provide a meaningful way to extract PAR evacuation information such that a relationship involving evacuation as a primary parameter can be established. Therefore, for the graphical approach, evacuation is considered implicitly through the parameter of warning time - i.e., greater warning time results in lower fatality rates because a greater portion of the PAR is able to evacuate the flood area.

The amount of warning received by a PAR is typically part of the case history documentation. For the same event, there may be several different population groups, and each may have received a different amount of warning time. A review of the case history data indicates that in most cases, the PAR received either little to no warning, or hours of warning. The way that "some" warning was defined in DSO-99-06 is as a relatively narrow window of time (between 15 and 60 minutes), and thus most cases have warning times that tend to fall outside of these limits. For many of the older case histories (i.e. prior to about the mid-1900s) communication networks and emergency management systems were not in place to enable warning. In addition, there may have been a general reluctance to issue a warning too soon, with operating personnel instead waiting until failure was more certain or there may have been a lack of understanding that dam overtopping could lead to dam failure. Finally, many dams that failed featured relatively small reservoirs and resulted in flooding that attenuated within minutes or a few hours of failure. For these reasons, with older case histories, receiving hours of warning was rare.

The flood severity understanding factor used in DSO-99-06 is the most subjective variable and the influence of this factor on fatality rates from the case history database is generally intuitive; i.e., the greater the understanding of the flood severity, the lower the fatality rate. There is no quantitative way of measuring flood severity understanding, and there is no way of measuring the understanding of each person in the PAR. For example, for a given event where the flood severity understanding may have been "precise" for the majority of the PAR, those that died may have had a "vague" understanding. In the 2014 methodology, flood severity understanding is considered a factor that can influence fatality rate but there is not a direct quantitative relationship.

Given the above considerations, the basis or foundation for the graphical approach involves establishing continuous relationships between flood severity and fatality rate for different warning time scenarios. Because of the relative lack of case histories with "some" warning time, only two warning time scenarios, little to no warning and adequate warning, are used in this 2014 methodology. The influence of flood severity understanding is considered in a more subjective way and can be used to provide support for a higher or lower fatality rate in a given flooded area, depending on the anticipated flood severity understanding.

When the DSO-99-06 recommended fatality rates are compared with DV values, it is apparent that there are abrupt changes in those fatality rates at the boundaries between flood severity categories. However, the empirical case history data support a smoother transition of fatality rate between flood severity categories. Therefore, one objective of the graphical approach is to allow for a smoother transition of fatality rates over the entire range of possible DV values.

8.2 Graphical Approach - Suggested and Overall Limits

Two charts were developed for selecting fatality rates using the graphical approach, as listed below:

- Fatality Rate vs. DV for Little or No Warning - Figure 8.11
- Fatality Rate vs. DV for Adequate Warning - Figure 8.12

Both of these charts include 11 points that reflect case histories with "partial" warning, as opposed to "little or no" or "adequate" warning. These are cases where the amount of warning was not clear, where warning may have been different for various portions of the PAR, or where the warning was marginal with respect to providing the PAR with enough time to successfully evacuate. Since these cases fall in between little or no warning and adequate warning, they are included on both charts (and are clearly portrayed as solid blue squares).

Each chart includes dashed lines that represent "suggested" and "overall" limits for fatality rates over the full range of DV values. The suggested limits were selected visually based on the most representative case history data points for each warning time scenario, with no mathematical or statistical formulation of the curves. Cases with questionable data were given less influence on the suggested range. The overall limits, also established visually, are intended to represent the upper and lower bounds of fatality rates, between which nearly all case history data falls. The limits shown are not intended to be used by estimators directly, but rather they are intended to help the estimator interpret the data trends from the case histories. For example, the range of overall limits for little to no warning and a DV of 50 ft2/s covers over four orders of magnitude; however it is unlikely that the range of uncertainty in the fatality rate for a given project would span that full range. The next section describes how the overall and suggested limits were developed based on key case history data.

8.3 Application of the Procedure

Estimation of life loss resulting from a dam failure requires consideration of many factors - some of the major factors are listed below.

- The potential failure mode for the dam
- The assumed breach parameters
- The extent and severity of downstream flooding
- The time of day (or season) of the flooding
- Flood wave travel time
- Assumptions of warning (timing; effectiveness) and evacuation (easy vs. difficult; routes)
- The downstream population at risk
- The fatality rates

The full consideration of all these factors is a complex problem that requires (1) detailed modeling of the physical processes (breach characteristics and flood routing), (2) estimation of human responses, and (3) the estimation of the performance of technological systems such as warning and evacuation systems, transportation systems and buildings under flood loading. Using empirical data from case histories of dam failures and other similar events, this procedure provides a practical approach to this complex problem of estimating life loss for use in dam safety risk analysis.

The procedure for estimating life loss involves completion of 10 tasks as summarized in Table 1 below. A detailed discussion of each task is included in the subsections that follow. Note that with each task, the selected values should be justified (a case built for the estimates or assumptions).

Table 8-1 Summary of Tasks for Estimating Life Loss

Task	Description
1	Select dam failure scenarios (e.g. sunny day, flood, etc.) that correspond to dam potential failure modes
2	Select appropriate time categories (e.g. day/night, seasonal, weekend/weekday, etc.)
3	Review and evaluate flood inundation mapping and define appropriate reaches or areas flooded (by river reach, town, etc.) for each dam failure scenario
4	Estimate flood severity range (i.e. DV range) for the flooded areas. Some towns or river reaches may have PAR in multiple DV ranges, depending on the flood characteristics. Justify the estimates.
5	Estimate the population at risk (PAR) within each reach for each failure scenario, DV range and time category. Justify the estimates and provide any referenced resources.
6	Estimate when dam failure warnings would be initiated. Estimate the warning time categories for flooded areas (e.g. little to no warning, adequate warning, or between the two; see Task 6 discussion below). Justify the estimates.
7	For each PAR reach, use the graphical approach to estimate an appropriate fatality rate range based on DV values, warning time and other considerations. Justify the estimates.
8	Estimate life loss range for each PAR reach by applying appropriate fatality rate range limits to each PAR. Sum the life loss estimates for each PAR to get the total estimated life loss range. Estimate life loss range for different dam failure scenarios as needed in Task 1.
9	Evaluate how uncertainties and variability in various parameters affect overall uncertainties in life loss estimates. Perform sensitivity studies if needed. Identify areas of higher and lower uncertainty.
10	Build the case for the life loss estimates by documenting all assumptions and references used. Discuss confidence in the life loss estimates.

8.3.1 Task 1 - Selection of dam failure scenarios that correspond to dam potential failure modes

A Potential Failure Mode Analysis (PFMA) was performed for the Bisri Dam to identify potential failure modes under static loading, normal operating water level, flood water level, and earthquake conditions. The PFMA results indicate that, while the risk of failure is very low, the most probable failure modes are seismic loading and flood overtopping.

The primary mode of potential failure of the Bisri Dam is considered to be breaching and overtopping due either to seismic activity or flooding.

8.3.2 Task 2 - Select appropriate time categories

Since an emergency action plan will be developed for Bisri dam, and very long warning times for downstream population should be given, the dam breach will be considered to take place during the day. However, sensibility comparisons for worst case scenarios will be also considered.

8.3.3 Task 3 - Review and evaluate flood inundation mapping and define appropriate reaches or areas flooded

Bisri flood inundation model provides estimates of the inundation areas, the severity of flooding, and flood wave travel times. Also assumptions about the type of breach that will occur is given in previous chapters.

8.3.4 Task 4 - Estimate the flood severity range for the flooded areas

Flood severity has a significant influence on fatality rate. In general, case history data indicates that the highest estimated fatality rates are associated with the highest estimated DV values. When the flood severity is lower, there is greater observed scatter in the fatality rates, most likely because other factors (such as the amount of warning, the forcefulness of the warnings, the response of the PAR to warning, as well as evacuation opportunities or constraints) are more significant at the lower DV values. Estimation of flood severity for Bisri dam failure is particularly important because the graphical charts provide relationships between DV and fatality rate.

Mapping of D (Maximum Water Depth) and consequently DV (Maximum Water Depth x Maximum Velocity) is produced for the flooded area. The results of this mapping are illustrated in figures 8.1 to 8.5 for D and in figures 8.6 to 8.10 for DV.

8.3.5 Task 5 - Estimate the population at risk (PAR) for each DV range

After the DV values have been estimated in each flooded area, the PAR in each area was estimated. PAR is defined as the number of people occupying the dam failure flood plain prior to the issuance of any warning or evacuation.

The development of the PAR estimate was done based on the topographic survey of the area downstream of the dam and counting houses in the inundation zone. The flood inundation boundary was overlaid with the topographic survey in a GIS and the number of inundated PAR households was calculated.

