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LITANI RIVER BASIN MANAGEMENT SUPPORT PROGRAM

LITANI RIVER FLOOD MANAGEMENT REPORT
MAY 2012

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This report was produced for review by the United States Agency for International Development (USAID). It was prepared by International Resources Group (IRG) under Contract EPP-I-00-04-00024-00 order no 7.

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ACRONYMS

DEM	Digital Elevation Model
HEC-RAS	Hydrologic Engineering Center of the US Army Corps of Engineers
IQC	Indefinite Quantity Contract
IRG	International Resources Group
LRA	Litani River Authority
LRBMS	Litani River Basin Management Support
PAEP	Participatory Agriculture Extension Program
USAID	United States Agency for International Development

FOREWORD

This Litani River Flood Management Report was prepared by Dar Al Handasah Nazih Taleb (DAHNT) under subcontract with International Resources Group (IRG), the main contractor under the Litani River Basin Management Support (LRBMS) Program, a USAID-funded program in Lebanon (Contract EPP-I-00-04-00024-00 Task Order No.7) under the Integrated Water and Coastal Resources Management Indefinite Quantity Contract (IQC) II.

EXECUTIVE SUMMARY

PROGRAM BACKGROUND

The LRMBS Program is a four-year program to improve water management in the Litani River Basin in the Bekaa. It is undertaken by IRG, in cooperation with LRA, and is funded by USAID. The program began in October 2009 and has four components: Building institutional capacity, Water monitoring, Irrigation management and Risk management.

CONTEXT

The Litani River Basin drains the Central and South Bekaa Valley. The valley is sandwiched between Mount Lebanon to the west and the Anti-Lebanon mountain range to the east. Winter precipitations fall heavily on both ranges and engender heavy flows which then spread across the valley whose bottom is almost flat and with a low north-south slope. Floods are thus common occurrences in the valley but with the development of human activities (farming and urbanization), their impacts are increasing.

FLOODS AND FLOOD MANAGEMENT PRINCIPLES

Storms and floods are natural events and have both positive and negative effects on human well-being. High flows and flood waters are needed to cleanse channels of accumulated debris, build stream banks, deposit nutrients in the floodplains, recharge aquifers and sustain riparian habitat.

But storms and floods also cause direct (physical damage due to submersion and water flows) and indirect (disruption of human and notably economic activities) damage to the economic and social sectors such as infrastructure, agriculture, industry, and human settlements. With population growth and economic development, more and more infrastructures and human activities settle or take place in floodplains and thus get impacted by floods.

> **SUSTAINABLE FLOOD PREVENTION GUIDELINES (UN/ECONOMIC COMMISSION FOR EUROPE, 2000)**
>
> Seven basic principles and approaches:
>
> - Flood events are a part of nature.
> - Human interference into the processes of nature has increased the threat of flooding.
> - Flood prevention should cover the entire catchment area.
> - Structural measures will remain important elements of flood prevention and protection, especially for protecting human health and safety, and valuable goods and property.
> - Everyone who may suffer from the consequences of flood events should also take precautions on their own.
> - Human uses of floodplain should be adapted to the existing hazards.
> - In flood-prone areas, preventive measures should be taken to reduce the possible adverse effects on aquatic and terrestrial ecosystems.

While managers and engineers are quick to go for structural solutions such as embankments and dams to address flood concerns, these solutions are:

- Dangerous, as they give a false sense of security, while absolute protection does not exist, there may always be a larger/stronger flood (than the design flood) that will cause extensive damage; and
- Expensive, while there should be a comparison between the cost of flood protection works and the cost of potential damage.

In most situations, more emphasis needs to be given to natural solutions (such as flood expansion areas) and nonstructural approaches (such as smart urban planning).

STUDY METHODOLOGY

In order to evaluate the magnitude and extent of potential floods of the Litani River and guide the prevention and/or mitigation of their damage, the following steps were undertaken:

- An assessment of past flood events, based on an extensive field survey (see separate "Litani River Flood Field Survey Report");
- A topographic survey to collect elevation data on the river and its tributaries, as well as past flood highwater marks;
- A hydrological study to deifne the characterictics of large floods;
- The use of a computer flood model to:

- Properly understand and describe past flood events;
- Extrapolate to other types of floods;
- Simulate flood protection and mitigation measures and thus assess their effectiveness; and
- Define flood protection strategies (in terms of works/structures, improved urban and farming practices and activities).

FIELD SURVEY

The main objectives of the field survey can be summarized as follows:

- Assess the type of floods that occur in the Litani River Basin;
- Identify a reference flood that can be used to calibrate a flood model;
- Collect data and accounts from witnesses to define this reference flood;
- Assess the magnitude of flood damages; and
- Define the topographic survey necessary to build the model.

The main findings are that the Litani River Basin suffers from three types of flooding:

- Flooding from the Litani River and Major tributaries (Ghzayel, Berdawni, Qabb Elias); this is due to natural floodplain characteristics, compounded by lack of riverbed maintenance, existence of obstructions such as insufficient road bridges and irrigation weirs or other illegal constructions in the riverbed, dumping of all type of solid and hazardous waste, etc.
- Seasonal flooding from minor channels (Howayzek, Oqeyber, Faregh) mostly due to lack of agricultural drainage; this is due to the impermeability of soils (mostly clayey), and poor maintenance and disappearance of many drainage ditches in farm lands; and
- Local flooding in urban areas (Bar Elias, Marj) during winter rains for lack of storm /sewage networks

The flood of February 2003 was found as historically significant because:

- It is one of the two largest floods in human memory, in addition to possibly 1968;
- The flood caused significant damages:
  - Thousands of hectares of cultivated areas in the Beqaa valley were inundated
  - The West Bekaa was transformed into a series of isolated islands only accessed by the mean of boats or heavy trucks
- It is a recent flood and hence the collection of field information from residents is possible;
- Discharge and level data is available for this flood (from LRA gauging stations)

It was thus used as design flood to calibrate the flood model, assess floodable areas, recommend flood mitigation measures and design flood protection works.

TOPOGRAPHIC SURVEY

Based on the findings of the field survey, a topographic survey was defined and carried out in order to build the computer model. The area surveyed is situated in the upper and mid catchments of the Litani River between Haouch er Rafqa and the Qaraoun Lake in the Bekaa. About 150 river cross sections were surveyed along with 40 identified highwater levels from the 2003 flood.

A Digital Elevation Model was also purchased to provide accurate topography of the central Bekaa and thus provide good support for the mapping of flood risk areas.

HYDROLOGIC STUDY

The peak discharge of the February 2003 flood has been estimated at 182 m3/s in Joub Jenine. Based on available discharge data for the Liatni River, this corresponds to a period of return of 70 years, that is a 1/70=1.4% probability of happening any given year. It confirms the findings from the field survey, that 2003 was quite a rare event.

Two smaller and less frequent floods were also defined:

- A quite frequent flood event (period of return 10-year, that is a 1/10=10% chance of happening any year) with 70% of the intensity of 2003;
- A rarer flood event (period of return 25 years, that is a 1/25=4% chance of happening any year) with 85% of the intensity of 2003.

FLOOD MODEL: CHOICE AND CALIBRATION

The objective of the flood model is to assist in the definition of mitigation measures and structures to address river flooding as a public issue.

One dimensional models are deemed sufficient here, considering both the extent and types of floods in the Litani river basin, as well as LRA's current modeling capacity. HEC-RAS was chosen since it is widely used world-wide and notably in the US where it is the model for 90% of flood studies.

HEC-RAS exist with both steady and unsteady versions, is freely available on Internet, and is maintained and regularly updated by the Hydrologic Engineering Center of the US Army Corps of Engineers.

The calibration process of the computer flood model is essential to ensure that the model accurately represents the reality of flows in the Litani River and tributaries. This was achieved by simulating the 2003 flood and matching water levels from the model with highwater marks identified during the field survey. The criterion used was ± 20 cm which is often used for this type of water courses. The results of the calibration process are good and summarized in the table below:

Tributary	Available water level	Flood model water level	ΔH (cm)
Litani	Joub Janine Gauging Station (861.07m)	L31 (861.09m)	-2
	MG2 - Mansoura Bridge (862.645m)	L27 (862.7m)	-5.5
	M1 - Marj (868.91m)	L19 (869.02m)	-11
	M2 - Marj (868.36m)	L19A (868.55m)	-19
	D2 - Dalhamieh (882.426m)	L12 (882.3m)	12.6
	MK1 - Mkharit (891.818m)	L9 (891.71m)	10.8
	TA1 - Tell Amara (903.703m)	L6 (903.57m)	13.3
Ghzayel	Damascus Road Gauging Station (868.406m)	G1 (868.47m)	-6.4
	R2 - Rawda (867.209m)	G2 (867.1m)	10.9
	M12 - Marj (866.613m)	G4 (866.60m)	1.3
	B8 - Bar Elias(873.951m)	HO1-B (873.8m)	15.1
	B1 - Bar Elias - Howayzek (871.02m)	HO1-A (871.12m)	-10
	DR1 - Damascus Road - Oqayber (870.521m)	O1 (870.54m)	-1.9
Faregh	H2 - Haouch El Harimeh (865.108m)	F1(865.3m)	-19.2
Berdawni	Damascus Road Gauging Station (871.98m)	B9(871.8m)	18

FLOOD MAPPING

The main objective of the computer flood mapping is to delineate the flood-prone areas, and to define water depths within these areas. Three sets of maps covering the central Bekaa valley from Rayak to Joub Jenine have been thus established:

- One for the 10-year flood (70% of 2003) where flooding is limited to:

- The Litani River banks upstream of the Damascus highway;
- Some areas (up to 50 cm depth) along the Howayzeh, reaching Bar Elias around the Damascus highway;
- An area west of the Litani River immediately downstream of the Damscus highway (at the junction with the Chtoura and Berdawni); and
- Some local areas around and downstream of the village of Haouch el Harim.

• One for the 25-year flood (85% of 2003), where flooding is more widespread:

- All along the Howayzeh from Dalhamiye to Bar Elais;
- Along the Damascus highway; and
- Between Haouch el Harim and Mansoura.

• Finally one for the 2003 flood, which confirms the observed flooding, a 2-3 km wide area along the Litani River from Dalhamiye to Mansoura, impacting mostly Bar Elias, Marj and Haouch el Harim.

In all flooded areas, different levels of depths have been identified (0-20cm, 20-50cm, 50-100 cm, 100cm+) to inform about increasing flood intensities.

HUMAN ACTIVITIES INCREASING THE IMPACTS OF FLOODS

Through the field survey and flood analysis, several types of improper human practices and mismanagement were found to exacerbate flood extent and damages:

- Lack of maintenance and vegetation growth in riverbeds
- Direct dumping of solid waste and worksite debris in waterways the riverbed
- Presence of improperly designed bridges or culverts with undersized openings
- Tampering with riverbeds and banks: construction of farmer diversion weirs, ponds and pump sumps, local levees, etc.

Specific bottlenecks are insufficiently sized bridges, where backwater impacts can elevate upstream water levels by 30 cm and much more. Most of these bridges with insufficient sections are situated in the upper part of the Litani river in addition to secondary tributaries such as Howayzek, Oqayber and Faregh.

RECOMMENDATIONS FOR FLOOD PROTECTION AND MITIGATION

The flood management approach is that:

- Protecting all areas for all types of floods is impossible since there can always be a larger flood than the one used to design protections, and can quickly become expensive when it involves infrastructure works; and

- Protecting urban areas should be the priority while rural areas should be kept as expansion areas (flood volumes need to go somewhere and cannot be simply channeled through).

Flooding damage can be prevented or at least significantly mitigated with simple foreseeing urban planning measures. The following recommendations are meant to enhance the safety of persons, limit the damage to property and the nuisances for human activities, while ensuring the free flow of water and the conservation of areas designated for flood expansion. They consist of prohibitions on land use and requirements and recommendations to prevent damage:

Flooded zone with flooding higher than 20cm	**Where**	**Urban development**	
		Flooded zone with flooding higher than 20cm	**Where**
A: Urban centers	Centers of Bar Elias, El Marj and Haouch El Harime	Any new buildings, but basements should be avoided. For commercial and industrial buildings, the functional levels should be above flood levels.	Sensitive equipments/buildings such as electric transformers, hospitals, etc.
B Peri-urban	Regions surrounding Dalhamieh, Bar Elias, El Marj, Er Raouda and Haouch El Harime	New buildings but areas lost to large commercial/industrial buildings should be compensated (landfill should be taken from the same plot)	Sensitive equipments/buildings such as electric transformers, hospitals, etc.
C Farmlands, rural areas	Most of the Litani river valley	Buildings and facilities used for agricultural purposes and outdoor recreation (parks, gardens, sports fields, etc.) Areas lost to large landfills should be compensated.	All other types of construction (residential, commercial, industrial).

For all new constructions in flooded areas, real estate developers should be informed of the potential risks at the time of delivery of construction permit and in turn inform their buyers.

Some infrastructural works are suggested in order to protect the most sensitive urban areas(where strictly necessary and where the cost of such works is less than the potential flood damage):

Sector	Solution	Cost
Region between Dalhamieh and Bar Elias	• Cleaning and Widening of Howayzek (4-5 km). • Reconstruction of Culvert on Howayzek near Bar Elias. • Construction of Levee (4-5 km) on Litani Left Side.	450,000 US$
Region of El-Marj on the right bank of Litani River	• Adding 1.5 to 2 km of Levees on both sides of the Chtaura River. • Adding 2.5 to 3 km of Levees on both sides of the Berdawni River.	450,000 US$
Region of El Marj on the left bank of Litani River	• Adding 3 to 4 km of Levees on the left side of the River.	200,000 US$
Region of Rawda on the left bank of Ghzayel River	• Adding 2-3 km of Levees on the left side of the River.	150,000 US$
Haouch El Harimeh at the left Bank of Faregh	• Cleaning and Widening of Faregh. • Building Bridges with adequate Section.	500,000 US$

Maintenance costs are not included here as riverbeds would have to be re-excavated on a regular basis (at least every 5 years).

To justify the expenses, total costs have to be compared to actual flood damages. Such damages were estimated at \$2-5M for 2003, with an annual probability of 1.5%, and thus an average yearly damage of \$50-100,000.

1. INTRODUCTION

1.1. GENERAL DESCRIPTION OF THE PROJECT

The purpose of the LRBMS project is to set the ground for improved, more efficient and sustainable basin management at the Litani river basin through provision of technical support to the Litani River Authority and implementation of limited small scale infrastructure activities.

The project is composed of the following four components:

- 1: Building Capacity of the Litani River Authority (LRA) towards Integrated River Basin Management
- 2: Water Monitoring of the Upper Litani River
- 3: Integrated Irrigation Management
  - 3a: Participatory Agriculture Extension Program (PAEP)
  - 3b: Machghara Plain Irrigation Plan
- 4: Risk Management
  - 4a: Qaraoun Dam Monitoring System
  - 4b: Litani River Flood Management Model

1.2. REPORT / STUDY OBJECTIVES

The objective of this report is to develop a flood management plan for the Upper Litani River, that is to:

i. Define flooding events, in terms of duration, extent, damages, and produce mapping of floodable and risk areas for different magnitudes of floods.

ii. Identify structures and urban development and agricultural practices negatively impacting floods and their impacts.

iii. Define structures and river management works that will decrease/mitigate the impact of floods.

iv. Prepare recommendations to promote urban development and agricultural practices that mitigate flooding in the Litani river basin.

Most of the report findings, notably the definition of risk areas and of mitigation works, is based on the use of a flood model for the Upper Litani River, that is a mathematical flood model which was developed through:

- A topographical survey to collect river geometry;
- A field survey to collect 2003 maximum flood levels from witnesses and pictures;

- A calibration process whereby the flood model parameters are adjusted so that the model flood levels (for 2003 discharges) are close (+/- 30 cm) to the witnessed flood levels.