In order to calculate the population, each building in the rural area was considered composed of two apartments and occupied by 5 persons and each building in the urban area was considered composed of ten apartments and occupied by 5 persons. The resulting total population was estimated equal to 14,000.

8.3.6 Task 6 - Estimate when dam failure warnings would be initiated and estimate the warning time categories for flooded areas

Although the graphical method utilizes the time that warning reaches the PAR, it is important to understand that the warning process consists of several steps as illustrated in chapter 7, including detection of a failure in progress, initiation of warning by emergency management officials or others, and flood wave travel time. The time at which dam failure warnings are initiated is defined as the time at which public safety officials, using assistance from the media (as applicable), begin informing the public of the imminent dam failure danger and directing people at risk to either immediately evacuate or begin evacuation preparations.

In the most ideal situation, a dam breach in progress would be detected, well in advance of the beginning of catastrophic outflows, and warnings and a strong evacuation order would be issued to downstream PAR without delay, with all of the PAR moving safely out of the flood zone by the time flooding arrives downstream. Dam failure and flash flood case histories indicate the ideal situation does not always develop. The sequence of events that takes place is often a mix of physical and social phenomena combined with some element of chance or luck.

Therefore, two cases of warnings were developed in the present study:

- Little to no warning,
- Adequate warning.

8.3.7 Task 7 - Use the graphical approach to estimate an appropriate fatality rate range based on flood severity and warning time

This task involves using all of the information available for a dam failure scenario to estimate fatality rate ranges for each PAR area. For PAR areas that are judged to receive little or no warning, Figure 1 is used, and for PAR areas that are assumed to receive adequate warning, Figure 2 is used.

At this step, the DV value for each building was retrieved and the adequate fatality rate was obtained.

8.3.8 Task 8 - Estimate life loss range for PAR by applying appropriate fatality rate range limits to each PAR

The range of estimated life loss for each specific PAR was determined by simply multiplying the appropriate fatality rate range limits by each PAR estimate. The life loss estimates from each PAR were summed to get the total estimated life loss range.

- For the case of little to no warning, the estimation of life loss will range between 5,000 and 13,000.
- For the case of adequate warning, the estimation of life loss will range between 10 and 340.

8.3.9 Task 9 - Evaluate how uncertainties and variability in various parameters affect overall uncertainties in life loss estimates

As evidenced by case histories, there can be a large range of fatality rates from dam failure flooding. This is not surprising, considering the variability in PAR, severity of flooding, and warning time. However, even within a given category of flood severity or warning time there can still be a wide range of fatality rates.

Several uncertainties and variability in various parameters are to be considered for Bisri dam inundation study (Dam Breach parameters, Failure Scenarios, Population Estimate...). The loss of life estimate was done for the most stringent parameters.

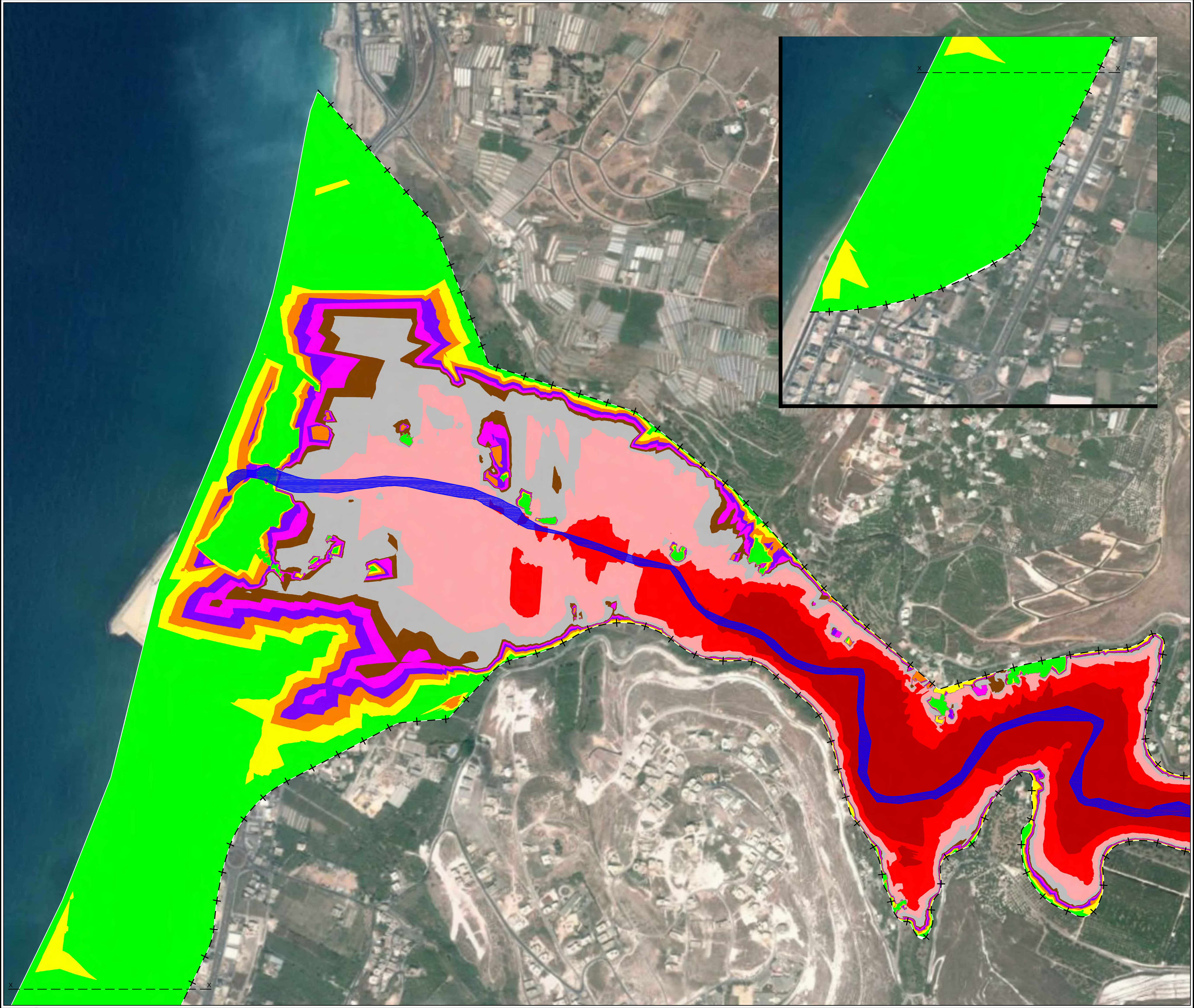
8.3.10 Task 10 - Build the Case for the Life Loss Estimates

In order to build the case for the life loss estimates for Bisri dam, the key inputs that are included in the preparation of the loss of life estimates were addressed:

- Available inundation studies: The inundation study for Bisri dam was done based on a 1D model performed on HEC-RAS in addition to a validation using a 3D model.
- Failure scenarios: The primary mode of potential failure of the Bisri Dam is considered to be breaching and overtopping due either to seismic activity or flooding. Piping failure scenario will result in smaller flooding.
- Breach assumptions: Sensitivity analysis on breach time and breach side slopes was done. The most stringent logical results were taken into consideration in order to estimate the Breach flows.
- Accuracy of information used to estimate the population at risk along the inundated area: The accuracy of the data is open to discussion since

no site census was made. Nevertheless, the population estimate is considered as an upper limit.

- The efficiency of the Emergency Action Plan: Since the execution of Bisri dam will be financed by the World Bank, large attention will be given to the application of the EAP.



Legend

Maximum Water Depth			
Minimum Elevation (m)	Maximum Elevation (m)	Area m²	Color
0.00	0.50	1088341.19	
0.50	1.00	242318.02	
1.00	1.50	153824.62	
1.50	2.00	139311.61	
2.00	2.50	138590.73	
2.50	3.00	142321.84	
3.00	5.00	452308.94	
5.00	10.00	769520.82	
10.00	20.00	932845.14	
20.00	40.00	1745875.21	
+ 40.00		2104994.33	

Bisri River

Maximum Flood Area

0m 100m 250m

Scale $\frac{1}{10000}$ @ A3 Size

N

Fig. 8.1

Maximum Water Depth (1 / 5)

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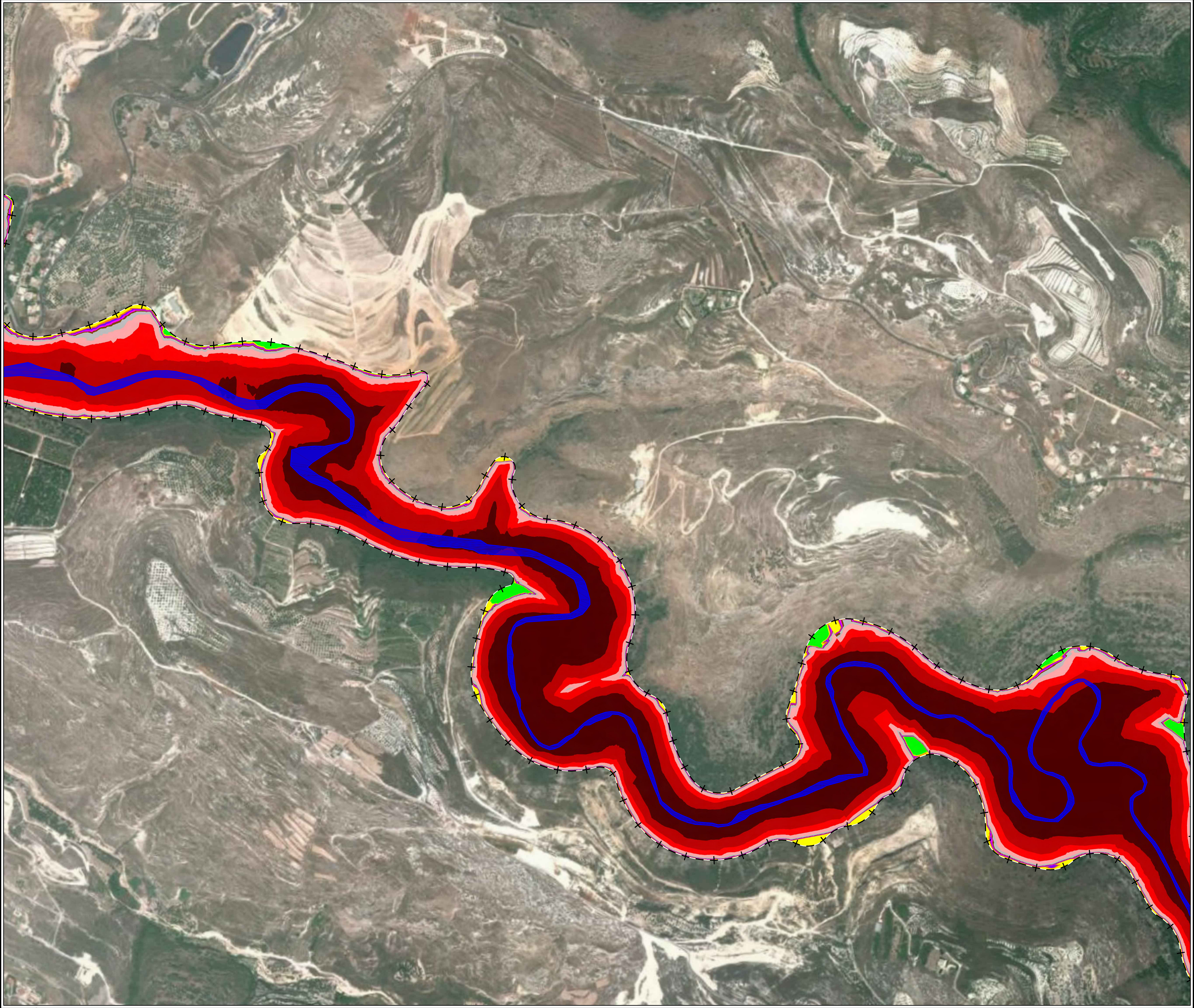

Legend

Maximum Water Depth			
Minimum Elevation (m)	Maximum Elevation (m)	Area m²	Color
0.00	0.50	1088341.19	
0.50	1.00	242318.02	
1.00	1.50	153824.62	
1.50	2.00	139311.61	
2.00	2.50	138590.73	
2.50	3.00	142321.84	
3.00	5.00	452308.94	
5.00	10.00	769520.82	
10.00	20.00	932845.14	
20.00	40.00	1745875.21	
+ 40.00		2104994.33	

Bisri River

Maximum Flood Area

Fig. 8.2

0m 100m 250m

Scale $\frac{1}{10000}$ @ A3 Size

N

Maximum Water Depth (2 / 5)

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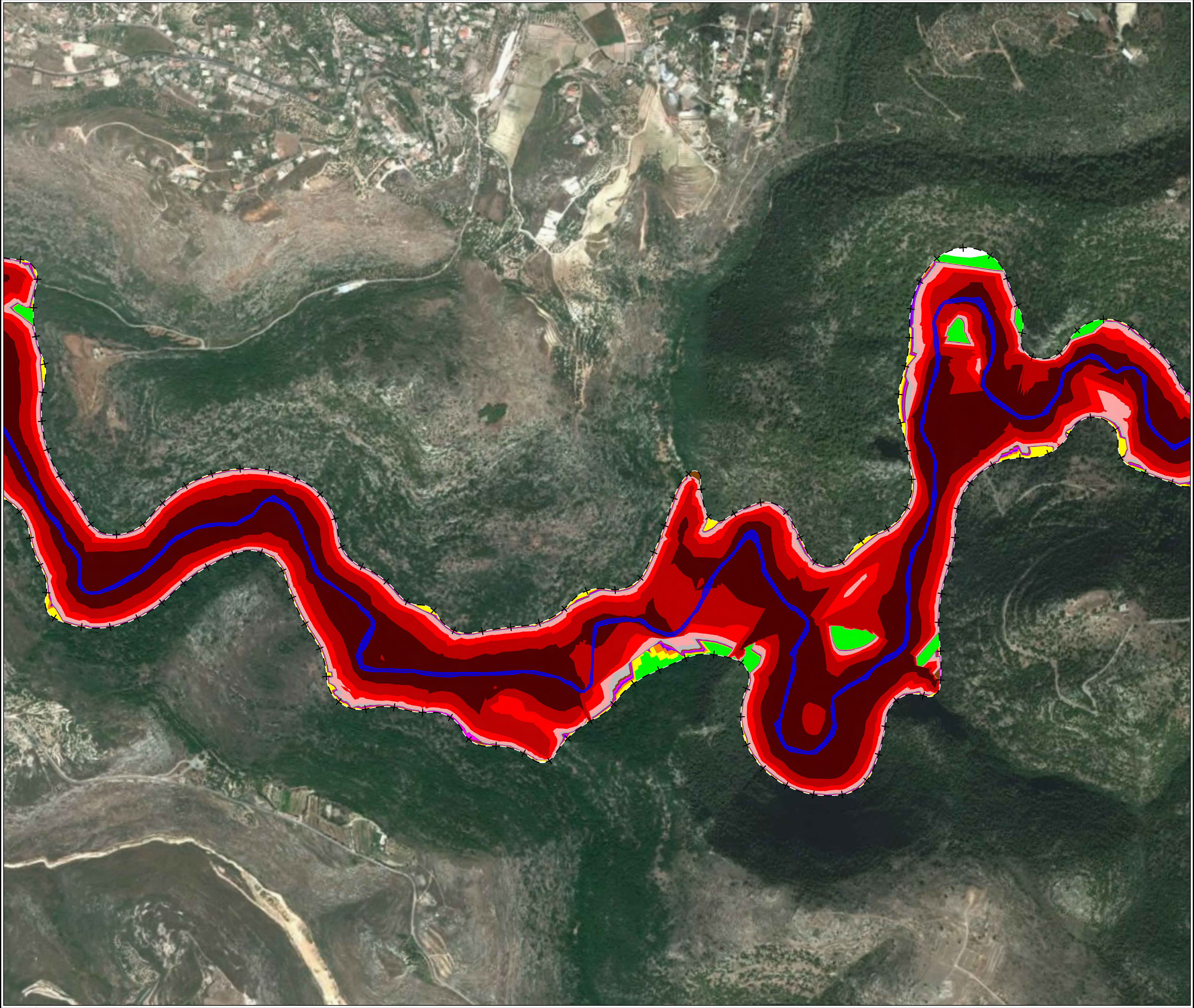

Legend

Maximum Water Depth			
Minimum Elevation (m)	Maximum Elevation (m)	Area m²	Color
0.00	0.50	1088341.19	
0.50	1.00	242318.02	
1.00	1.50	153824.62	
1.50	2.00	139311.61	
2.00	2.50	138590.73	
2.50	3.00	142321.84	
3.00	5.00	452308.94	
5.00	10.00	769520.82	
10.00	20.00	932845.14	
20.00	40.00	1745875.21	
+ 40.00		2104994.33	

Bisri River

-+-+- Maximum Flood Area

0m 100m 250m

Scale $\frac{1}{10000}$ @ A3 Size

N

Fig. 8.3

Maximum Water Depth (3 / 5)