The flood model can then be used to represent other floods than 2003, either smaller and thus more likely to happen, or larger and thus less likely to occur but more likely to cause damage.

1.3. PROJECT AREA

The area concerned by this study is situated in the upper and mid catchments of the Litani River.

The upper sub-catchment covers approximately half of the basin (50%), having a considerable width (up to 30 km), and hosting the major springs yielding in the basin. The middle sub-catchment covers 20% of the basin and imbeds the Quaroun Lake. Slope gradient shows a moderate increase from upper sub-catchment to middle sub-catchment.

Its total area is provided in figure 1.1 and includes the following villages and towns:

Haouch er Rafqa, Temnine el Tahta, Rayak, Haouch Hala, Tell Amara, Dalhamieh, Bar Elias, El Marj, El Establ, Haouch el Harime, Ghazze, Mansoura, Tell Znoub, Joub Jannine...

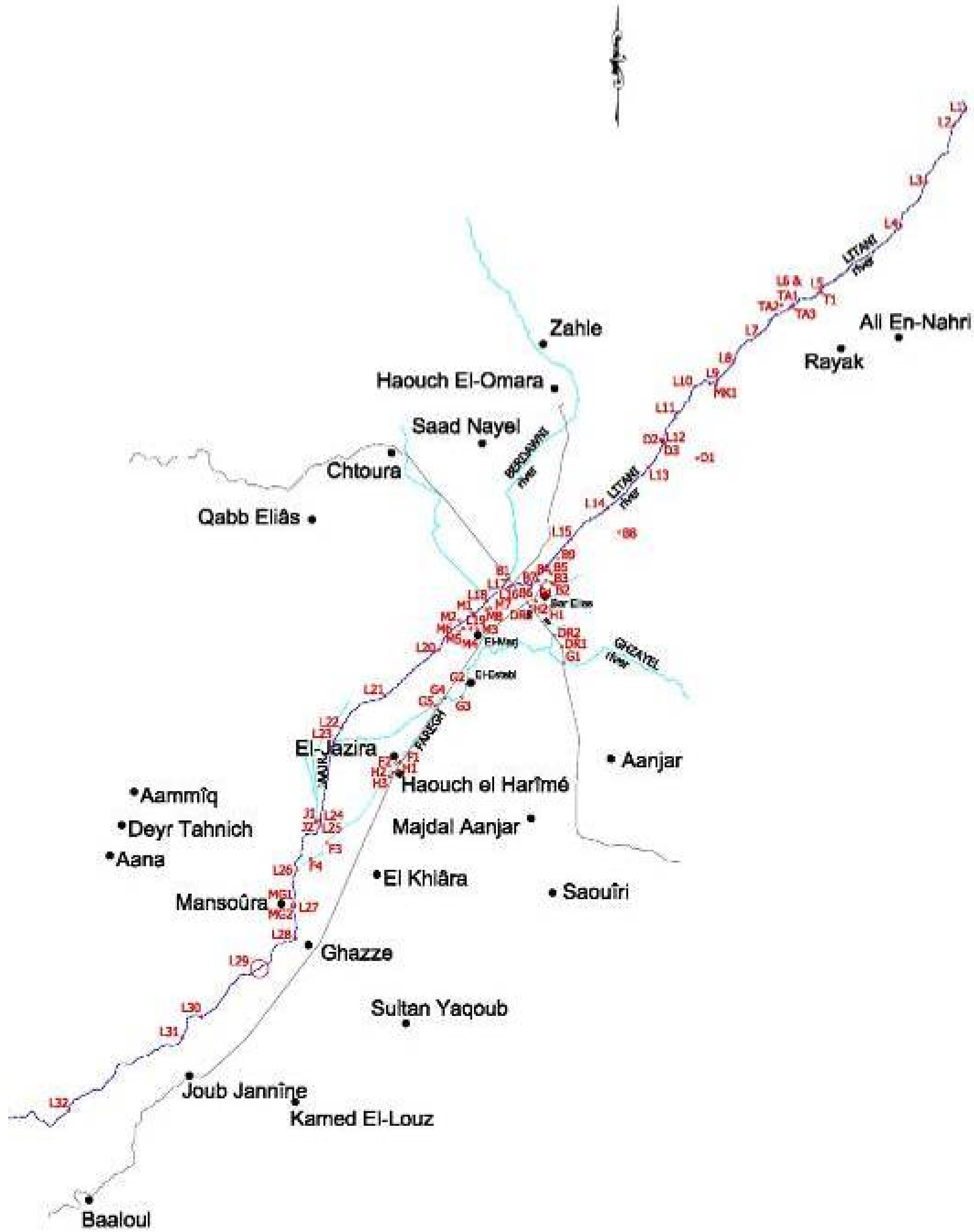

Figure 1.1: Illustration of the Assessed Area

2. FLOODS AND FLOOD MANAGEMENT PRINCIPLES

2.1. FLOODS AND IMPACTS

Storms and floods are an integral part of ecosystem dynamics and have both positive and negative effects on human well-being. Flooding is part of the dynamic nature of healthy rivers and ecosystems. The Bekaa Valley was shaped by its rivers and their occasional floods, all of which helped produce the region's rich soils, agricultural lands, and wildlife habitat. High flows and flood waters are needed to cleanse channels of accumulated debris, build stream banks, deposit nutrients in the floodplains, recharge aquifers and sustain riparian habitat.

But storms and floods also cause direct and indirect damage to the economic and social sectors such as infrastructure, agriculture, industry, and human settlements. With population growth and economic development, more and more infrastructures and human activities settle or take place in floodplains and thus get impacted by floods. Damages due to floods 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 following table illustrates, for each type of structure or activity the direct and indirect damages.

Table 2.1: Direct and Indirect Damage to Different Structures

Types of damage	Direct	Indirect
Residential houses	Destruction or degradation	Alternative housing during reconstruction/repair Decrease in house value
Factories and private sector facilities	Destruction or degradation	Interruption of production, loss of clients, loss of jobs, bankrupcy
Farms	Destruction or degradation of crops	Decrease in land value Bankrupcy, loss of jobs
Public infrastructure (hospitals, schools, administrative buildings, etc.)	Destruction or degradation	Service interruption
Road infrastructure	Destruction or degradation of roads and structures (e.g. bridges)	Road or bridge restriction or closure, increased travel times for users
Other transport infrastructure (ports, airports, railways, canals, etc.)	Destruction or degradation	Transport restriction or closure, increased travel times for users
Public services (water, electricity)	Destruction or degradation of infrastructure (networks, plants, etc.)	Service interruption
Tourist infrastructure (hotels, restaurants, campings, etc.) & historic locations/buildings	Destruction or degradation	Decrease in tourism
Natural environment (rivers, wetlands, forests)	Destruction or degradation	Pollution

Floods (notably flash floods) can also claim lives of human beings, even if such occurrences have not been reported so far regarding floods of the Litani River.

2.2. PRINCIPLES OF FLOOD MANAGEMENT

The United Nations and Economic Commission for Europe Sustainable Flood Prevention Guidelines (UN/ECE 2000) outline seven basic principles and approaches:

- Flood events are a part of nature.
- Human interference into the processes of nature has increased the threat of flooding.
- Flood prevention should cover the entire catchment area.
- Structural measures will remain important elements of flood prevention and protection, especially for protecting human health and safety, and valuable goods and property.
- Everyone who may suffer from the consequences of flood events should also take precautions on their own.
- Human uses of floodplain should be adapted to the existing hazards.
- In flood-prone areas, preventive measures should be taken to reduce the possible adverse effects on aquatic and terrestrial ecosystems.

The UN/ECE guidelines focus on recommendations for water retention areas, land use, zoning and risk assessment, structural measures and their impact, and early warning and forecast systems. Public awareness, education, and training comprise another important element of preventive strategies.

2.3. FLOOD MANAGEMENT APPROACHES

Historically, responses to reduce the negative impacts of storms and floods have emphasized physical structures/measures (dams/reservoirs, embankments, channel widening/recalibration, drainage, etc) over natural environment and social institutions (maintenance and enhancement of environmental features and social institutions that inform and coordinate behavior changes to reduce losses).

In many cases, such efforts have been implemented without assessing their possible long-term effects on ecosystems. Such measures often create a false sense of security and encourage people to live in floodplains and thus incur flood risks.

Nature itself provides its own type of flood reduction systems. The open space of floodplains adjacent to rivers and streams helps store and slowly release floodwaters, thus reducing flood flow peaks and their subsequent impacts during small and frequent flood events. Wetland areas act as giant sponges, soaking up floodwaters in addition to filtering and adding to groundwater supplies. Healthy forests can also slow runoff from mountains and hillsides The preponderance of evidence indicates that, in most situations, more emphasis needs to be given to the natural environment and nonstructural measures and less to structural measures.

Moreover the design of flood management/mitigation approaches is always a comparison between the cost of flood structures/systems and the cost of potential damage (product of damages due to a flood by the probability that it will occur).

Finally there is a myth of flood control. Absolute protection does not exist: whatever the flood management approaches, there may always be a larger/stronger flood that will cause extensive damage.

This is true as with all kinds of natural disasters, even when probability is low. Smart urban planning and risk management can only reduce/mitigate flood impacts, sometimes significantly, but cannot eliminate them.

The table below shows the advantages and disadvantages for each type of flood management approach.

Table 2.2: Advantages and Disadvantages of Flood Management Approaches

Type of flood management	Advantages	Disadvantages
Embankment	Simple to design Protection of areas behind up to design flood	Cost Increased damage for larger floods than design Increased downstream flows Difficult drainage of lands behind at end of flood
River bed recalibration	Simple to design Increases flow capacity Lowers flow levels	Cost Need for maintenance River bed stability issues Increased downstream flows
Dams	Protection of downstream areas	Cost Need for operation and maintenance Increased damage for larger floods than design
Agricultural drainage	Reduces crop damage	Increased downstream flows
Wetlands	Simple to design No maintenance Low cost	Requires land
Urban planning	Mitigates damage to urban areas and sensitive infrastructure	Requires planning and enforcement
Early warning systems	Low cost Mostly useful to save lives (e.g. flash floods)	Difficult to implement Requires constant monitoring, planning & enforcement

3. INTRODUCTION TO FLOOD MODELS

3.1. DEFINITION OF A FLOOD

A flood is an overflow of an expanse of water that submerges land. The EU Floods directive defines a flood as a temporary covering by water of land not normally covered by water. In the sense of "flowing water", the word may also be applied to the inflow of the tide. Flooding may result from the volume of water within a body of water, such as a river or lake, which overflows or breaks levees, with the result that some of the water escapes its usual boundaries.

While the size of a lake or other body of water will vary with seasonal changes in precipitation and snow melt, it is not a significant flood unless such escapes of water endanger land areas used by man like a village, city or other inhabited area.

Floods can also occur in rivers, when flow exceeds the capacity of the river channel, particularly at bends or meanders. Floods often cause damage to homes and businesses if they are placed in natural flood plains of rivers. While flood damage can be virtually eliminated by moving away from rivers and other bodies of water, since time out of mind, people have lived and worked by the water to seek sustenance and capitalize on the gains of cheap and easy travel and commerce by being near water. That humans continue to inhabit areas threatened by flood damage is evidence that the perceived value of living near the water exceeds the cost of repeated periodic flooding.

3.2. PURPOSE OF A FLOOD MODEL

Preventing and/or mitigating flood damage to human, lives, constructions and activities due to flooding is commonly done through:

- An assessment of past flood events, based on an extensive field survey, which involves visual inspections of structures and unrepaired damage, identification of possible high water marks, riverbed erosions and other hydro-morphological signs. The interview of witnesses is also essential to inform the extent, duration, and impact of the floods, even if such accounts have to be cross-referenced. The field survey allows to identify properly all features impacting flows, both natural (meanders, riverbed changes, and artificial (bridges and other structures or obstructions, embankments, etc.) and their level of impact.
- A topographic survey (defined during the field survey) that provides essential hydraulic data such as river cross-sections, opening and sections of bridges, crests of riverbanks, weirs and embankments, etc.
- A hydrological study based on available data from gauging stations such as flood discharges and water levels.
- The use of a flood model, which allows to:

- First properly describe past (known) flood events, so as to better understand these (through the mapping and floodable areas, the definition of high risk buildings and areas, the identification of bottlenecks such as bridges, etc.)
- Then extrapolate to other types of floods, either larger or simply different, to assess their potential impact on structures, constructions and human activities at large;
- Also simulate flood protection or mitigation measures (channel improvements, construction, modification or replacement of structures such as bridges and embankments, construction of reservoirs, etc.) and to assess their influence on flood impacts and potential damage.
- Finally define integrated flood protection plans that combine different activites (from urban planning
- Also simulate flood protection or mitigation measures (channel improvements, construction, modification or replacement of structures such as bridges and embankments, construction of reservoirs, etc.) and assess and compare their influence on flood impacts and potential damage;
- Finally define integrated flood protection plans that involve and combine the most effective, sustainable and cost efficient measures in terms of structures as well as practices and activities (from more responsible urban planning to better agricultural practices).

The various types of flood models are reviewed hereafter.

3.3. TYPES OF FLOOD MODELS

3.3.1 SLOPE-AREA METHODS

The simplest "model" available for computing flow levels and velocities is the use of empirical formulas such as Chezy and Manning equations. These formulas (slope-area methods) use simple relationships between discharge, slope, and cross-section geometry and roughness. They are only suitable for computing water conditions for a single discharge value (steady flows) under uniform flow conditions (constant cross-section, roughness and slopes, such as irrigation or other man-made canals). They are often inappropriate for natural river flows.

3.3.2 ONE-DIMENSIONAL STEADY FLOW MODELS

Steady flow hydraulic models, as the name implies, are confined to applications in situations of steady or gradually varied flow. These types of model are often easy to use and are based on simple hydraulic calculations using the principle of conservation of energy to compute flood levels. The hydraulic equation includes only the terms for "convective" acceleration (due to momentum), potential energy, friction losses and singular losses.

Steady flow models are restricted to modeling river and floodplain systems under the following conditions:

- The flood hydrograph is generally of long duration with a slow rate of rise such that attenuation effects are minor and backwater effects have the most significant influence on flood levels;
- The slope of the river reach is less than 1 in 10 (so that the flow is fluvial and computation proceeds upwards long the channel based on a set downstream condition);

- There is no significantly large floodplain which could significantly attenuate the flood hydrograph. If storage attenuation effects are significant, it may be necessary to first compute the attenuated flow (by runoff routing perhaps) before proceeding with the hydraulic model.

The most common of the steady flow one-dimensional models is HECRAS (US-Army Corps of Engineers). Steady flow models are normally one-dimensional, although models such as HECRAS have some quasi-two-dimensional capabilities with 'split-flow' option and can thus be used in a fairly creative manner to compute flood levels in reasonably complex river networks.

Field data requirements for this type of models are river cross-sections and dimensions of special structures (bridges, culverts, weirs, etc.) likely to cause backwater effects. The main model parameters are the roughness coefficients, and flow contraction/expansion coefficients (for friction and singular losses).

Applications of one-dimensional flow models are common and are generally quite appropriate for most river flood studies. Quite often, it is the significance of flood attenuation rather than limitations of one-dimensional flow assumptions that inhibits the wider application of steady one-dimensional flow models.

3.3.3 ONE-DIMENSIONAL UNSTEADY FLOW MODELS

Unsteady flow models are more rigorous, taking into consideration the significance of hydrograph and storage characteristics on flood attenuation. Briefly, the hydraulic equation includes the local acceleration term (time variation of velocity) along with the terms of the steady equation: convective acceleration (due to momentum), potential energy, friction losses and singular losses.