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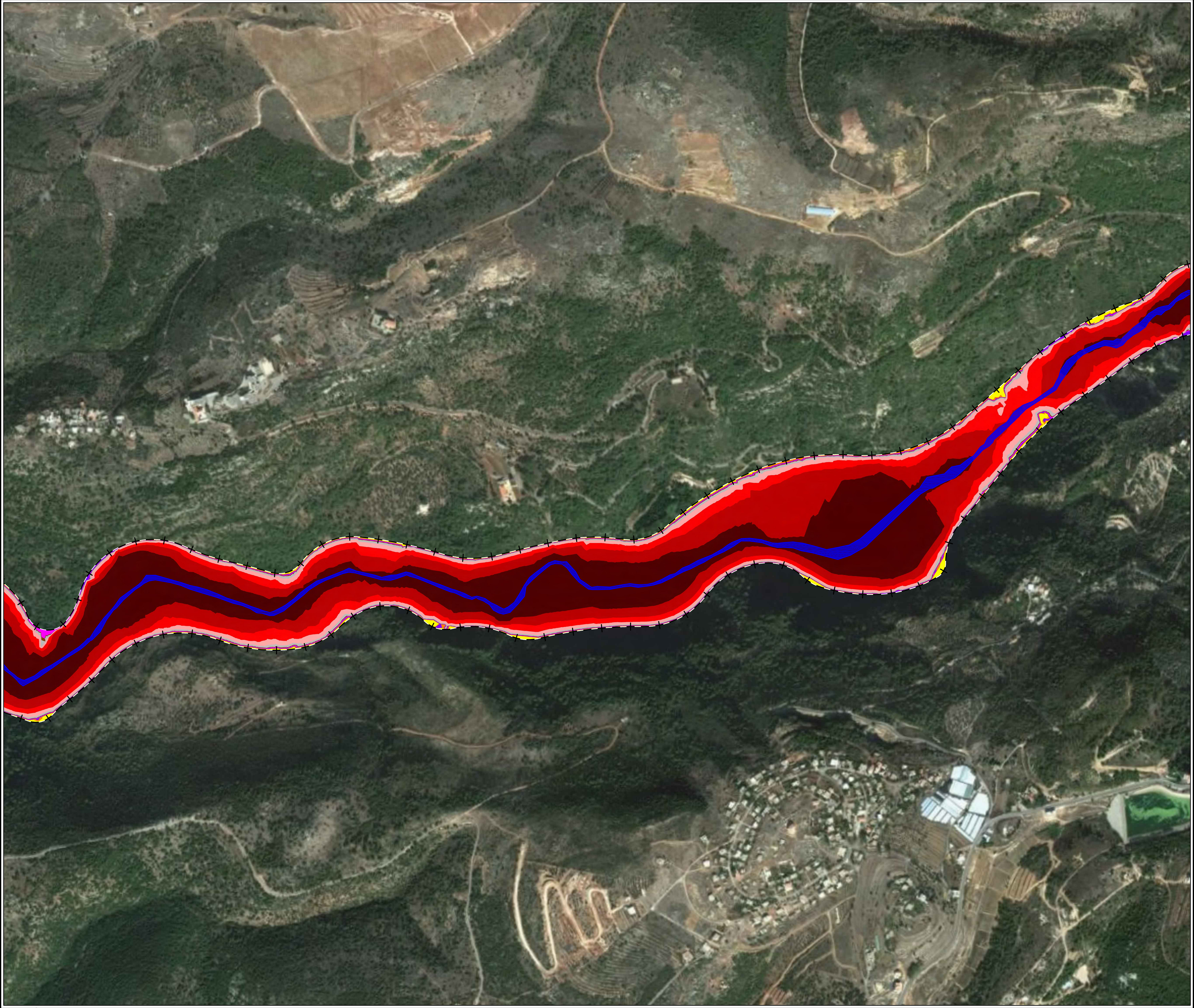

Legend

Maximum Water Depth			
Minimum Elevation (m)	Maximum Elevation (m)	Area m²	Color
0.00	0.50	1088341.19	
0.50	1.00	242318.02	
1.00	1.50	153824.62	
1.50	2.00	139311.61	
2.00	2.50	138590.73	
2.50	3.00	142321.84	
3.00	5.00	452308.94	
5.00	10.00	769520.82	
10.00	20.00	932845.14	
20.00	40.00	1745875.21	
+ 40.00		2104994.33	

Bisri River

-+-+- Maximum Flood Area

0m 100m 250m

Scale $\frac{1}{10000}$ @ A3 Size

N

Fig. 8.4

Maximum Water Depth (4 / 5)

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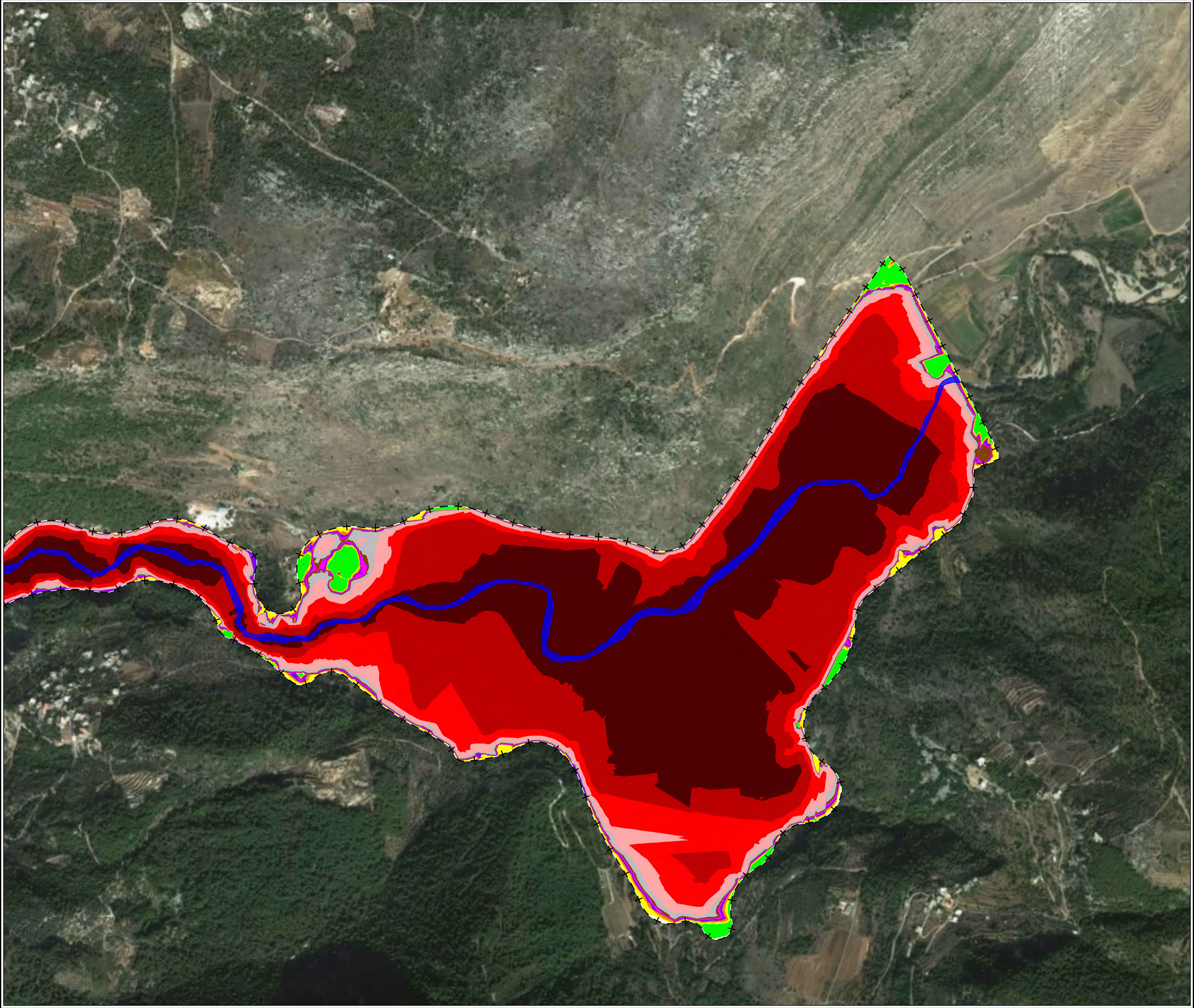

Legend

Maximum Water Depth			
Minimum Elevation (m)	Maximum Elevation (m)	Area m²	Color
0.00	0.50	1088341.19	
0.50	1.00	242318.02	
1.00	1.50	153824.62	
1.50	2.00	139311.61	
2.00	2.50	138590.73	
2.50	3.00	142321.84	
3.00	5.00	452308.94	
5.00	10.00	769520.82	
10.00	20.00	932845.14	
20.00	40.00	1745875.21	
+ 40.00		2104994.33	

Bisri River

Maximum Flood Area

Fig. 8.5

0m 100m 250m

Scale $\frac{1}{10000}$ @ A3 Size

N

Maximum Water Depth (5 / 5)

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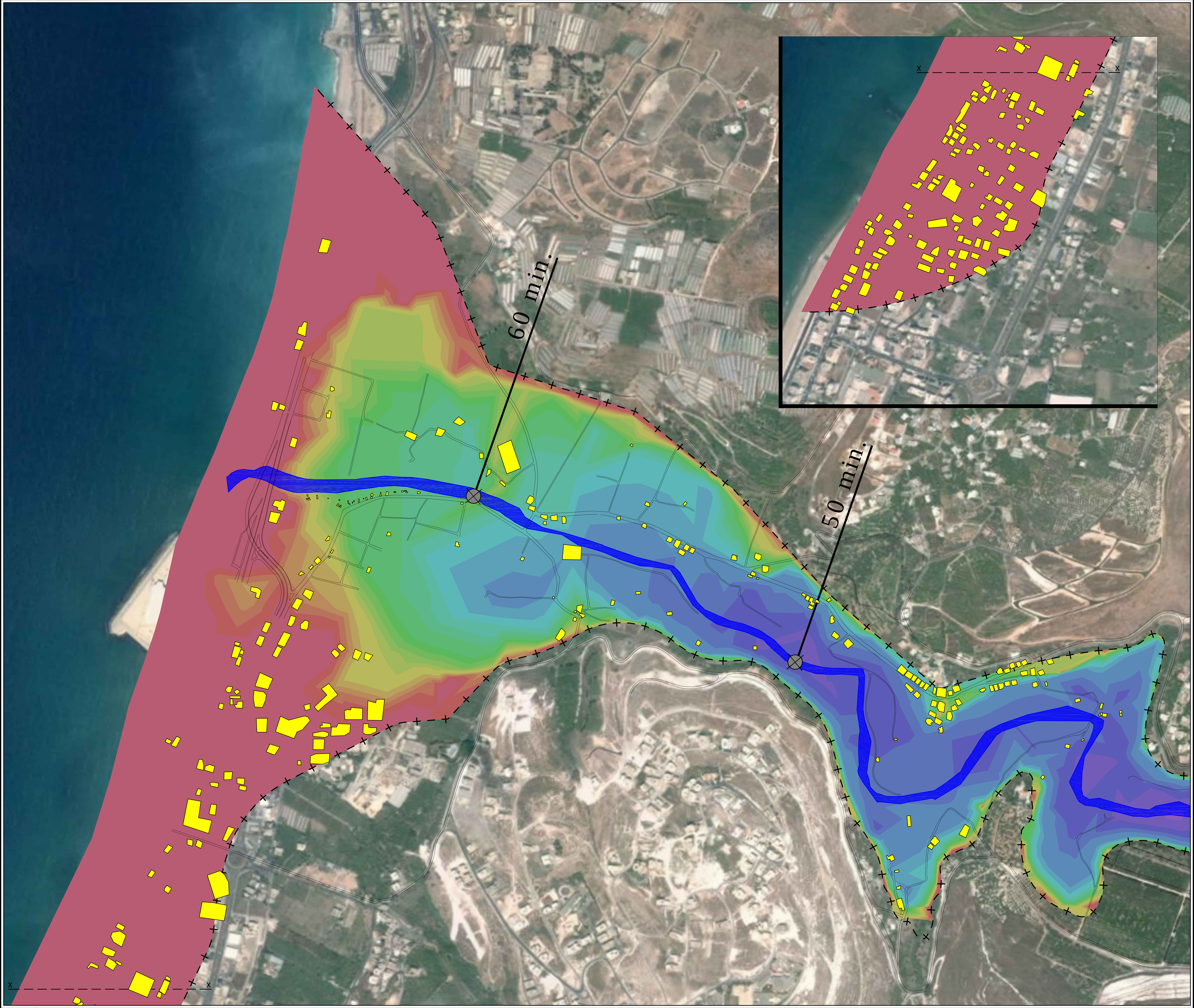

Legend

DV				
Discharge Speed m^2/s			Area	Color
$\leqslant$ 1.58			972217.21	
1.58	—	3.83	124821.22	
3.83	—	5.72	99364.96	
5.72	—	7.47	84060.58	
7.47	—	8.92	63996.66	
8.92	—	10.83	73492.29	
10.83	—	12.96	65713.32	
12.96	—	14.80	64769.75	
14.80	—	17.02	95919.70	
17.02	—	19.62	82942.22	
19.62	—	22.61	86204.09	
22.61	—	25.87	93099.72	
25.87	—	29.48	105294.46	
29.48	—	32.62	121535.05	
32.62	—	37.19	149608.44	
37.19	—	44.79	161822.67	
44.79	—	57.36	220263.94	
57.36	—	75.00	273983.43	
75.00	—	103.80	324743.64	
103.80	—	154.00	618325.89	
154.00	—	223.50	843862.55	
223.50	—	325.85	900453.19	
325.85	—	494.10	758183.75	
494.10	—	755.00	722597.89	
755.00	—	2593.50	686326.27	

Buildings

Bisri River

-+-+- Maximum Flood Area

60 Min

Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

Fig. 8.6

0m 100m 250m

Scale $\frac{1}{10000}$ @ A3 Size

N

DV Mapping (1 / 5)

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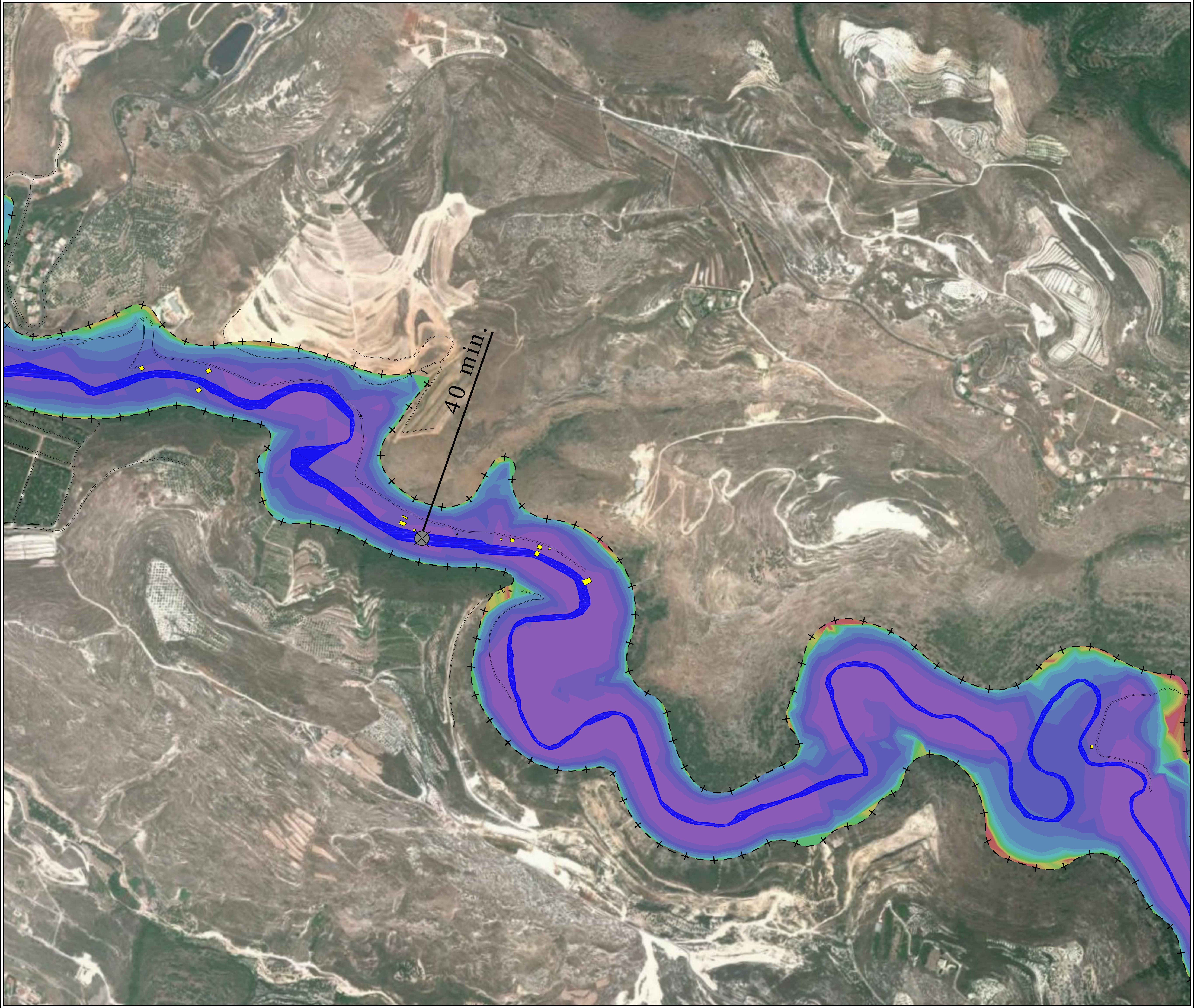