In most natural rivers under normal flood conditions, the local acceleration term is usually an order of magnitude lower than the convective acceleration term. This has led to many models discounting the local acceleration from the equation to improve model stability by relaxing the maximum space and time increment requirements. Models such as HEC-RAS (unsteady) or MIKE-11, fall into this group of unsteady flow models.

In a situation where the shape of the flood hydrograph is 'peaky', that is when flow conditions are rapidly varied (such as in a failure event of a dam or embankment), the additional local acceleration term becomes significant. Models such as DAMBRK and MIKE-11 are equipped to model such situations.

Field data requirements for this type of model are similar to those for steady models.

3.3.4 QUASI TWO-DIMENSIONAL FLOW MODELS

Even in gradually varied flow conditions, the occurrence of flood breakouts and floodplain storage in a channel/floodplain flow situation can have a significant influence on the attenuation/reduction of flow in the channel. This has led to the development of quasi two-dimensional models, aimed at a 'compromised' modeling structure of a fairly rigorous hydraulic computation in the primary flow direction (i.e. along the channel) and some accounting for lateral flow characteristics and floodplain storage. The lateral connections between cells/nodes are often by simple weir or channel flow formulas.

There is a further type of quasi two-dimensional model for water quality modeling in rivers. These models are 'two-dimensional' in the vertical axis to model such stratified flow phenomena as salt intrusion. Such models include MIKE-12, CARIMA, SOBEK and TIDEWAY-2DV.

Data requirements for this type of model are higher than one-D models: additional survey data will be needed on the ground profile at the lateral flow connections and dimensions of the side channels.

3.3.5 TWO- AND THREE-DIMENSIONAL FLOW MODELS

Full two and three-dimensional models solve the equation of motion in all directions of flow. They are by far the most rigorous but also require the most ground information to compute flow characteristics reliably. Owing to the rigorous nature of such models, computation can be time consuming and require high speed computers.

Two-dimensional models have been used to study localized hydraulic effects such as occur in the vicinity of bridge crossings or to study flows and tide effects in large floodplains or estuarie.

Three-dimensional models are not often applied to river and floodplain studies and are mainly used in ocean and estuary studies which involve water quality modeling investigations where variation of water pollutants is dependent on flow distribution (x and y directions) and density (z direction).

3.4. CHOICE OF SOFTWARE

In summary, the various models are:

Table 3.1: Various Software Models

Approaches	Models	Description
1D hydrodynamic	HEC-RAS, ISIS, MIKE 11, SOBEK, Vietnamese models: VRSAP, HYDROGIS, KOD,…	• 1D St-Venant equation for series of XS of main channel and the overbank perpendicular to the main channel. • Spatial interpolation of water level in the 1D computational grid points into 2D inundation extent map
2D hydrodynamic	TELEMAC-2D, MIKE 21, DELFT-FLS, DELFT 3D	• full St-Venant shallow water equations • Discretization of floodplain and main channel using structure grids (finite difference method), or unstructured grids (finite volume and finite element methods) using a variety of geometries, but typically triangles or quadrilaterals.
Coupled 1D-2D hydrodynamic	MIKE FLOOD, SOBEK OVERLAND FLOW	• floodplains are solved using 2D hydrodynamic approach • Main channels are solved using 1D hydrodynamic approach -using special links to describe the connection between the main channels and floodplains.

One dimensional models are deemed sufficient here, and considering both the extent and types of floods in the Litani river basin, as well as LRA's current modeling capacity.

HEC-RAS is strongly recommended as the model to be used. HEC-RAS is widely used world-wide and notably in the US where it is the model for 90% of flood studies.

HEC-RAS exist with both steady and unsteady versions, is freely available on Internet, and is maintained and regularly updated by the Hydrologic Engineering Center of the US Army Corps of Engineers.

3.5. HEC-RAS

HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities.

The HEC-RAS system will ultimately contain three one-dimensional hydraulic analysis components for:

- Ateady flow water surface profile computations;
- Unsteady flow simulation;
- Movable boundary sediment transport computations.

A key element is that all three components will use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the three hydraulic analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed. The current version of HEC-RAS supports Steady and Unsteady flow water surface profile calculations.

The Step by Step procedure for the creation of the model for Litani river and tributaries on HEC-RAS is presented in Appendix A.

4. FLOOD DIAGNOSTIC

4.1. REPRESENTATIVE FLOODS

4.1.1. PHYSICAL DESCRIPTION OF THE FLOOD EVENTS

The Litani River Basin suffers from two types of flooding:

- Flooding from the Litani River and Major tributaries (Ghzayel, Berdawni, Qabb Elias); this is due to natural floodplain characteristics, compounded by lack of riverbed maintenance, existence of obstructions such as insufficient road bridges and irrigation weirs or other illegal constructions in the riverbed, dumping of all type of solid and hazardous waste, etc.
- Seasonal flooding from minor channels (Howayzek, Oqeyber, Faregh) due mostly to lack of agricultural drainage; this is due to the impermeability of soils (mostly clayey), and poor maintenance and disappearance of many drainage ditches in farm lands.

4.1.2. HISTORICAL FLOODS

Most of the Litani River Basin occupies Central and South Bekaa Valley. The valley is sandwiched between Mount Lebanon to the west and the Anti-Lebanon mountain to the east. Winter precipitations fall heavily on both ranges and engender heavy flows which then spread across the valley whose bottom is almost flat and with a low north-south slope (on average 2.5 m/km). Floods are thus common occurrences but with the growth of human activities (farming and urban areas), their impacts are increasing.

According to witnesses' accounts and to information collected during the field survey, it was deducted that from 1962 to present, the flood of February 2003 is one of the two highest floods in addition to possibly 1968. In other years like 1992 people talk about smaller floods. The fact that limited recollection exists regarding other large historic floods can be understood from a combination of factors:

- Past floods had less impacts as people were more informed about floods and floodable areas and were either avoiding such areas (in terms of constructions and farming) or else coping with the events; urban growth has, as often, pushed people to occupy "riskier" areas and thus increased the related impacts;
- Lebanon has had its share of traumatic events in the past 35 years and floods are not necessarily the most dramatic ones, thus preventing good recollection; population changes and moves make it also difficult to find long-term senior residents with a good memory of past floods;
- Clayey soils make also for regular flooding of the valley along the Litani river and it is thus difficult to distinguish between lack of proper agricultural drainage and actual river flooding (as discussed before).

The flood of 2003 was selected to represent high flow conditions and to calibrate the model in accordance to its data since it is a recent flood and hence data collection is easier and since flow records for the Litani and its tributaries are available for this flood.

Based on the qualitative information collected on the field, it is also reasonable to assume that 2003 was a relatively rare event, with a period of return of about 50 years (otherwise said, such a flood has a 1/50=2% chance of occurring in any one year).

4.1.3. SEASONAL FLOODS

During the carrying out of the field survey, two seasonal floods were examined. The first one appeared in December 2009 and the second one in January 2010. The most affected regions by the floods are:

- The region situated upstream the village of Bar Elias along Howayzec tributary.
- The region situated upstream the Bridge on Berdawni River on Damascus Road.
- The region around the Mansoura Bridge on the Litani River.
- The region of the village of Haouch El Harime situated along the Faregh tributary.

In addition to those four major regions several other cultivated terrains were partially flooded because of lack or improper agricultural drainage.

4.1.4. FLOOD OF 2003

The heavy rains in February 2003 pounded the Lebanese territory and caused great losses. The February 2003 flood is one of the biggest historical floods ever encountered in the Litani. It occurred after approximately 10 consecutive days of heavy rainfall in combination with snowmelt. 36 mm of rainfall were recorded during one day at the station of Haoush el Omara (Zahle) in the Bekaa Valley (in reference to Assafir newspaper 22/2/2003).

The area in the valley affected by flooding is reported to be more than 400 km2, extending from north of Damascus road near the village of El Delhamieh to Job Jannine. The circulation was partially or completely stopped in more than three locations on Damascus road.

In the Bekaa valley, the meteorological station of Haoush el Omara has recorded 772.4 mm of rainfall since winter has started whereas it was only 451.1 mm in the same period of previous year. It must be noted that the average calculated over 30 years is 447 mm and that the recorded rainfall is the maximum since 1969 (Meteorological department, International Airport of Beirut).

The Qaraoun Dam has a maximum capacity of 220 MCM and regulates the downstream discharge. Flooding during the first part of February 2003 caused the Litany River Authority LRA to open the security outlets starting from February 16th (in reference to Al-Mustaqbal newspaper 15/2/2003) causing damages in the region located downstream the dam.

The flood caused big damages, 80% of the cultivated area in the Beqaa valley have been totally inundated (in reference to L'Orient le Jour newspaper 20/2/2003). The losses are huge and the most affected regions are: Haouch el Harime, El Khiara, Ghazze, El Mansoura and El Nasriyeh (in reference to Assafir newspaper 2/2003). The West Bekaa was transformed to a series of isolated islands only accessed by the mean of boats or heavy trucks (in reference to Al Anwar newspaper 22/2/2003).

4.1.5. CONCLUSION ON THE FLOOD EVENTS

The Flood of 2003 was the result of heavy rains during several short periods of time in addition to rainfall on snow producing snowmelt which produced a large water runoff.

The floods in the Litani River basin area can be divided into two categories:

- Flooding from the Litani River and Major tributaries (Ghzayel, Berdawni, Qabb Elias)
- Flooding from minor tributaries (Howayzek, Oqeyber, Faregh, Chtaura) and from lack of drainage Channels

The main causes of the flooding from Litani River and major tributaries are:

- Natural floodplain characteristics due to high runoff generated by heavy rainfalls on both mountain ranges and very low slope of the Bekaa valley leading to limited riverbed capacity;
- Natural weather regime with long dry season where flow is minimal thus generating sedimentation, island formation and instability of river banks.
- Growing of vegetation in the river bed (weeds, trees, marshes, bamboos…) which is caused by the presence of nutrients in the river coming from waste water and fertilizers.
- Dumping along the river of all type of solid and hazardous waste (wheels, dead animals, furniture, plastic bottles, chemicals…).
- Construction of embankment weirs for irrigation by pumping creating obstacles inside the river bed or lowering river sides to install pumps or to connect with irrigation channels.
- Existence of illegal buildings inside the River bed.
- Existence of numerous road bridges with insufficient hydraulic openings.

The main causes of the (seasonal) flooding from minor tributaries and from insufficient drainage:

- Poor maintenance and disappearance of many drainage ditches from farm lands, for example by ploughing all the way to the plot border (modern farmers tend to worldwide disregard old traditions and want to maximize short-term benefits).
- Lack of urban drainage networks.
- Very low slopes of the Bekaa valley and Litani riverbed leading to slow water flow and to high water levels.
- Growing of vegetation in the river bed (weeds, trees, marshes, bamboos…).
- Impermeability of soil in the Bekaa region (clay and hydromorphic texture) which causes low infiltration of running water.
- Dumping along the tributaries of all type of solid and hazardous waste (wheels, dead animals, furniture, plastic bottles, chemicals…).
- Heightening river sides by the creation of levees which blocks the water coming from small tributaries (Case of Chtaura tributary which floods into other tributaries which are blocked at their intersection with the Litani downstream El Marj Bridge) toward the Litani and other major tributaries which causes the flooding of the plain.
- Existence of bridges or culverts with limited section.

It must be made clear here that there is a difference between:

- River flooding which has significant impacts and is a public issue (river bed is public property) to be addressed by Central Government and/or local authorities(municipalities);
- Lack of proper agricultural drainage which at plot level is a private problem (farmer managing own private land) and thus not governmental responsibility; at the level of larger areas, the lack of proper agricultural drainage could be handled by local authorities but one needs to keep in mind that this should be done in collaboration with farmers and possibly with their contribution (why would some farmers benefit privately from public help as opposed to other water users somewhere else who have similar or different water issues?)

4.2. HYDROLOGY

4.2.1. INTRODUCTION

The upper Litani River Basin occupies the Central and South Bekaa Valley. The valley is sandwiched between Mount Lebanon to the west and the Anti-Lebanon range to the east. Flow of the Litani River follows the rainfall patterns, with a rainy winter season (November-April) and a dry summer season (May-October). Winter precipitations fall heavily on both mountain ranges and engender heavy flows which then spread across the valley whose bottom is almost flat and with a low north-south slope (on average 2.5 m/km). Floods are thus common occurrences but with the growth of human activities (farming and urban areas), their impacts are increasing.

The following sections show the principles and results of the flood analysis performed on the available data to assess the probabilities and magnitudes of large floods on the Litani River.

4.2.2. ANALYSIS PRINCIPLES

4.2.2.1. INTRODUCTION

On a river equipped with gauging stations like the Litani River is, statistical analysis of past flow records allows to estimate the probability and magnitude of large floods. Such analysis cannot predict when a large flood will occur, but it can predict what is the probability of a given flood level to be reached or passed.

Such estimates are essential for engineers, planners and decision-makers to guide investment and management decisions for building and operating all types of infrastructure. As an example, the design of dams and water systems relies on average river flows to ensure proper sizing, while the design of protections structures such as spillways and embankments relies on the assessment of extreme events (floods).

Another example is that proper urban planning in river valleys should consider the extent and spread of floods to mitigate flood damage by:

- Properly positioning sensitive infrastructure such as electrical transformers;
- Setting and enforcing building standards that reduce potential flood damage;
- Preventing river obstructions such as insufficient bridges or ill-located roads which would worsen floods;
- Informing residents of simple measures that reduce flood impacts; etc

As a last comment here, flood mitigation (and not protection) can only prevent or mitigate damage from common and rare floods, but greater (and thus rarer/more exceptional) floods can always occur (even if the probability is very small), and absolute protection does not exist!

4.2.2.2. CHOICE OF METHOD

The hydrologic analysis of floods of the Litani River could proceed at two different levels:

- A thorough hydrologic modeling: this would use a specific rain-runoff model, be based on a detailed examination of the hydrographs at the time of past floods, and would attempt to understand and stimulate the relationship between rain episodes and flood events; experience has shown that such approaches are scientifically interesting but in practice difficult to apply as they require:
  - Specific hydrologic models and expertise;
  - Extensive, detailed (hourly if possible), and accurate data (regarding rainfall, land use, actual river water levels sand entire hydrographs); and
  - Extensive calibration to adjust the model so that real rainfalls translate into simulated hydrographs that are close to the real/recorded ones (this is to ensure that the model properly represents reality).

Such approaches are often conducted for the design of storm runoff networks in urban areas, so as to properly size pipes and conduits. They are quite suitable for the task as they translate heavy sudden storms over small urban areas (with high runoff coefficients) quite faithfully into surge hydrographs and flows. For larger (and consequently mostly rural) watersheds, experience has shown that such models have difficulties representing the complexity of:

- Progressive soil saturation (due to successive rains which gradually increase runoff coefficients);
- Rain-runoff responses over different sub-areas (in terms of soil cover, land use, cropping patterns and stage, slopes, etc.);
- Aggregation of floods generated over said sub-areas (notably as in the case of the Litani watershed when steep hillsides border a flat and wide valley); and
- Flood routing over wetlands and large flood valleys.

These approaches are also very time- and resource-consuming and can only be justified to protect specific sensitive assets or large urban centers.

- A hydrologic analysis: the approach is based on the concept of peak flood frequency, that is that it is statically possible to relate peak flood discharges with probable frequencies of occurrence; the process requires to collect annual peak flood discharge for a minimum of 20 years and:
  - Use a statistical method (e.g. Gumbel formula) to assess peak discharges for given periods of return; and
  - Create (if needed) flood hydrographs for periods of return by simply extrapolating recorded ones.

This last approach has been adopted here, based on the lack of detailed rainfall data in Lebanon (daily data at best), the lack of detailed hydrographs for various flood events, the uncertain accuracy of existing records and the complexities mentioned above for hydrologic modeling.