Legend

DV				
Discharge Speed m^2/s			Area	Color
$\leqslant$ 1.58			972217.21	
1.58	—	3.83	124821.22	
3.83	—	5.72	99364.96	
5.72	—	7.47	84060.58	
7.47	—	8.92	63996.66	
8.92	—	10.83	73492.29	
10.83	—	12.96	65713.32	
12.96	—	14.80	64769.75	
14.80	—	17.02	95919.70	
17.02	—	19.62	82942.22	
19.62	—	22.61	86204.09	
22.61	—	25.87	93099.72	
25.87	—	29.48	105294.46	
29.48	—	32.62	121535.05	
32.62	—	37.19	149608.44	
37.19	—	44.79	161822.67	
44.79	—	57.36	220263.94	
57.36	—	75.00	273983.43	
75.00	—	103.80	324743.64	
103.80	—	154.00	618325.89	
154.00	—	223.50	843862.55	
223.50	—	325.85	900453.19	
325.85	—	494.10	758183.75	
494.10	—	755.00	722597.89	
755.00	—	2593.50	686326.27	

Buildings

Bisri River

-+-+- Maximum Flood Area

60 Min

Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

Fig. 8.7

0m 100m 250m

Scale $\frac{1}{10000}$ @ A3 Size

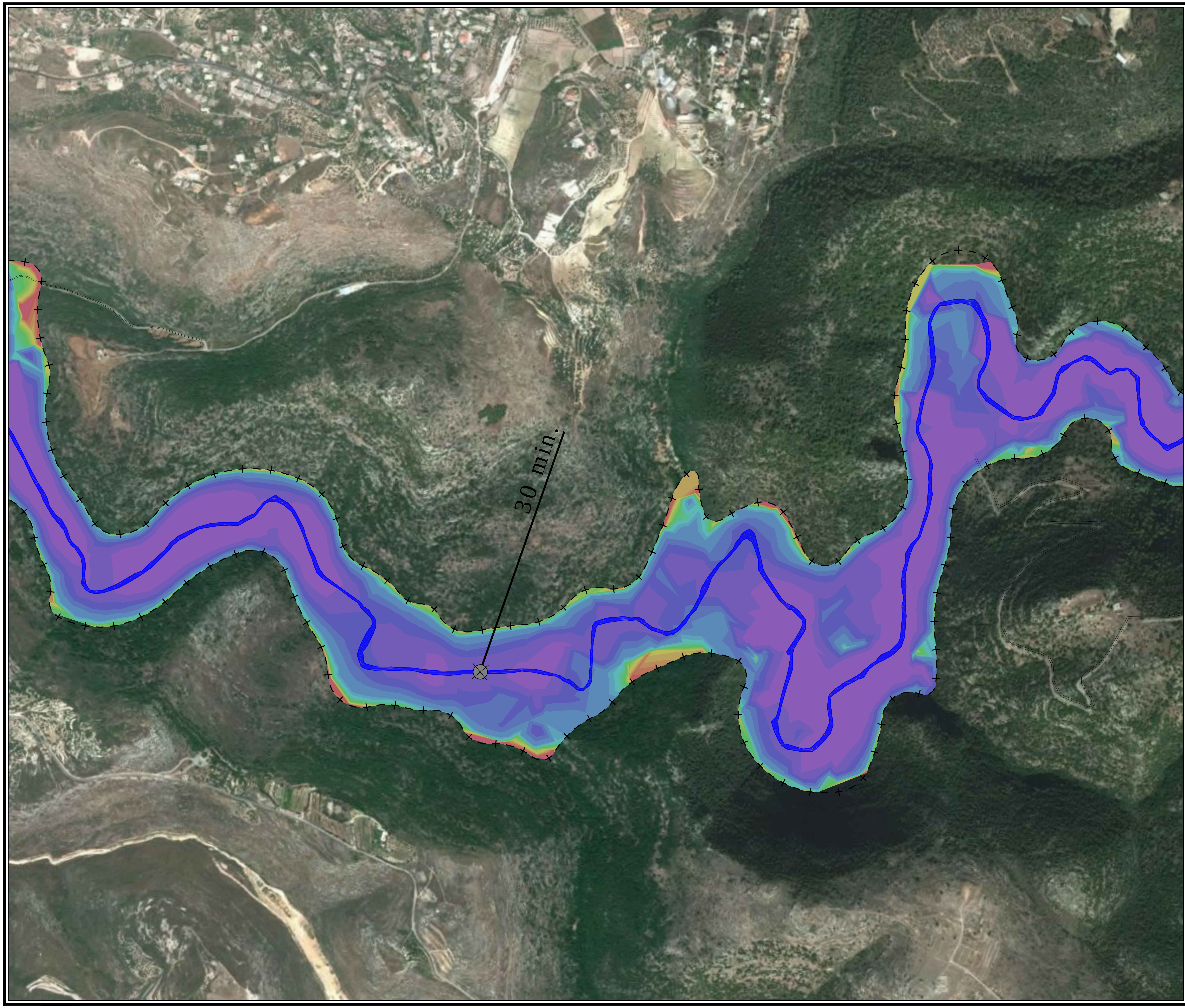
N

DV Mapping (2 / 5)

Founded 1956

DAR AL HANDASAH NAZIH TALEB & PARTNERS

دار الهندســـــة نزيـــه طالـــب وشركاه



Legend

DV				
Discharge Speed m^2/s			Area	Color
⩽ 1.58			972217.21	
1.58	—	3.83	124821.22	
3.83	—	5.72	99364.96	
5.72	—	7.47	84060.58	
7.47	—	8.92	63996.66	
8.92	—	10.83	73492.29	
10.83	—	12.96	65713.32	
12.96	—	14.80	64769.75	
14.80	—	17.02	95919.70	
17.02	—	19.62	82942.22	
19.62	—	22.61	86204.09	
22.61	—	25.87	93099.72	
25.87	—	29.48	105294.46	
29.48	—	32.62	121535.05	
32.62	—	37.19	149608.44	
37.19	—	44.79	161822.67	
44.79	—	57.36	220263.94	
57.36	—	75.00	273983.43	
75.00	—	103.80	324743.64	
103.80	—	154.00	618325.89	
154.00	—	223.50	843862.55	
223.50	—	325.85	900453.19	
325.85	—	494.10	758183.75	
494.10	—	755.00	722597.89	
755.00	—	2593.50	686326.27	

Buildings

Bisri River

Maximum Flood Area

60 Min

Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

Fig. 8.8

0m 100m 250m

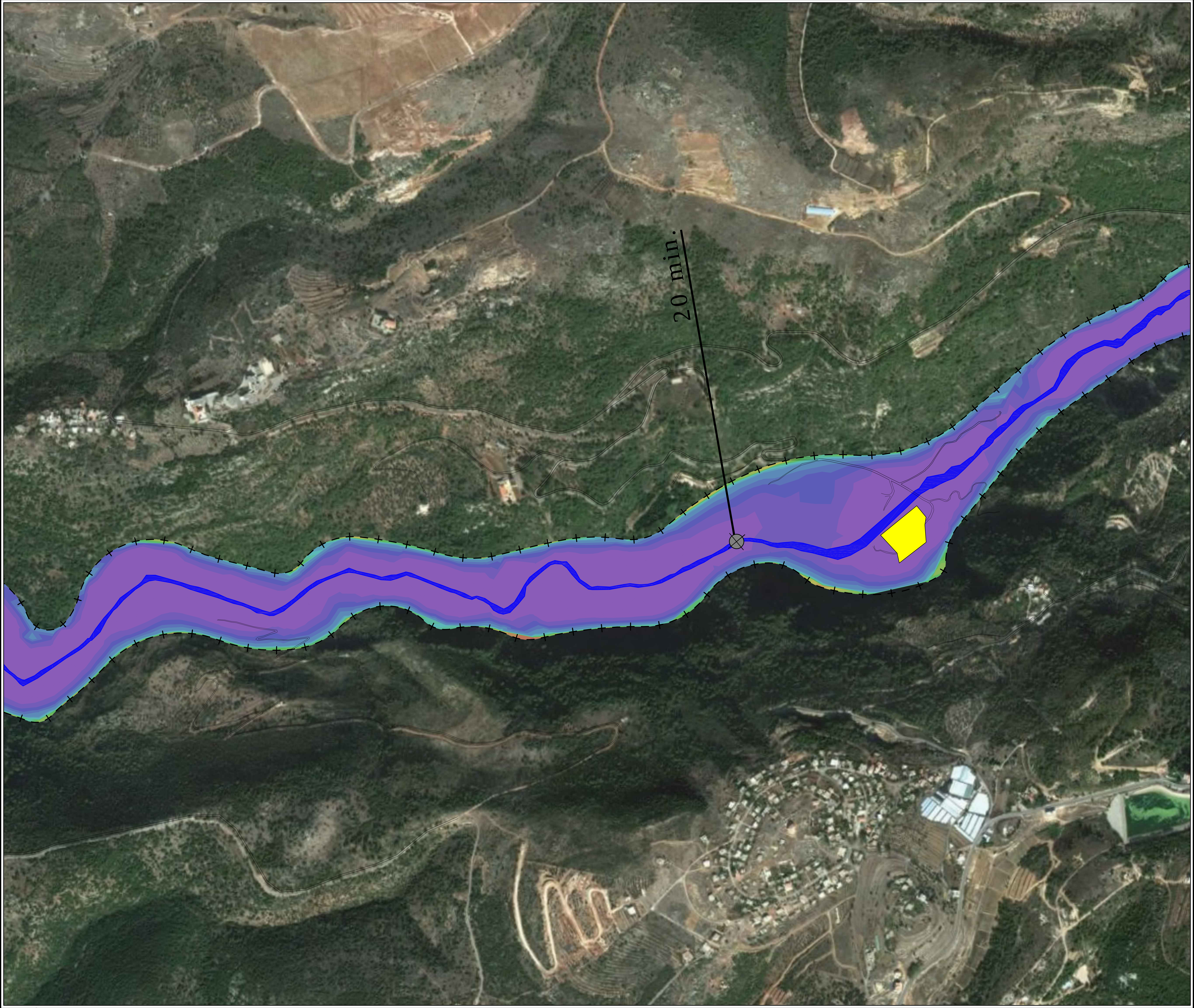
Scale $\frac{1}{10000}$ @ A3 Size

N

DV Mapping (3 / 5)

Founded 1956

DAR AL HANDASAH NAZIH TALEB & PARTNERS
دار الهندسة نزيه طالب وشركاه



Legend

DV				
Discharge Speed m^2/s			Area	Color
$\leqslant$ 1.58			972217.21	
1.58	—	3.83	124821.22	
3.83	—	5.72	99364.96	
5.72	—	7.47	84060.58	
7.47	—	8.92	63996.66	
8.92	—	10.83	73492.29	
10.83	—	12.96	65713.32	
12.96	—	14.80	64769.75	
14.80	—	17.02	95919.70	
17.02	—	19.62	82942.22	
19.62	—	22.61	86204.09	
22.61	—	25.87	93099.72	
25.87	—	29.48	105294.46	
29.48	—	32.62	121535.05	
32.62	—	37.19	149608.44	
37.19	—	44.79	161822.67	
44.79	—	57.36	220263.94	
57.36	—	75.00	273983.43	
75.00	—	103.80	324743.64	
103.80	—	154.00	618325.89	
154.00	—	223.50	843862.55	
223.50	—	325.85	900453.19	
325.85	—	494.10	758183.75	
494.10	—	755.00	722597.89	
755.00	—	2593.50	686326.27	

Buildings

Bisri River

-+-+- Maximum Flood Area

60 Min

Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

Fig. 8.9

0m 100m 250m

Scale $\frac{1}{10000}$ @ A3 Size

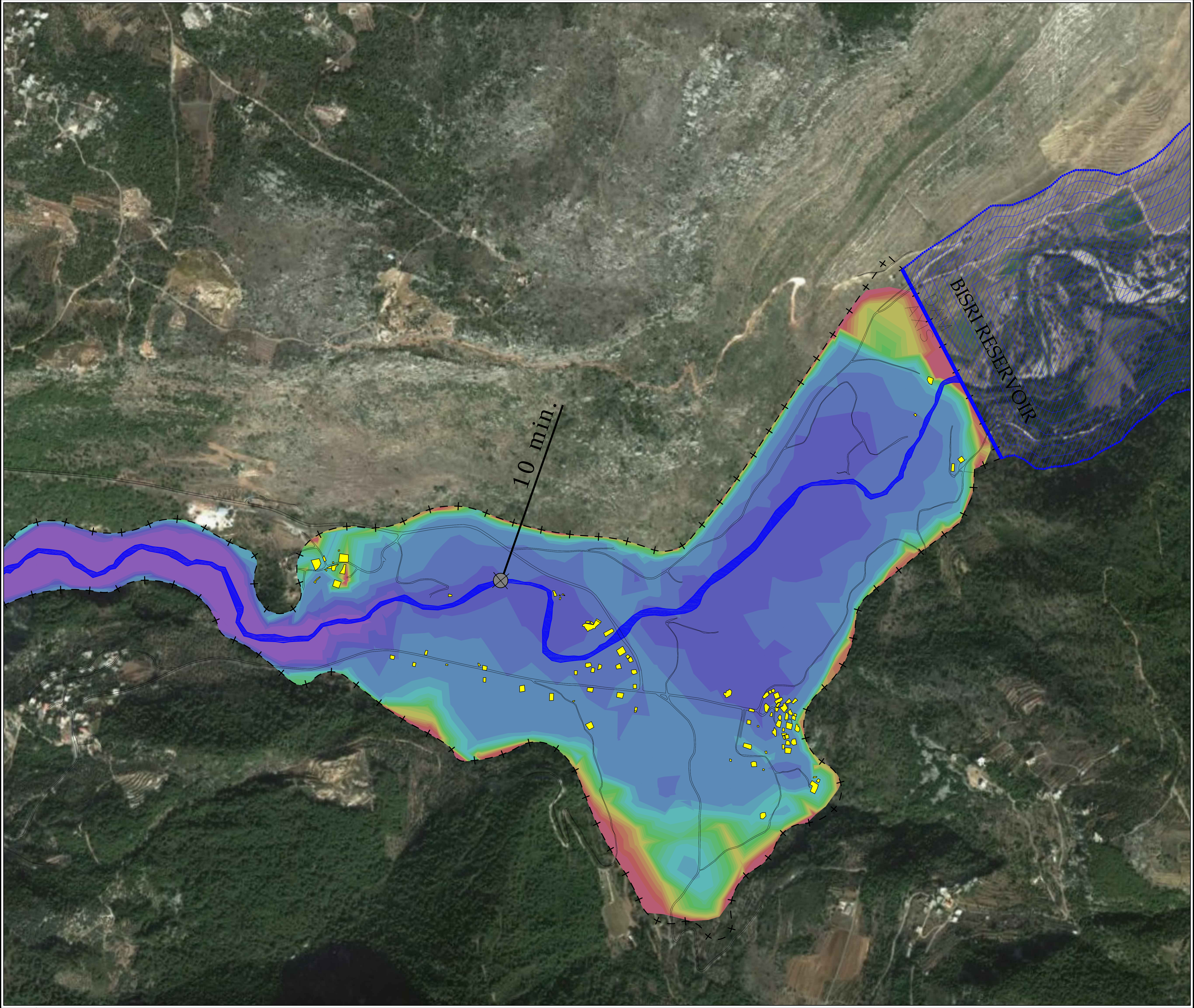
N

DV Mapping (4 / 5)

Founded 1956

DAR AL HANDASAH NAZIH TALEB & PARTNERS

دار الهندسة نزيه طالب وشركاه



Legend

DV		
Discharge Speed m^2/s	Area	Color
⩽ 1.58	972217.21	
1.58 — 3.83	124821.22	
3.83 — 5.72	99364.96	
5.72 — 7.47	84060.58	
7.47 — 8.92	63996.66	
8.92 — 10.83	73492.29	
10.83 — 12.96	65713.32	
12.96 — 14.80	64769.75	
14.80 — 17.02	95919.70	
17.02 — 19.62	82942.22	
19.62 — 22.61	86204.09	
22.61 — 25.87	93099.72	
25.87 — 29.48	105294.46	
29.48 — 32.62	121535.05	
32.62 — 37.19	149608.44	
37.19 — 44.79	161822.67	
44.79 — 57.36	220263.94	
57.36 — 75.00	273983.43	
75.00 — 103.80	324743.64	
103.80 — 154.00	618325.89	
154.00 — 223.50	843862.55	
223.50 — 325.85	900453.19	
325.85 — 494.10	758183.75	
494.10 — 755.00	722597.89	
755.00 — 2593.50	686326.27	