Moreover it is clear from historical evidence and the 2003 flood that large floods in the Litani River are not the result of one single rain event, but rather the product of very rainy winters where successive rains saturate the clayey soils and the none additional rainy event (even if not exceptional) generate exceptional flows. So the approach of generating a flood hydrograph through a rain-runoff model (which assumes that an exceptional flood is caused by an exceptional rain event) is not adapted to the Litani context (even if detailed rainfall data was available).

4.2.2.3. ASSUMPTIONS FOR STATISTICAL ANALYSIS

Such an approach relies on two key assumptions that are:

- Hydrologic stationary: this is the idea that even if there is seasonal and annual variability in rainfalls and discharges, long-term averages and distribution frequencies are constant, i.e. statistically the future will be indistinguishable from the past (in terms of averages, standard deviations, etc., i.e. probabilities remain the same, see comment below regarding climate change); and
- Annual independence: rainfall data is a random series and the resulting floods are independent from each other (true from year to year, not necessarily within one year or shorter periods of time, as an initial flood will saturate soils and much accentuate the magnitude and impact of a immediately succeeding but equivalent event).

These assumptions allow then to assign return periods to particular flood peak discharges. The definition is that if a specific discharge has a n% chance of occurring (or being exceeded) any given year, then that specific discharge has 1/n-year period of return. For example a 100-year flood peak discharge has a 1% chance of happening any given year. This does not mean (as is often misunderstood) that there should be an interval of 100 years between two such events. In fact the probability of having two 100-year floods within 10 years is close to 10%.

4.2.2.4. NOTE REGARDING STATIONARITY, CLIMATE CHANGE AND CYCLES

It is a proven fact that on a geologic scale (large periods of time, thousand years and more) climate changes do occur (e.g. North Africa experienced much more rainfall during the Roman Empire than today). Such changes are gradual and unfold over centuries or so. So even if hydrologic stationary is not real, one can assume that climate change is reasonably slow and that the statistical approach based on a few dozen years of data is quite valid (on a human/historical scale) to statistically envision events in the near future (within half a century or so).

Human-induced climate change is on the other hand a possibly faster phenomenon that is already impacting precipitations worldwide. But for lack of data, it remains difficult to predict how rainfall patterns and the resulting floods will evolve in different parts of the world. It is not considered here.

Some hydrologists and meteorologists try to identify cycles in the pattern of rainfalls. Cyclical patterns have also been mentioned when discussing weather events such as El Nino, possibly linked to solar activity. So far no clear correlation (if it exists) has been proven, and it would be erroneous to try to describe floods as cyclical events whose “regular” occurrence can be predicted.

4.2.2.5. GUMBEL FORMULA AND PROCESS

The Gumbel formula is the more traditionally used (under various forms) to correlate peak events (floods but also droughts, extreme rainfalls etc.) to periods of return. A simplified form of this equation (standard distribution) is the most favored:

$$F(x) = 1 - \exp(-\exp(x))$$

The process is rather straightforward:

- Annual peak discharges are identified and ranked (at least 20 years of daily data is needed);
- Recurrence intervals r=(i/n+1) and double logarithmic values (-ln(-ln(r)) are calculated for each of these n values; and
- A linear regression Ax+B is then estimated (by using the "least squares" method).

For a given period of return T, and an annual probability of occurrence p=1/T, then the corresponding peak flood discharge would be Q(T) = A x [-ln(-ln(1-1/T))] +B

4.2.3. ANALYSIS AND RESULTS

4.2.3.1. AVAILABLE DATA AND REVIEW

Several gaging stations have been operated in the Litani River Basin over the years. Due to the civil war disruption, data series are pre-1975 or post 1995:

Table 4.1: Gaging Stations in the Litani River Basin

Station	Alt.	Km2	Available	Comments
Damascus Road	866	880	1952-71	20 years available but data series is obviously inaccurate (weak discharges and annual volumes as compared to other stations)
Mansourah	859	1345	1931-73	42 years partially available but data doubtful (peak discharges are low, probably due to incomplete rating curve not calibrated to floods overflowing river banks)
Joub Janine Bridge	859.7	1433	1998-2009	10 years available
Qaraoun	810	1545	1938-61	23 years available
Qillaya	521	1680	1949-72 & 2004-07	23+4 years available but Data post-64 not usable due to filling of Qaraoun reservoir
Khardale	239	1815	1939-71 & 2002-07	32+4 years available but Data post-64 not usable due to filling of Qaraoun reservoir

The accuracy of above data varies from reasonably good to uncertain to questionable1.

The construction in the early 1960s of Qaraoun Dam (reservoir filling in 1965) effectively segregated (for hydrologic purposes) the upper and lower Litani River Basin: flows from the upper basin only reach the lower river course through occasional releases and during large floods. Discharges recorded in the downstream stations (such as Khardale) no longer reflect the “natural” hydrology of the river basin and cannot thus be used for our statistical purposes.

All the data series were compared in terms of annual runoffs:

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1 The evaluation of river flows is commonly done through stage recording and occasional discharge measurements which allow the establishment of a rating curve correlating water levels and discharges. Using this rating curve allows then to translate continuous stage recording into continuous discharge information. The difficulty for the development and use of such rating curves is the fact that while low stage discharge measurements are easy to perform and common, high stage measurements require more specific equipment, expertise and opportunities (occurrence of a flood). As a consequence, high stage measurements are sometimes lacking. The issue is then that the extrapolation of low flow measurements to higher stage floods commonly ignores the change of behavior in the flow (and thus an inflexion point in the rating curve) when the flood overflows the bank, reaches the underbeam of a bridge, etc. Today high stage discharge measurements are rarely done in Lebanon and with limited accuracy (floating method).

This is obvious at Mansourah where peak discharges for flood events are much too low (50% or more) and annual volumes are at least 30% under-estimated compared to Khardale and Qillaya. For example the peak discharge for the Jan 1940 flood is estimated at 140 m3/s in Qaraoun and only 40 m3/s in Mansourah !!

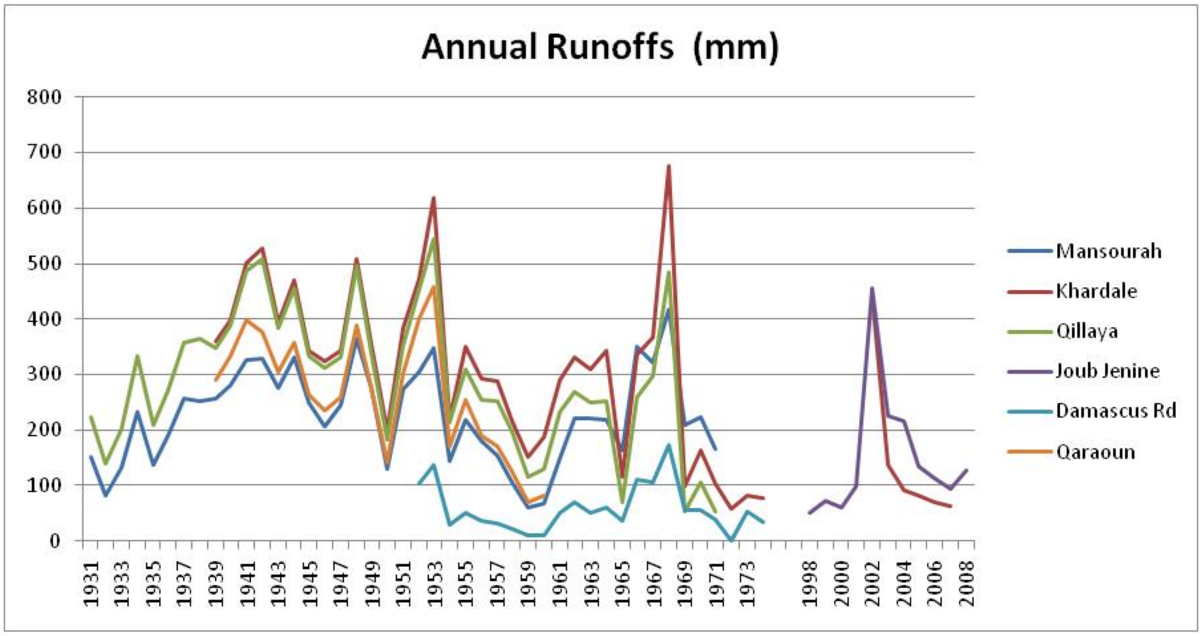


Figure 4.1: Annual Runoffs (mm)

This graph shows that:

- Data from the Damascus Road gaging station is confirmed as untrustworthy;
- Runoffs increase as we proceed downstream from Mansoura-Qaraoun to Qillaya-Khardale. This is due to the narrowing of the valley and increased precipitations on the southern Mount Lebanon (Jabbal el Barouk and Jabbal Niha);
- The Central and South Bekaa experienced a drought from the mid 50s till the mid 60s;
- Historic floods (1942, 1954, 1968, 2003) are usually linked to high annual runoffs (wet years), which means that floods are due to a succession of rainy events saturating the valley soils and not a direct consequence of single and extreme rainy events (intense storms).

4.2.3.2. RESULTS

The longest available series of daily flows is at Khardale from 1938 until 1964 (note these are daily average flows, but flood hydrographs for the Litani river are spread over several days, the difference between daily average and peak is small, 10% or so). Maximum daily discharges were selected (based on hydrological years to ensure one flood per year). And then used for a Gumbel analysis:

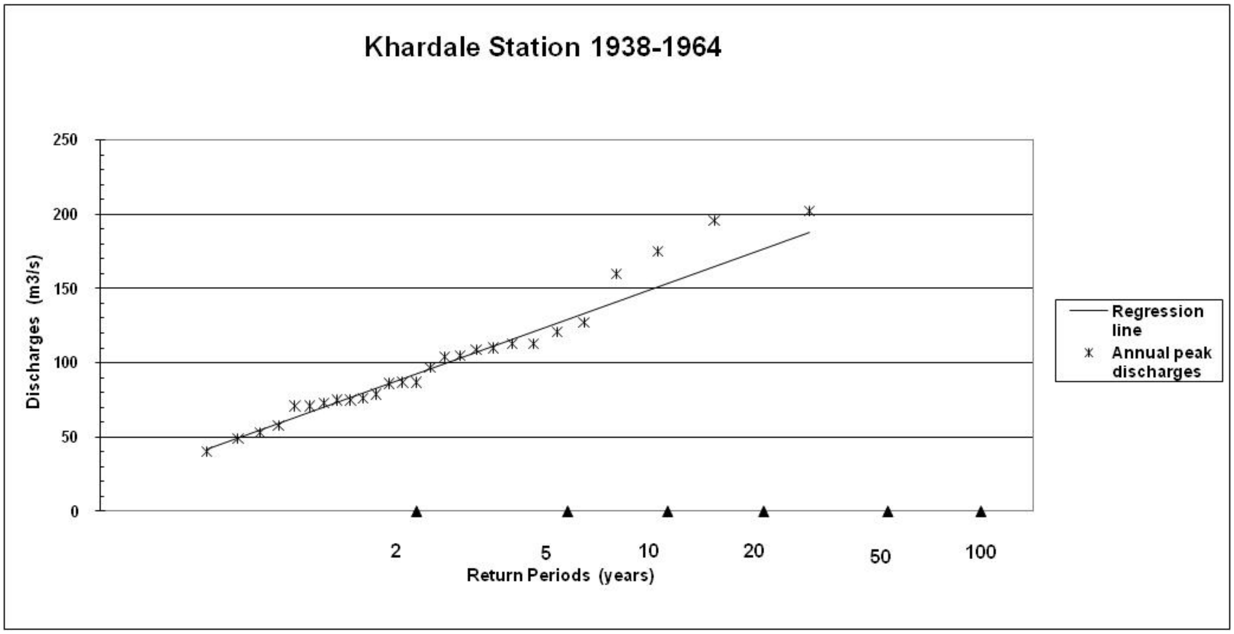


Figure 4.2: Annual Peak Discharge at Khardale Station

Results are as follows:

Table 4.2: Peak Discharge Values at Khardale, Joub Jenine and Qaraoun

Period of return (years)		10	25	50	100
Peak discharge (m3/s)	Khardale (1815 km2)	153	184	206	229
	Joub Jenine (1435 km2)	123	147	165	183
	Qaraoun (1545 km2)	130	156	175	195

These results compare to two available older hydrologic studies carried out on the Litani floods:

- Development Plan for the Litani River Basin –Appendix to volume III, Hydrology, US Bureau of Reclamation, 1954: this analysis was carried out as the basis for the development of water resource exploitation in the Liatni River and led to the construction of Qaraoun Dam; the hydrologic analysis is based on short (20 years) time series since gaging stations started operating in Lebanon in the 30s; peak flood discharges compare favorably to our analysis:

Table 4.3: Peak Discharge Values at Khardale and Qaraoun (1954)

Period of return (years)		10	25	50	100
Peak discharge (m3/s)	Khardale (1815 km2)	170	195	220	235
	Qaraoun (1545 km2)	120	140	165	180

NB. On the other hand, the flood hydrographs defined by the USBR study are much too slim and do not truly represent the volumes that floods can convey in the Litani Valley.

- Analyses carried out in 1999-2002 by Sene, Houghton-Carr & Hachahe give slightly higher values, but within the same range:

Table 4.4: Peak Discharge Values at Khardale and Qaraoun (1999-2002)

Period of return (years)		10	25	50	100
Peak discharge (m3/s)	Khardale (1815 km2)	175	220	240	275
	Qaraoun (1545 km2)	145	180	200	225

4.2.3.3. ADJUSTED RESULTS

The analysis done above, even if it is as best as feasible, still suffers from several short-comings:

- Data series is rather short (less than 30 years);
- Does not include the largest known flood (2003);
- Does not use recent data

In order to correct these, the Khardale time-series was:

- Adjusted to Joub Jenine (through an area ratio);
- Combined with the 1998-2009 data series of daily flows in Joub Jenine.

Results of the Gumbel analysis are as follows:

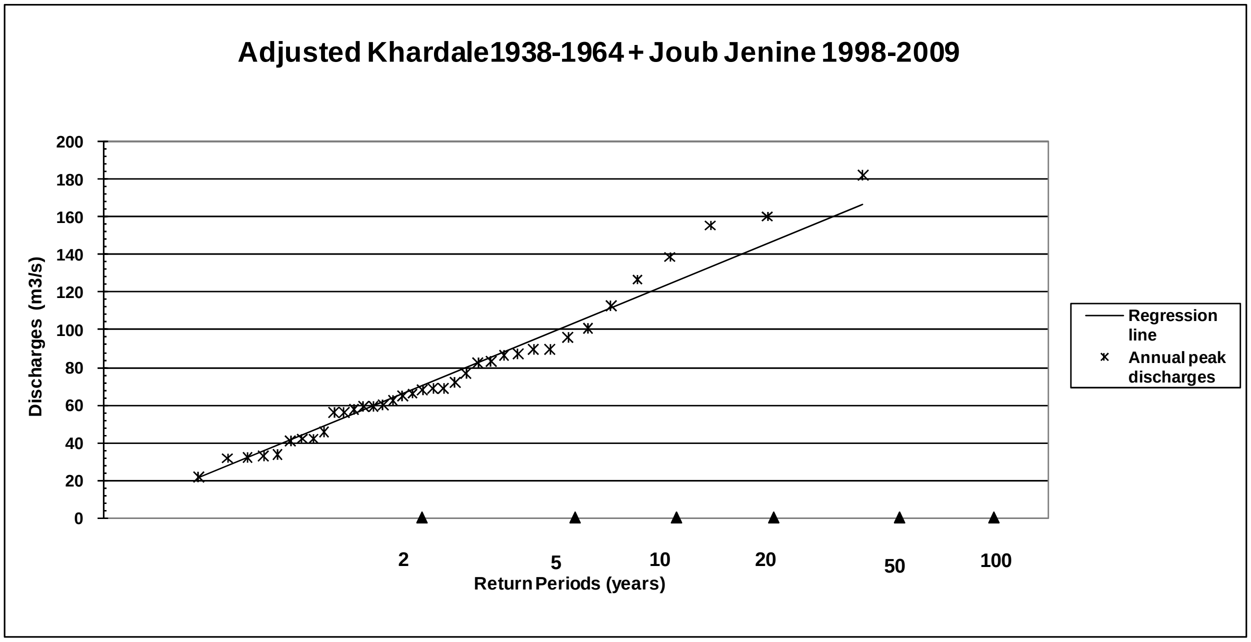


Figure 4.3: Adjusted Annual Peak Discharge at Khardale and Joub Jenine (?)

Table 4.5: Peak Discharge Values at Khardale and Qaraoun (1954)

Period of return (years)		10	25	50	100
Peak discharge (m3/s)	Joub Jenine (1435 km2)	125	155	175	195

The period of return of the 2003 flood is thus estimated to be about 70 years.

4.2.4. CONCLUSION

The peak discharge of the February 2003 flood has been estimated at 182 m3/s in Joub Jenine. This corresponds to a period of return of 70 years. It confirms the findings from the field survey, which are that 2003 was a quite rare event.

The 2003 flood will be used as reference flood to calibrate the flood model, and as a historically representative flood to define and design flood mitigation measures and structures.

Two smaller and less frequent floods will also be considered:

- A quite frequent flood event (period of return 10-year, that is a 1/10=10% chance of happening any year) with 70% of the intensity of 2003;
- A rarer flood event (period of return 25 years, that is a 1/25 = 4% chance of happening any year) with 85% of the intensity of 2003.

5. DEVELOPMENT OF THE FLOOD MODEL

5.1. FIELD SURVEY

Preventing or mitigating flood damage to human, lives, constructions and activities due to flooding is commonly done through:

- An assessment of past flood events, based on an extensive field survey;
- A topographic survey (defined during the field survey) that provides essential hydraulic data such as river cross-sections, opening and sections of bridges crests of riverbanks, weirs and embankments, etc.
- The use of a flood model.

Information of past floods relies usually on three sources of information:

- Hydrologic data (discharges and water levels), as recorded by gauging stations;
- Field survey: so as to get a hydraulic feel for how water flows along the river and through the various structures (bridges, weirs, culverts, etc. it is here critical for proper calibration to understand that some of these structures may have modified, built or rebuilt after the reference flood, with consequences for the flow conditions); and
- Witnesses: residents who witnessed recent floods and can describe its extent, duration, impacts, etc; maximum water levels are usually easy to identify from witnesses and pictures are sometimes available; It is especially interesting to identify senior residents who have been living in the same location for a long time as they can put recent floods in perspective and compare them to older events.

It is important to note why witnesses are essential. First because hydrologic data is not always available or reliable or covering long periods of time. Second because gauging stations at best provide water levels in a few locations and are thus insufficient to define past floods and also properly calibrate a flood model that would cover a long stretch of river.

The validity (or truthfulness) of a flood model heavily depends on its calibration, that is on the process of constructing and adjusting the model so that it can properly represent past known events. It is then legitimate to extrapolate the model to represent events of higher magnitude and expect the results to be reasonably valid.

5.2. CONSTRUCTION AND CALIBRATION

5.2.1 INTRODUCTION

The reliability of the results of a hydraulic model study depends mainly on the applicability of the model to the physical situation, and the quality of the data used to both model the study reach and calibrate the model.

The objective of the calibration process is to match the output of the model with observed data (usually water surface elevations). This process is performed by adjusting one or more parameters, such as Flow and Manning's n, until a satisfactory match of model results with known data is achieved. When a set of known conditions has been approximately matched by the model, one can apply the model to unknown conditions with more confidence that the model output is reasonably representative of the physical processes associated with that event. However, to be confident, the observed data for calibration should be obtained from an event that is near the scale of the events to be modeled.

Observed data includes data recorded at gages along with that obtained from field observations and from interviews with local residents. Recorded discharges, stages, and velocities are valuable for calibration purposes; however, it is rare that sufficient gage data are available for comprehensive calibration. The preponderance of calibration data usually comes from local observations during and after an event. The hydraulic engineer should plan for several days of field work to obtain highwater marks from local residents' observations or following an event that occurs during the study. The best data often come from people who have lived near the stream for many years. They can supply information concerning flood elevations, erosion or deposition tendencies, local channel modifications (when and where), tendencies for debris to obstruct bridge openings, how often the stream gets out of banks, and possible flow transfers between watersheds during floods. As much information as possible should be obtained from local residents for use in the calibration process. While all information is useful, the hydraulic engineer should recall that the further back in time, often the hazier the memory of the individual is for exact flood heights. The exact water level of the flood may not be accurately recalled. The engineer should not expect that model results will match every highwater mark exactly.

5.2.2 CONSTRUCTION PROCESS

The construction of the model is based on the findings of the field survey conducted during the period between November 2009 and January 2010 which enabled to:

- Identify the flood of 2003 as a reference flood that can be used to calibrate the flood model and to collect data and account from witnesses to define this reference flood;
- Define the topographic survey necessary to build the model.

5.2.2.1 REFERENCE FLOOD

The flood of 2003 was selected to calibrate the model because:

- One of the two highest floods in addition to possibly 1968
- Recent flood and hence data collection is easier
- Flow records are available for this flood
- Largest in recollection of long term residents
- The flood caused big damages:

– Thousands of hectares of cultivated areas in the Beqaa valley have been totally inundated

– The West Bekaa was transformed into a series of isolated islands only accessed by the mean of boats or heavy trucks.

5.2.2.2 TOPOGRAPHIC SURVEY

The area covered by the topographic survey is situated in the upper and mid catchments of the Litani River between Haouch er Rafqa and the Qaraoun Lake in the Bekaa. About 150 river cross sections were surveyed along with 40 identified highwater levels from the 2003 flood and the reference level of the gauging stations along the Litani and its tributaries.

The locations of the Cross-Sections are presented on the General Plan View (Appendix B).

A Digital Elevation Model was also developed to provide accurate topography of the central Bekaa and thus provide good support for the mapping of flood risk areas.

5.2.2.3 AVAILABLE WATER LEVELS

As mentioned above, all the gauging stations of the project area situated on the Litani river and its tributaries along with 40 identified water marks were surveyed. The available water levels on these locations are illustrated in the table 5.1 below:

Table 5.1: Available Water Levels

Tributary	Available water level	Tributary	Available water level
Litani	Joub Janine station (861.07m)	Ghzayel, Howayzek, Oqayber	Damascus Road station (868.406m)
	MG1 Upst. Mansoura Bridge (862.174m)		R1 Rawda (867.311m)
	MG2 Dst. Mansoura Bridge (862.645m)		R2 Rawda (867.209m)
	M1 Marj - Litani Right Side (868.91m),		R3 Rawda (867.209m)
	M2 Marj - Litani Right Side (868.36m)		M8 Marj - Ghzayel Right Side (869.672m)
	M3 Marj - Litani Left Side (868.25m)		M10 Downstream Marj (866.631m)
	M4 Marj - Litani Left Side (868.21m)		M11 Downstream Marj (866.692m)
	M5 Marj - Litani Left Side (867.981m)		M12 Downstream Marj (866.613m)
	M6 Marj - Litani Left Side (867.821m)		M13 Downstream Marj (866.627m)
	B1 Bar Elias - Litani Left Side (871.02m)		
	B4 Bar Elias - Litani Left Side (870.568m)		B8 Howayzek - Right Side (873.951m)
	B5 Bar Elias - Litani Left Side (870.925m)		DR1 Damascus Road - Oqayber (870.521m)
	B6 Bar Elias - Litani Left Side (870.808m)	Faregh	H1 Haouch El Harimeh (864.52m)
	B7 Bar Elias - Litani Left Side (871.285m)		H2 Haouch El Harimeh (865.108m)
	B9 Bar Elias - Litani Left Side (871.281m)		H3 Haouch El Harimeh (865.052m)
	D2 Dalhamieh - Road to Zahleh (882.426m)	Berdawni and Chtaura	Damascus Road station (871.98m)
	D3 Dalhamieh - Road to Zahleh (884.89m)		C3 Chtaura - Bridge Downstream Deir Taanayel (871.45m)
	MK1 Mkhat El Laouz (891.818m)		
	T1 Temnine (908.834m)		
	TA1 Tell Amara (903.703m)		
	TA2 Tell Amara (902.87m)		
	TA3 Tell Amara (903.217m)		

5.2.3 CALIBRATION PROCESS

The calibration process of the computer flood model is essential to ensure that the model accurately represents the reality of flows in the Litani River and triubutaries. This was achieved by simulating the 2003 flood and matching water levels from the model with highwater marks identified during the field survey.

Adjustments to the model are done by changing the Manning n coefficient, which represent the natural riverbed friction.

Rigorous guidance on acceptable calibration errors cannot be given. The judgment and experience of the responsible hydraulic engineer and reviewers was the base of this adjustment. The criterion used was ± 20 cm which is often used for this type of water courses.

The values adopted for the Manning Coefficient for each reach are as follows:

Table 5.2: Values adopted for the Manning Coefficient

Reach	Manning Main Channel	Manning Flood Plain
Litani River - Upstream Mansoura Village	0.05	0.16
Litani River - Downstream Mansoura Village	0.037	0.16
Farergh Tributary	0.065	0.16
Berdawni and Chtaura Tributaries	0.045	0.16
Hafir and Jaair Tributaries	0.045	0.16
Ghzayel River	0.05	0.16
Howayzek and Oqayber Tributaries	0.065	0.16

5.2.4 CALIBRATION RESULTS

Table 5.2 summarizes the discharges and the corresponding watershed areas with the ratio m3/s/km2 for the Litani River and each of the tributaries.

Figure 5.1 summarizes the discharges and the corresponding manning coefficient for the Litani River and each of the tributaries.

Table 5.3 summarizes the results of the water levels calibration for the Litani River and each of the tributaries.

Table 5.3: Discharges and the Corresponding Watershed Areas with the ratio $m^3/s/km^2$ for the Litani River and Each of the Tributaries

Water course	Q (m^3/s)	Cumulative watershed area (km^2)	Ratio (Q/area)
Upper Litani	63	752	0.08
Litani between Berdawni and Ghzayel	78	817	0.10
Litani between Ghzayel and Qabb Elias	123	1019	0.12
Litani between Qabb Elias and Faregh	168	1186	0.14
Litani between Faregh and Joub Janine	182	1487	0.12
Faregh	14	33	0.42
Chtoura	7	19	0.37
Berdawni	14	46	0.30
Hafir	25	74	0.34
Jaiir	20	93	0.22
Ghzayel under Oukaiber	16	139.3	0.11
Ghzayel between Oukaiber and Houeisii	23	143.5	0.16
Ghzayel between Houeisii and Faregh	29	182.4	0.16
Ghzayel between Faregh and Litani	37	202	0.18
Houeisii	6	17.8	0.34
Oukayber	7	31.3	0.22

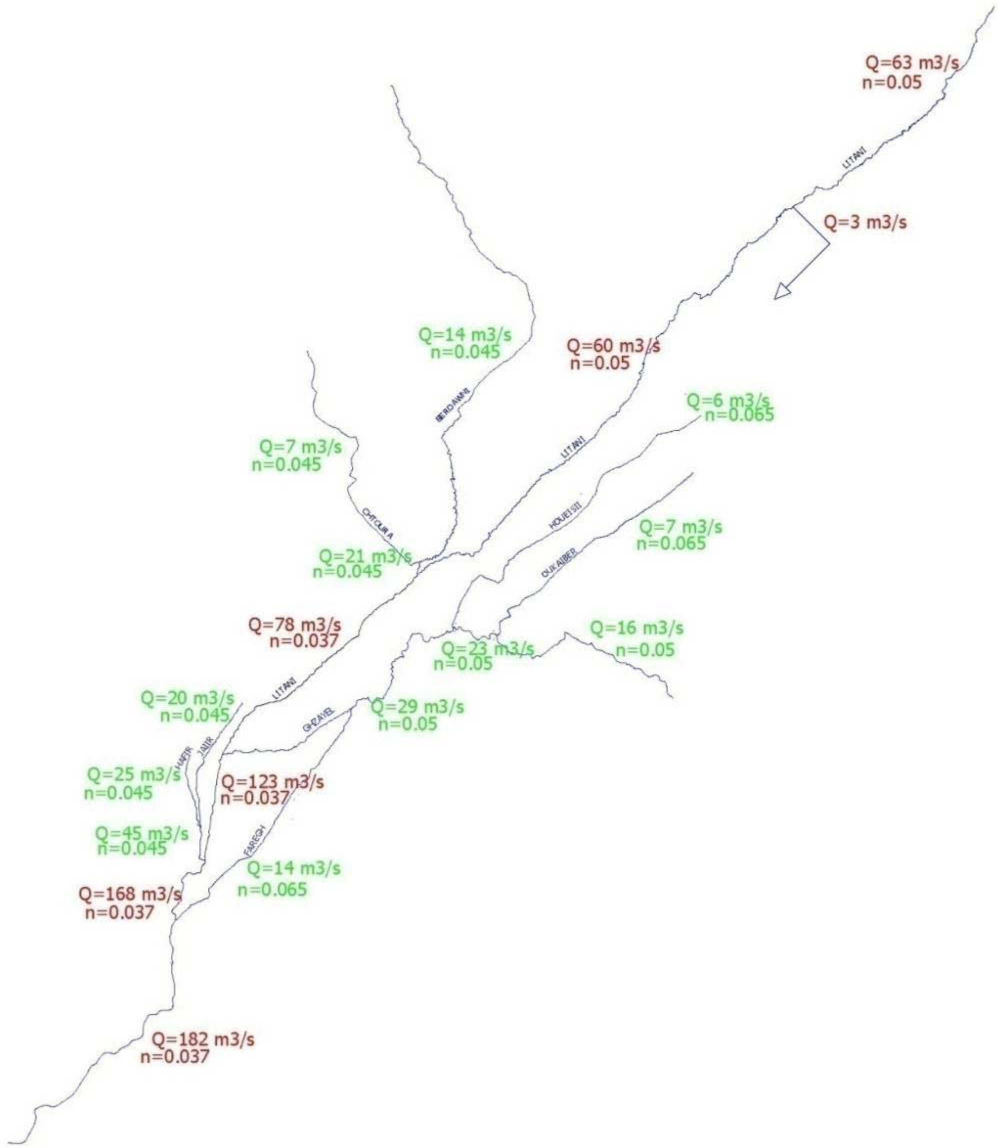


Figure 5.1: Discharges and the Corresponding Manning Coefficient for the Litani River and Each of the Tributaries

Table 5.4: Results of the Water Levels Calibration for the Litani River and Each of the Tributaries

Tributary	Available water level	Flood model water level	ΔH (cm)
Litani	Joub Janine station (861.07m)	L31 (861.09m)	-2
	MG2 Dst. Mansoura Bridge (862.645m)	L27 (862.7m)	-5.5
	M1 Marj - Litani Right Side (868.91m),	L19 (869.02m)	-11
	M2 Marj - Litani Right Side (868.36m)	L19A (868.55m)	-19
	D2 Dalhamieh - Road to Zahleh (882.426m)	L12 (882.3m)	12.6
	MK1 Mkhat El Laouz (891.818m)	L9 (891.71m)	10.8
	TA1 Tell Amara (903.703m)	L6 (903.57m)	13.3
Ghzayel	Damascus Road station (868.406m)	G1 (868.47m)	-6.4
	R2 Rawda (867.209m)	G2 (867.1m)	10.9
	M12 Downstream Marj (866.613m)	G4 (866.60m)	1.3
	B8 Howayzek - Right Side (873.951m)	HO1-B (873.8m)	15.1
	B1 Bar Elias - Litani Left Side (871.02m) (871.02m)	HO1-A (871.12m)	-10
	DR1 Damascus Road - Oqayber (870.521m)	O1 (870.54m)	-1.9
Faregh	H2 Haouch El Harimeh (865.108m)	F1(865.3m)	-19.2
	H2 Haouch El Harimeh (865.108m)	F2(865.3m)	-19.2
Berdawni	Damascus Road Station (871.98m)	B9(871.8m)	18

5.2.5 CALIBRATION VERIFICATION

In order to evaluate the initial calibration made on the basis of Flood Water Levels of the 2003 Flood, a verification of this calibrations was done in March 2012 based on real measured discharges on three gauging stations as illustrated in the following table:

Table 5.5: Measured Discharge at Gaging Stations

Gaging station	Measured Discharge (m3/s)
Litani at Joub Jenine	39
Litani + Berdawni at Marj	11.74
Ghzayel at Damascus highway	9.86

During the same period, a topographic survey of the water levels for the Litani and Ghzayel between Tell Amara and Joub Jenine was done and a model using the calibrated manning values of the 2003 Flood with the measured flows was simulated.