Buildings

Bisri River

-+-+- Maximum Flood Area

60 Min

Initial rise time of the flood counting from initiation of the dam breach is 60 minute at this location

Fig. 8.10

0m 100m 250m

Scale @ A3 Size

N

DV Mapping (5 / 5)

DAR AL HANDASAH NAZIH TALEB & PARTNERS

دار الهندسة نزيه طالب وشركاه

Founded 1956

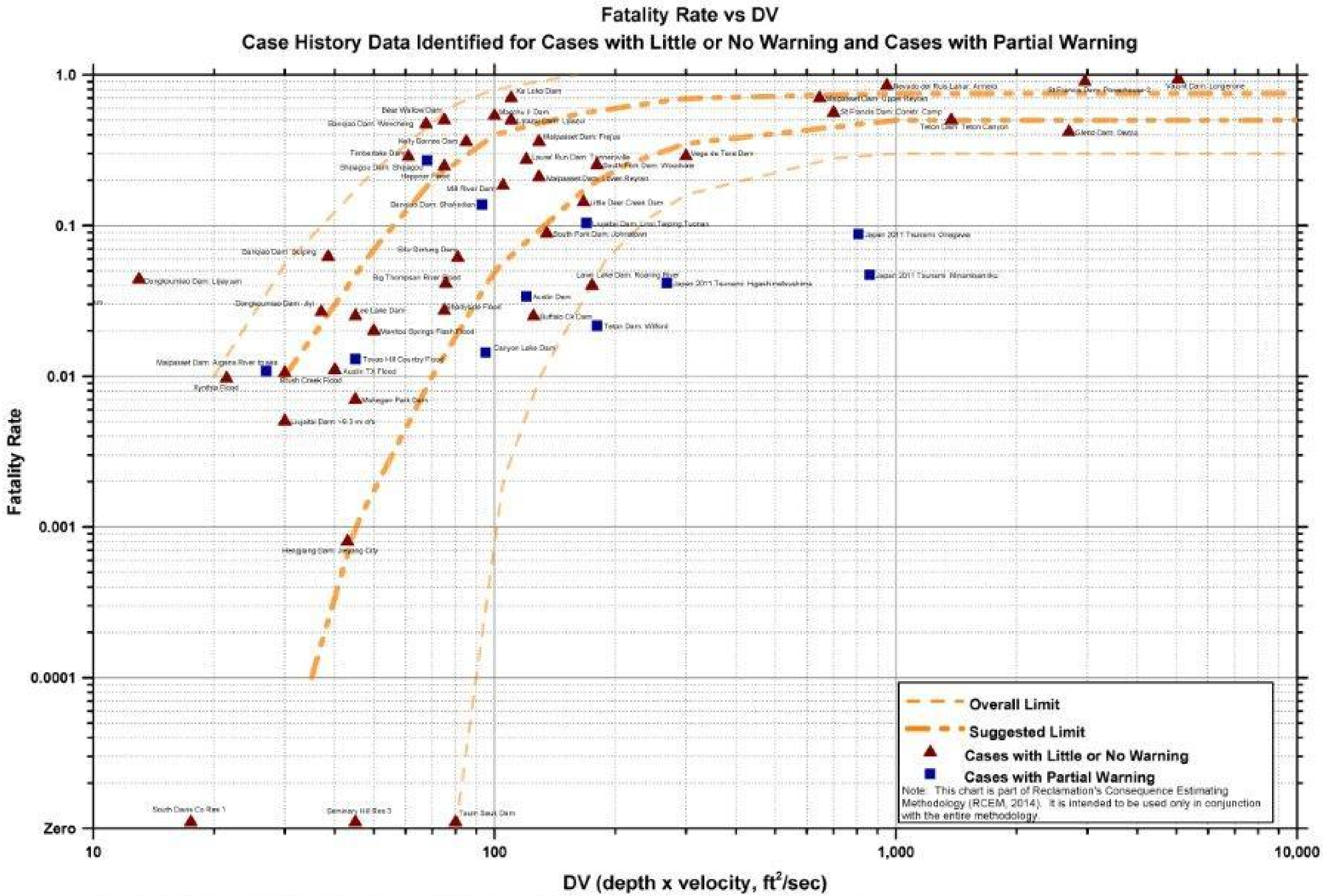


Figure 8-11 Fatality Rate vs. DV - Case History Data Identified for Cases with Little or No Warning and Cases with Partial Warning

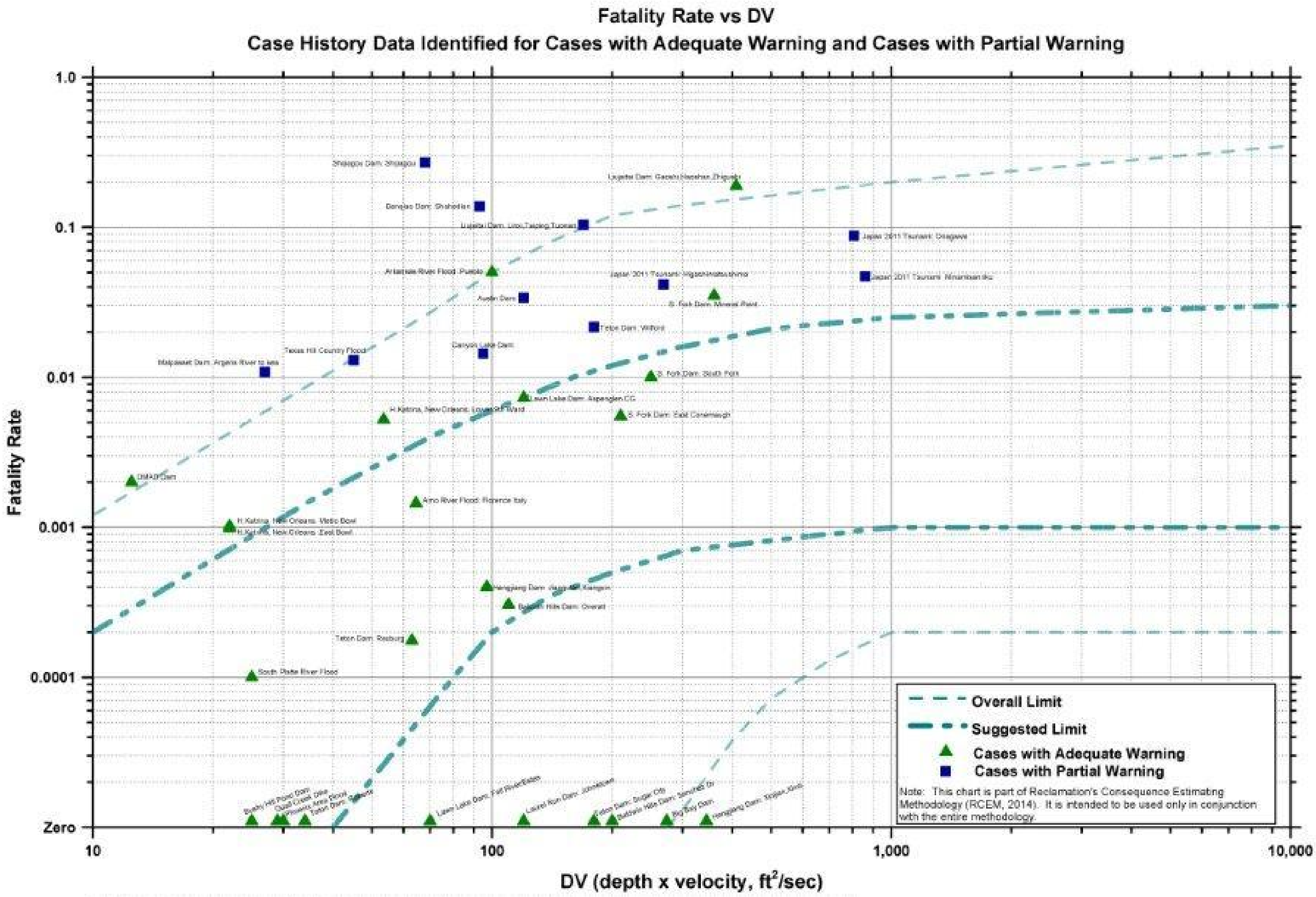


Figure 8-12 Fatality Rate vs. DV - Case History Data Identified for Cases with Adequate Warning and Cases with Partial Warning