The results of the comparison between the HEC-RAS model and the topographic survey of water levels shows very similar values on two of the three measured sections and comparable values on one of them. The table below shows the results of this comparison:

Table 5.6: Results of Comparison between HEC-RAS Model and Topographic Survey of Water Levels

Section	HEC RAS	Topographic Survey	Difference
L6 (Tell Amara)	901.81	901.896	-0.086
L12 (Dalhamieh)	880.48	881.065	-0.585
L16 (Damascus Road)	868.59	869.06	-0.47
L19 (Berdawni-Litani Intersection)	867.18	867.63	-0.45
L27 (Mansoura)	860.08	860.1	-0.02
L31 (Joub Jannine)	858.17	858.09	0.08
G1 (Ghzayel - Damascus Road	867.88	867.85	0.03

5.3. SENSITIVITY TESTS

The selection of an appropriate value for Manning's n is very significant to the accuracy of the computed water surface profiles. The value of Manning's n is highly variable and depends on a number of factors including: surface roughness; vegetation; channel irregularities; channel alignment; scour and deposition; obstructions; size and shape of the channel; stage and discharge; seasonal changes; temperature; and suspended material and bed load.

For each reach, the effect of the increase or decrease of the Manning n values on water levels was simulated first by increasing the Manning's n by 10% and then by decreasing it by 10%. The variation in water levels is limited in both cases:

- Increase of Manning values: the computer simulation shows water level values ranging between 5 and 20 cm higher than the original simulation with an average difference of 10 cm.
- Decrease of Manning values: the computer simulation shows water level values ranging between 5 and 25 cm lower than the original simulation with an average difference of 12 cm.

6. FLOOD MAPPING

6.1. INTRODUCTION

The main objective of this task was to delineate the flood-prone areas, and to define the potential water depths within these areas. The elevations of the water levels provided by the HEC-RAS computer model are compared to the elevations of the ground in the Valley and thus provides water depths. A Digital Elevation Model (with a 1-m accuracy) was used here to give better information (then existing topographic maps) on the topography of the valley. Data sources were thus:

- **Topographic Survey:** Consisting of cross-sections along the Litani River and Tributaries.
- **1/20,000 Topographic Maps.**
- **Digital Elevation Model (DEM):** a 1m DEM was purchased and covered most of the area under study. An existing 5m DEM (lower accuracy) was used to extend to cover fringe areas.

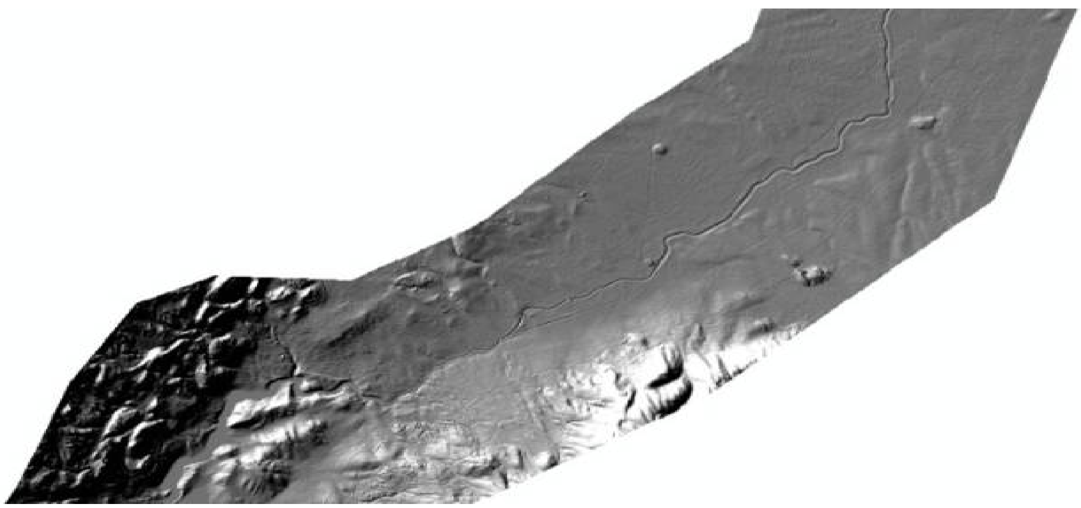


Figure 6.1: Existing Digital Elevation Model (DEM) with Lower Accuracy

6.2. RESULTS

The resulting maps represent flooded areas for three different floods:

- A repeat of the 2003 flood, which is exceptional (period of return of 70 years, that is a 1.5 % of happening every year);
- A 25-year flood (85% of 2003), with a 4% chance of happening annually;
- A 10-year flood (70% of 2003), with a 10% chance of happening annually.

Each flood is represented though five maps covering the Litani river from Dalhamiyeh to Joub Jenine:

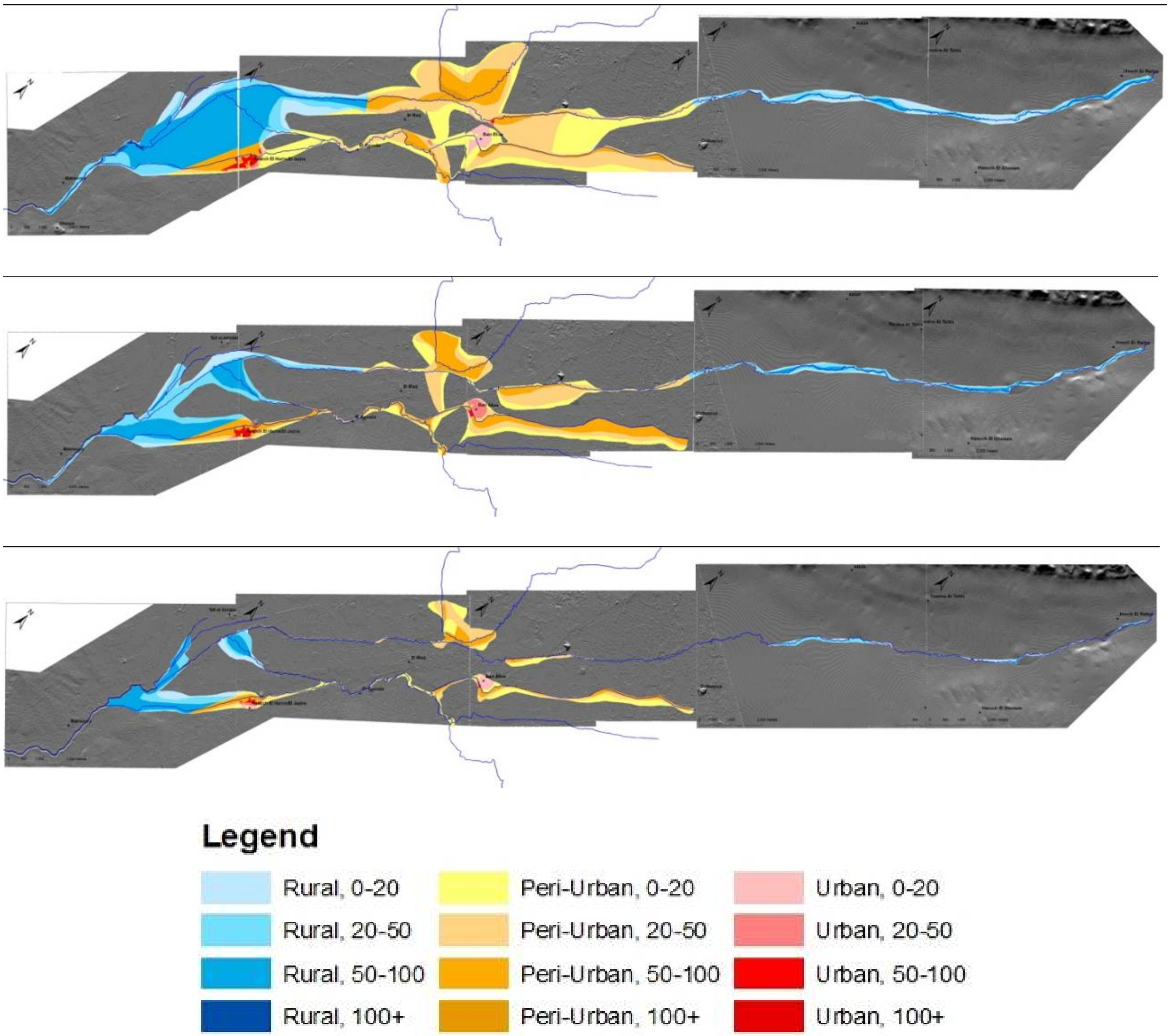


Figure 6.2: Flood Maps

Depth zones have been identified (0-20cm, 20-50cm, 50-100cm, 100+) as they represent increasing damage and danger, and compared with the criticality of the zones: urban centers, peri-urban areas (mix of buildings and farmlands), and rural areas (mostly farmlands, few buildings).

Flood management approaches should be adapted to the magnitude of the risk (essentially flood depths for the Litani River as velocities remain low to engender much damage), and to the sensibility of the zones, with urban areas being priority zones while rural areas should be less protected if at all (the flood volumes need to go somewhere, it would be too expensive and unsustainable to over-excavate the riverbed to convey large floods).

7. FLOOD AGGRAVATING ACTIVITIES AND OTHER HUMAN IMPACTS

Floods are natural events that happen with or without human presence. Risks and property damages are a direct consequence of people decisions to live in areas prone to flooding. While prevention and mitigation measures can be taken to reduce significantly the risks and potential damages, conversely there are also many human decisions and activities that can increase flood extent, duration and impacts. Such human actions activities need to be identified and reversed or prevented when possible. They include by order of importance:

- Riverbed maintenance;
- Bridges; and
- Riverbed infringements and other detrimental activities.

7.1. RIVERBED MAINTENANCE

A riverbed is a constantly evolving natural feature. Large floods will erode riverbanks and enlarge the riverbed, while prolonged periods of low flows will favor vegetation development, sedimentation, formation of bars. The lateral shifting of a riverbed can in some instances be quite significant, and can of course cause damage to farmlands and real estate property.

The usual human response is to stabilize banks by gabions, riprap or concrete channelization. Unfortunately this approach is expensive and can in the medium to long term create instabilities. For example concrete banks will accelerate the river flow, and thus increase the bottom erosion, which can jeopardize the stability of the banks and of bridges. Lining also the bottom is even more expensive, and often not sustainable while turning the river into a "dead" pipe by preventing any fauna or flora development. Moreover channelizing and increasing the river flow simply transfers flood issues and erosion further downstream.

Riverbed management is thus a difficult comparison between protecting human activities and property without worsening the situation and in parallel ensuring that the river remains healthy for riparians and biodiversity.

There is currently no planned approach to riverbed maintenance of the Litani. It is the role of the Ministry of Energy and Water which intervenes on an ad-hoc basis, that is:

- After large floods such as 2003 to increase the conveyance capacity of the river; and
- When the development of vegetation and accumulation of solid waste (residential and industrial/construction garbage) reaches such a level that riparians are complaining about it (complaints are actually about the smell which comes mostly from the sewage content of the river).

In both cases, the riverbed maintenance is carried out (expensively and locally) with the use of excavators who indiscriminately remove garbage, vegetation and bank soil, thus progressively widening the riverbed and increasing the development of vegetation and sedimentation in the dry summer months. Over several years, this sedimentation and vegetation development ends up reducing the river conveyance capacity and increasing flood impacts.

Photograph 7.1: Over-excavated Litani riverbed in Joub Jenine: vegetation development and sedimentation are recreating a smaller and meandering riverbed

7.2. IMPACT OF BRIDGES

7.2.1. BRIDGE HYDRAULICS

Bridges are essential for human beings to safely cross waterways. The proper design of waterways must ensure that the bridge is high enough to stay above the waterline during floods but also that the section under the bridge is large enough to convey riverflows even during high floods. Installing on a river a small culvert or building a bridge with an elevated deck and a thick (and thus low reaching) beam is like building a dam on the river: during a flood the water level will rise, and reach the beam. The upstream water level will keep rising to force/push water to go under the bridge. This artificial rise will eventually overflow the banks. A bridge that is too small can easily cause an upstream sur-elevation of 50cm and more.

7.2.2. BOTTLENECKS ON LITANI RIVER AND TRIBUTARIES

The simulation of river flows with HEC-RAS allows to calculate the impact of any bridges in terms of upstream sur-elevation. For the Litani River, simulating the flood of 2003 on HEC-RAS shows the impacts of the existing bridges (bridges engendering sur-elevations higher exceeding 30 cm are marked in red):

Table 7.1: Impacts of Existing Bridges

	Bridge	ΔD m
Litani	(L2 UP) Near Haouch Er Rafqa	0.31
	(L2 DN) Near Haouch Er Rafqa	0.01
	(L3) Road to Bednayel	0.35
	(L4) Jisr El Nahriyye	0
	(L5) Temnine El Tahta road	0.18
	(L6) Ablah - Tell Amara road	0.47
	(L8) Rural road upstream Mkhat El Laouz	0.1
	(L9) Rural road Mkhat El Laouz	0.38
	(L10) Rural road downstream Mkhat El Laouz	0.25
	(L11) Rural Road upstream Dalhamieh	0.15
	(L12) West of Dalhamieh	0.25
	(L13) Zahle-El Faour Road	0.3
	(L16) Damascus Road	0.11
	(L19) Marj-Jdita road	0.08
	(L24) Connection with Jaiir	0.1
	(L27) Ghazze-Mansoura road	0.03
	(L31) Kefraya-Joub Jenine road	0.07
Chtaura	(C1) Near Taanayel Lake	0.06
	(C2) Inside Deir Taanayel Lands	0
	(C3) Just Downstream Taanayel Lands	0.01
Berdawni	(B1) Saadnayel Road	0.09
	(B2) Rural Road downstream Saadnayel	0.04
	(B3) Rural Road downstream Saadnayel	0.01
	(B9) Damascus Road	0

Faregh	(F1) Haouch El Harimeh - El Jazira Region	0.18
	(F2) Haouch El Harimeh - El Jazira Region	0.03
	(F3) Rural Road Mkhadet el Cheberkiyeh	0.1
	(F4) Rural Road Haqlet El Mathaneh	0
	(F5) Culvert at the Intersection with Litani	0.30
Ghzayel	(G1) Damascus Road	0
	(G2) El Raouda Road	0.01
	(G2A1) Downstream El Raouda	0.18
	(G2A 2) Downstream El Raouda	0.02
	(G3) Downstream El Raouda	0.03
	(G4) El Marj - Haouch El Harimeh Road	0.02
	(HO1) Near Bar Elias	0.03
	(HO2) Damascus Road	0.95
	(O1) Damascus Road	1.17
Qabb Elias	(J1) Tell El Akhdar Road	0
	(H1) Rural Road Downstream Tell El Akhdar	0.01

The following comments can be made on the bridges engendering backwaters (sur-elevations) exceeding 30 cm :

- L2 UP is a bridge on Litani River situated near the village of Haouch Er Rafqa that was destroyed during the war of 2006 and was replaced by 4 pipes of a diameter of 1200 mm each. The section of the new bridge / culvert is not sufficient and should be replaced by a well designed bridge. The culvert serves only as an access to a farm.

Photograph 7.2: Section of Bridge/Culvert (L2 UP) showing 4 Pipes near Haouch Er Rafqa

- L3 is a bridge on Litani River on the road that leads to Bednayel that was destroyed during the war of 2006 and was replaced by a new bridge with a much better section. The reason of having a level difference between upstream and downstream the bridge is the presence of a weir / Free fall just downstream the bridge section which will lead to further erosion downstream and to stability problems.

Photograph 7.3: Bridge (L3) on Road that Leads to Bednayel showing Level Difference

- L6 is a bridge on Litani River on Ablah road that was destroyed during the war of 2006 and was replaced by a new bridge. The new bridge is 50cm lower than the old one. The area was flooded in 2003 but less than the area simulated. The section of the new bridge is not sufficient and should be replaced by a well designed bridge.

Photograph 7.4: Bridge (L6) on Ablah Road

- L9 is a bridge on Litani River in Mkhat El Laouz that was destroyed during the war of 2006 and was replaced by a new bridge with similar cross section. The area was flooded in 2003 similarly to what was simulated. The section of the bridge is not sufficient and should be replaced by a well designed bridge.

Photograph 7.5: Bridge (L9) in Mkhat El Laouz

- F5 is a culvert that serves as an access to a Farm on Faregh tributary on the intersection with the Litani that was flooded in 2003 and is flooded on seasonal flooding. The section of the culvert is highly not sufficient and should be replaced by a well designed bridge and the water course should be cleaned regularly.

Photograph 7.6: Culvert (F5) on Faregh Tributary

- H2 is a bridge on Howayzek tributary near Bar Elias that was flooded in 2003 and is flooded on seasonal flooding. The section of the bridge is not sufficient and should be replaced by a well designed bridge and the water course should be cleaned regularly.

Photograph 7.7: Water Course at Bridge (H2) on Howayzek Tributary

- O1 is a bridge on Oqayber tributary on Damascus road that was flooded in 2003. The section of the bridge is not sufficient and should be replaced by a well designed bridge and the water course should be cleaned regularly.

7.3. OTHER HUMAN IMPACTS

Furthermore, several other human activities negatively impacts the intensity and the damages caused by the floods. These include:

- Dumping along the river of all type of solid and hazardous waste (wheels, dead animals, furniture, plastic bottles, chemicals…).

Photograph 7.8: Dumping of Solid and Hazardous Waste

- Also dumping of construction rubble directly in the riverbed:

Photograph 7.9: Dumping of Construction Rubble

- Heightening river sides by the creation of levees which blocks the water coming from small tributaries (Case of Chtaura tributary which floods into other tributaries which are blocked at their intersection with the Litani downstream El Marj Bridge) toward the Litani and other major tributaries which causes the flooding of the plain.

Photograph 7.10: Heightened River Sides via Levees

- Construction of embankment weirs for irrigation by pumping creating obstacles inside the river bed or lowering river sides to install pumps or to connect with irrigation channels and Existence of illegal buildings inside the River bed.

Photograph 7.11: Embankment Weirs for Irrigation

- Growing of vegetation in the river bed (weeds, trees, marshes, bamboos…) which is caused by the presence of nutrients in the river coming from waste water and fertilizers.

Photograph 7.12: Growing Vegetation in River Bed

Basically all these activities are individual actions for personal convenience/benefits which unfortunately impact all the community. These can only be prevented through better field-based water management and enforcement, as well as involving residents and raising their awareness.

8. FLOOD MITIGATION AND PROTECTION

8.1. METHODOLOGY

Chapter 6 provided an assessment of the areas prone to flooding, and also crossed this information with the level of human presence, with three land use categories being:

- Zone A urban centers: characterized by an dense urbanization, a continuity of buildings and mixed uses between housing, shops and services; for the Litani River Baisn, these zones are the centers of Bar Elias, El Marj and Haouch El Harime; these zones should be protected in priority.
- Zone B peri-urban areas: more sparsely occupied areas which do not meet all the characteristics of "urban centers"; these zones deserve a lower level of protection.
- Zone C corresponding to farmlands and regions with very limited constructions which should be preserved for the flood expansion.

Table 8.1: Land Use Categories and Corresponding Flood Management Approach

Zone	Where	Flood management approach
A: Urban centers	Centers of Bar Elias, El Marj, Er Raouda and Haouch El Harime	To be protected in priority as damages can be important during flooding
B Peri-urban	Regions surrounding Dalhamieh, Bar Elias, El Marj, Er Raouda and Haouch El Harime	Lower level of protection, where economically justified
C Farmlands, rural areas	Most of the Litani river valley	To be kept as flood expansion areas; protecting these is not justified economically (costs would be higher than potential damage) and would be detrimental to the protection of zones A and B

Two parallel approaches are recommended to address flood risks in these areas:

- Urban planning to guide urbanization towards safe areas and prevent the disappearance of flood expansion areas; and
- Infrastructure works where strictly necessary and where the cost of such works is less than the potential flood damage.

Keeping in mind that:

- Protecting all areas for all types of floods is impossible since there can always be a larger flood than the one used to design protections, and can quickly become expensive when it involves infrastructure works; and

- Protecting urban areas should be the priority while rural areas should be kept as expansion areas.

8.2. FLOOD MITIGATION (URBAN PLANNING)

Urban planning is a technical and political process concerned with guiding the use of land over a given area, often a urban center and its surroundings. The objective is to harmonize urban development so that industries, shops and services, and residential areas are allocated separate but connected zones. Urban planning also concerns itself with the planning of transportation and service networks (energy, water, sewage, etc.) and the mitigation of natural risks (fires, landslides, earthquakes, and flooding), as well as with the preservation of natural spaces for environmental purposes and agricultural activities

Flooding damage can be prevented or at least significantly mitigated with simple foreseeing urban planning measures. The following recommendations are meant to enhance the safety of persons, limit the damage to property and the nuisances for human activities, while ensuring the free flow of water and the conservation of areas designated for flood expansion. They consist of prohibitions on land use and requirements and recommendations to prevent damage.

Table 8.2: Prohibitions on Land Use and Recommendations to Prevent Damage

Flooded one with flooding higher than 20cm	Where	Urban development	
		Allowed	Should be avoided/prohibited
A: Urban centers	Centers of Bar Elias, El Marj and Haouch El Harime	Any new buildings, but basements should be avoided. For commercial and industrial buildings, the functional levels should be above flood levels.	Sensitive equipments/buildings such as electric transformers, hospitals, etc.
B Peri-urban	Regions surrounding Dalhamieh, Bar Elias, El Marj, Er Raouda and Haouch El Harime	New buildings but areas lost to large commercial/industrial buildings should be compensated (landfill should be taken from the same plot)	Sensitive equipments/buildings such as electric transformers, hospitals, etc.
C Farmlands, rural areas	Most of the Litani river valley	Buildings and facilities used for agricultural purposes and outdoor recreation (parks, gardens, sports fields, etc.) Areas lost to large landfills should be compensated.	All other types of construction (residential, commercial, industrial). Embankments along the river and other works preventing flooding.

For all new constructions in flooded areas, real estate developers should be informed of the potential risks at the time of delivery of construction permit and in turn inform their buyers.

8.3. FLOOD PROTECTION (PROPOSED INFRASTRUCTURE WORKS)

8.3.1. INTRODUCTION

In chapter 6, the flooding area was delineated according to the model results for the 2003 flood. The main residential areas in the region are Bar Elias, El-Marj and Haouch El-Harime. The flood maps showed that the residential areas flooded are concentrated mainly in the following regions:

- Region situated between the left bank of Litani River and the right bank of Howayzek Tributary between Dalhamieh and Bar Elias villages.
- Region of El-Marj village situated between the right bank of Chtaura Tributary and the right bank of Litani River.
- Region of El-Marj village situated at the left bank of Litani River.
- Rawda villages at the left bank of Ghzayel River.
- Haouch El-Harime village at the left bank of Faregh Tributary.

In order to reduce the floods effect on the above mentioned residential areas, several simulations were conducted by implementing infrastructural modifications on the channels. The modifications were concentrated mainly on the tributaries taking into consideration that several cleaning and recalibration works were previously conducted on the Litani River.

These infrastructure works are meant to be:

- Reasonably expensive as compared to the potential damage;
- Easy to implement and maintain; and
- Modest so as not to not to increase damage for more exceptional floods (as an example high embankments engender much higher damage when they fail than if they were absent, see for example New Orleans).

Maintenance costs are however not included here as riverbeds would have to be re-excavated on a regular basis (at least every 5 years).

To justify the expenses, total costs have to be compared to actual flood damages. Such damages were estimated at $2-5M for 2003, with an annual probability of 1.5%, and thus an average yearly damage of $50-100,000.

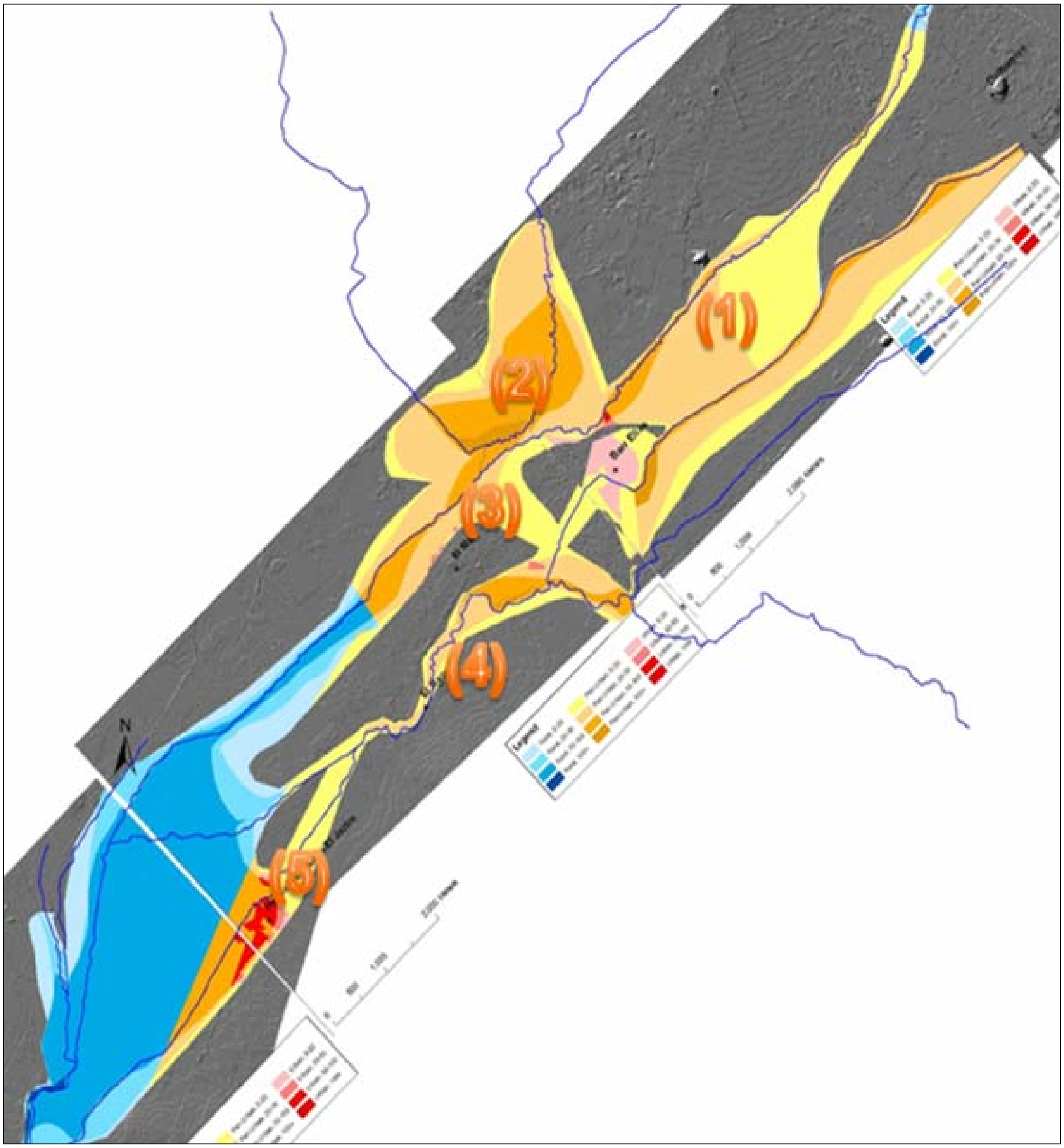


Figure 8.1: Main Regions of Concern

8.3.2. NORTH OF DAMASCUS HIGHWAY: BETWEEN DALHAMIEH AND BAR ELIAS

The following facts concerning this region can be stated:

- The examination of the topographic maps and surveys reveals that the lateral slope of this region goes from the Litani River left bank towards the Howayzek Tributary. The lowest point is not the Litani River.
- According to the residents testimonies, the water flows out from the Litani River course near the village of Dalhamieh towards the lands and residential areas situated at the East and towards Howayzek which add an extra flow that this water course can not contain.

- According to the flood maps generated from the 2003 flood model:
  - The rural region situated on the right of the Litani River is not flooded.

The majority of the dense residential area in Bar Elias is flooded partly from the Litani and partly from Howayzek. In order to examine this situation and to propose solutions, the Howayzek River bed which is covered with high weeds was simulated with the following modifications:

- Cleaning of the channel (represented by a modification of the Manning coefficient, value set to 0.04 instead of 0.065).
- Widening of the main channel.

The results of each of the simulations are illustrated in the figure below. The following can be deducted:

- The construction of 4 to 5 km of levees of about 1 m height on the left bank of the Litani River upstream Damascus road or more to the east in order to create an additional expansion area on the left bank, will force the flooding to appear in the rural region situated on the right bank.
- The cleaning and widening of the Howayzek by an average 2m width for a length of 4 to 5 km without any modifications on the existing bridges neither on the water course bed level, will reduce the flooding around Howayzek significantly and the dense resident region of Bar Elias will be more protected against future floods.
- The reconstruction of the culvert HO1 near Bar Elias village with better hydraulic section and in conformity with the general widening can decrease local flooding upstream this section.
- The cost of these works is estimated to 150,000 US$ for the levees, 200,000 US$ for the cleaning and widening and 100,000 US $ for the new culvert.

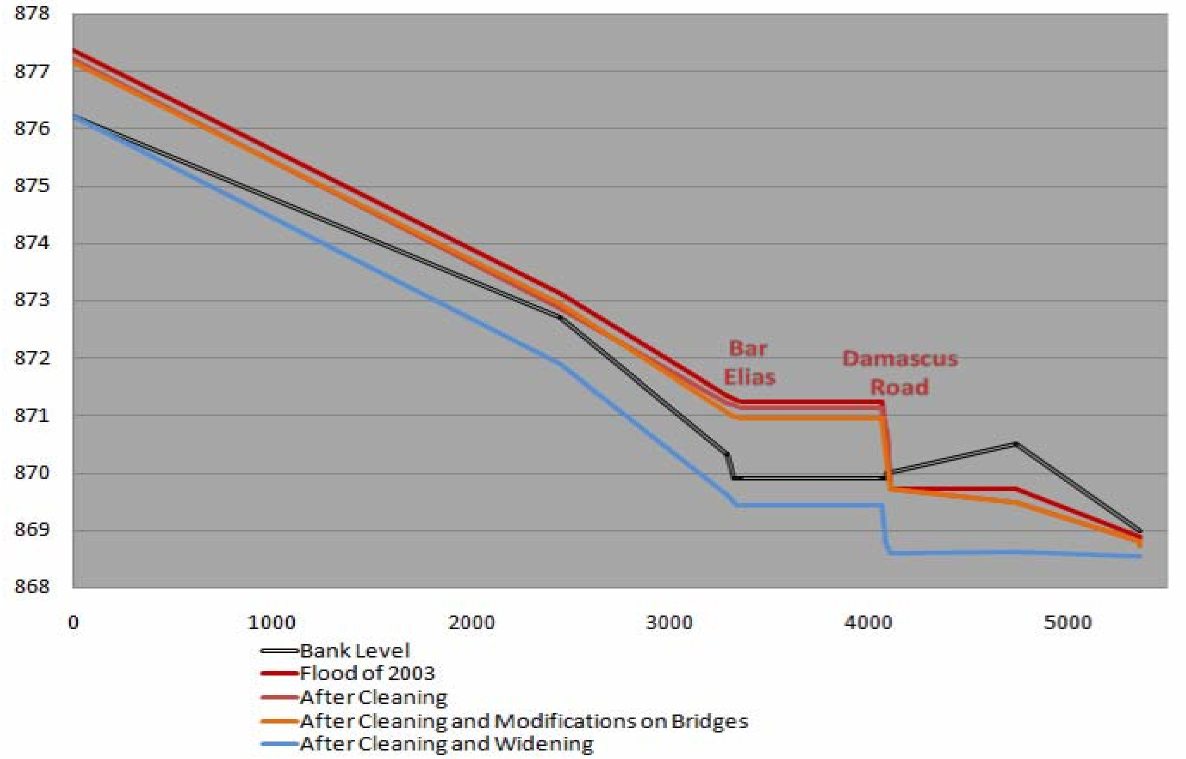


Figure 8.2: Results of Simulations: Bar Elias and Damascus Road

8.3.3. AROUND EL-MARJ (RIGHT BANK OF THE LITANI)

The following facts concerning this region can be stated:

- According to the residents testimonies, the water flows out from the Chtaura Tributary water course just downstream Taanayel monastery towards the lands and residential areas situated downstream.
- The observation of the water course reveals that it is clean upstream and all along the lands of the monastery and then neglected downstream until reaching the Berdawni River. Also several illegal diversion dams are constructed downstream in order to divert the river water for use in the industry.
- According to the flood maps generated from the 2003 flood model, the regions situated on both banks of Chtaura Tributary are flooded.

In order to examine this situation and to propose solutions, the Chtaura River bed was simulated with the following modifications:

- Cleaning of the channel (represented by a modification of the Manning coefficient, value set to 0.04 instead of 0.045).
- Widening of the main channel.
- Addition of levees in the last sections.

The results of the simulation are illustrated in the figure below. It can be deducted that by cleaning and widening the Chtaura Tributary without any modifications on the existing bridges neither on the water course bed level, the flooding in this region is slightly reduced.

The creation of levees in the last 1.5 to 2 km of Chtaura River can be a solution for the flooding in this region but should be accompanied with proper urban and agricultural drainage and cleaning and adding levees on both sides of the Berdawni River for the 2.5 to 3 km. In fact, the backwater generated from the water level in the Berdawni River is the main cause of flooding in this region.

The cost of these works is estimated to 200,000 US$ for Chtaura and 250,000 US$ for Berdawni.

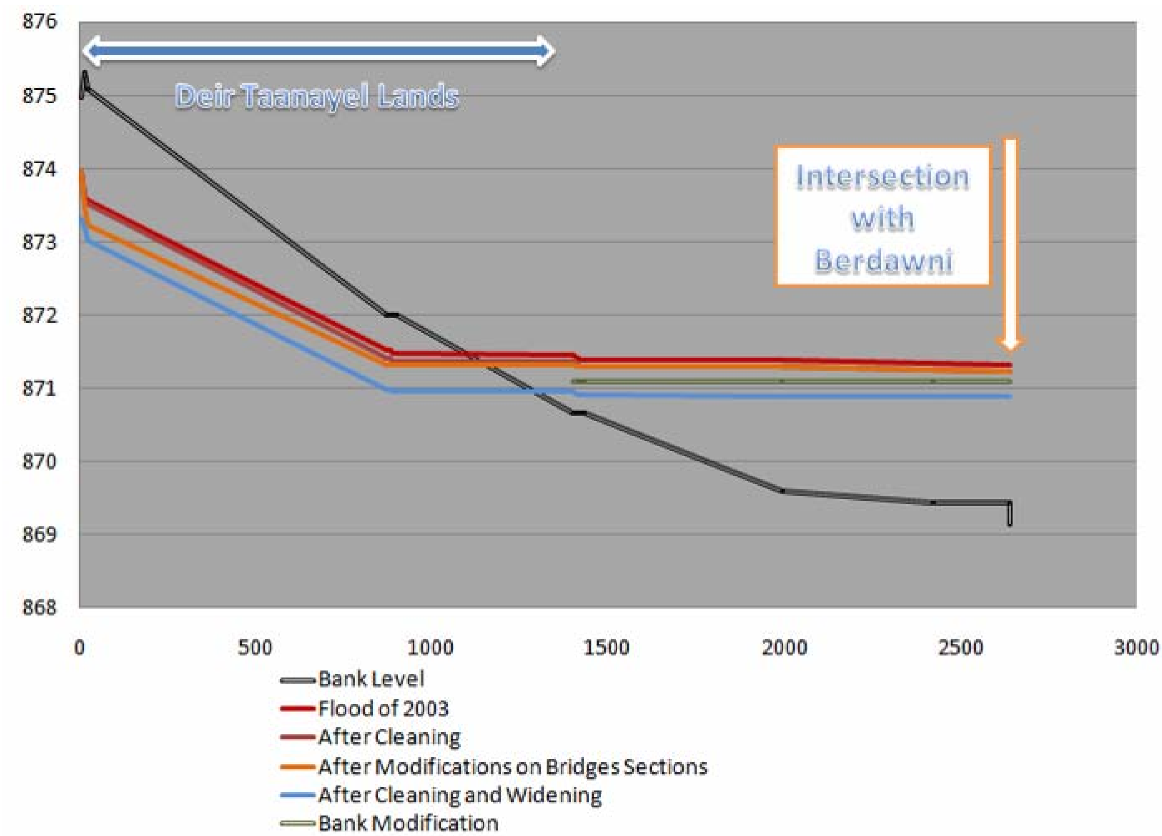


Figure 8.3: Results of Simulations: Deir Taanayel Lands and Intersection with Berdawni

8.3.4. AROUND EL-MARJ (LEFT BANK OF THE LITANI)

The following facts concerning this region can be stated:

- According to the residents testimonies and the results of the field survey, the water flows out of the Litani River in this region.
- The Litani River bed in this region was cleaned and recalibrated after the flood of 2003.
- Some levees were also executed on both sides of the river.

In order to examine this situation and to propose solutions, the Litani River bed was simulated after the creation of levees continuously for 3 to 4 kilometers only on the left side of the river in order to protect the urban center of El Marj.

The results of the simulation show that by adding levees of 1.5 m height, the effect of floods in this region can be minimized (No flooding for the flows of 2003).

The execution of levees should be accompanied with the installation of adequate equipments (Check Valves) which allow the drainage of small tributaries and irrigation channels towards the river.

The cost of these works is estimated to 200,000 US$.

8.3.5. AROUND RAWDA (LEFT BANK OF THE GHZAYYEL)

The following facts concerning this region can be stated:

- According to the residents testimonies and the results of the field survey, the water flows out of the Ghzayel River in this region.
- The Ghzayel River bed in this region was cleaned and recalibrated after the flood of 2003.

In order to examine this situation and to propose solutions, the Ghzayel River bed was simulated after the creation of levees continuously on both sides of the river.

The results of the simulation show that, in order to reduce the flooding effect in the urban center of Rawda, a minimum of 2 to 3 km of levees should be executed on the left side of the River Bed in this region.

The execution of levees should be accompanied with the installation of adequate equipments (Check Valves) which allow the drainage of small tributaries and irrigation channels towards the river.

The cost of these works is estimated to 150,000 US$.

8.3.6. AROUND HAOUCH EL HARIMEH (LEFT BANK OF THE FAREGH)

The following facts concerning this region can be stated:

- The examination of the 1/20,000 drawings reveals that a significant part of the Ghzayel Tributary catchment area flows into the Faregh Tributary.
- According to the residents testimonies and to the field survey findings, the residential region becomes a series of isolated islands.
- According to the flood maps generated from the 2003 flood model, the residential areas at the left bank and the agricultural area at the right bank are totally flooded.
- All the bridges sections passing through Faregh tributary are largely under-designed.
- At the intersection of the Faregh Tributary with the Litani River, a culvert with a very limited section is serving as an access road to a Farm.

In order to examine this situation and to propose solutions, the Faregh River bed which is covered with high weeds was simulated with the following modifications:

- Cleaning of the channel (represented by a modification of the Manning coefficient, value set to 0.04 instead of 0.065).

- Widening of the main channel by 2 to 3 meters.
- Replacement of the two bridges near Al-Jazira in addition to the culvert on the intersection with Litani which are under-designed with new ones having adequate sections.

The results of each of the simulations are illustrated in the figure below. It can be deducted that by cleaning the Faregh Tributary and by executing bridges with adequate sections, the flooding in this region is largely minimized especially in the residential areas.

The cost of these works is estimated to 300,000 US$ without widening and to 500,000 US$ after widening.

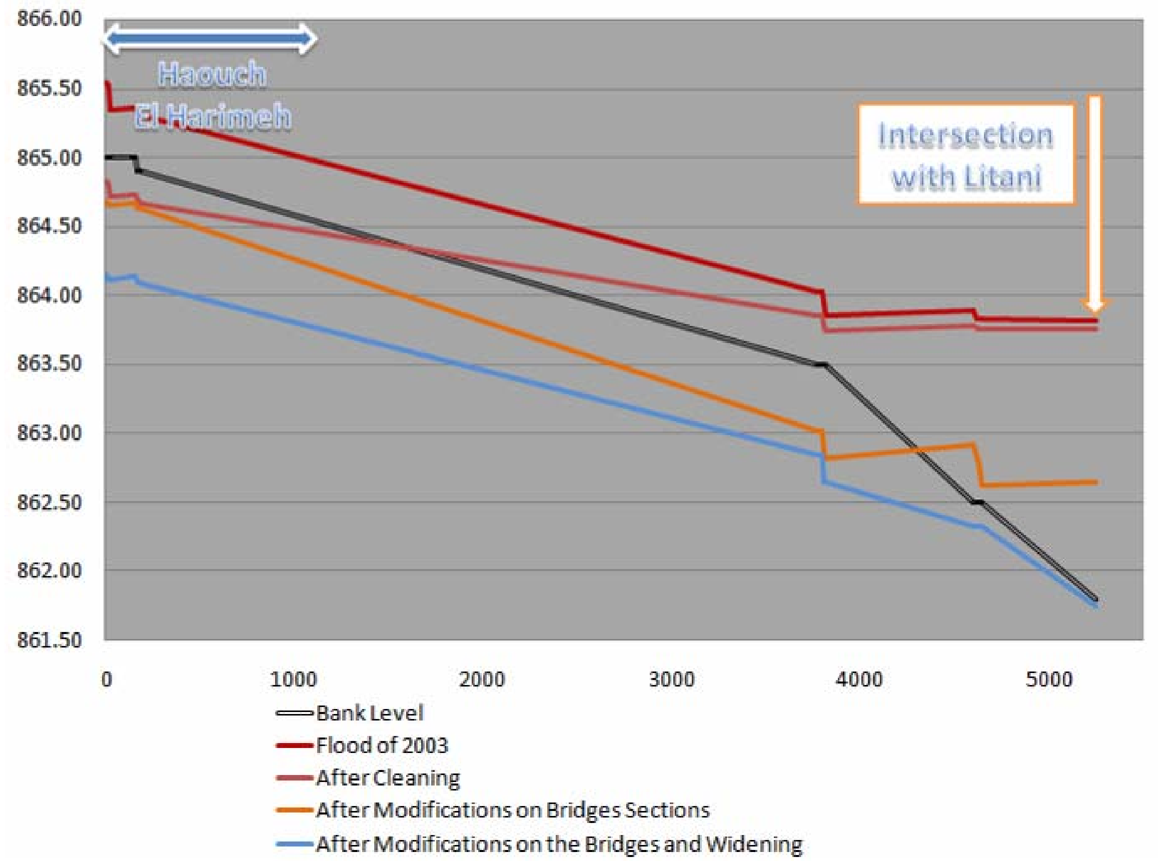


Figure 8.4: Results of Simulations: Haouch El Harimeh and Intersection with Litani

APPENDICES

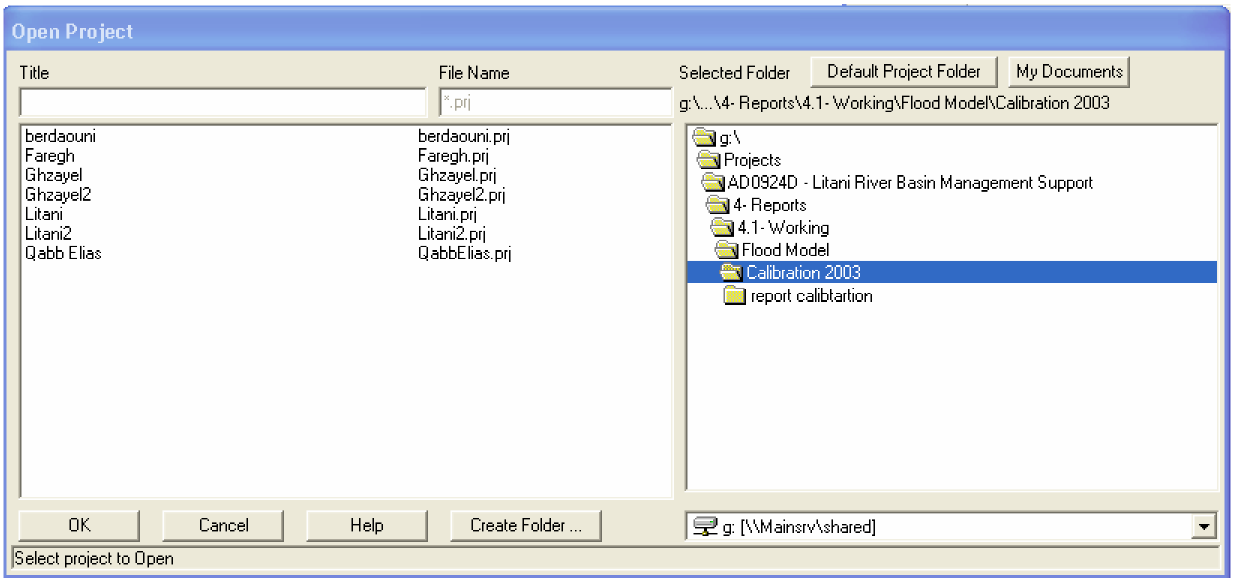
APPENDIX A
LITANI MODEL ON HEC-RAS

The creation of the hydraulic model of Litani River in Hec Ras followed five steps:

- Starting a new project
- Entering geometric data
- Entering flow data and boundary conditions
- Performing the hydraulic calculations
- Viewing and printing results

A.1 STARTING A NEW PROJECT

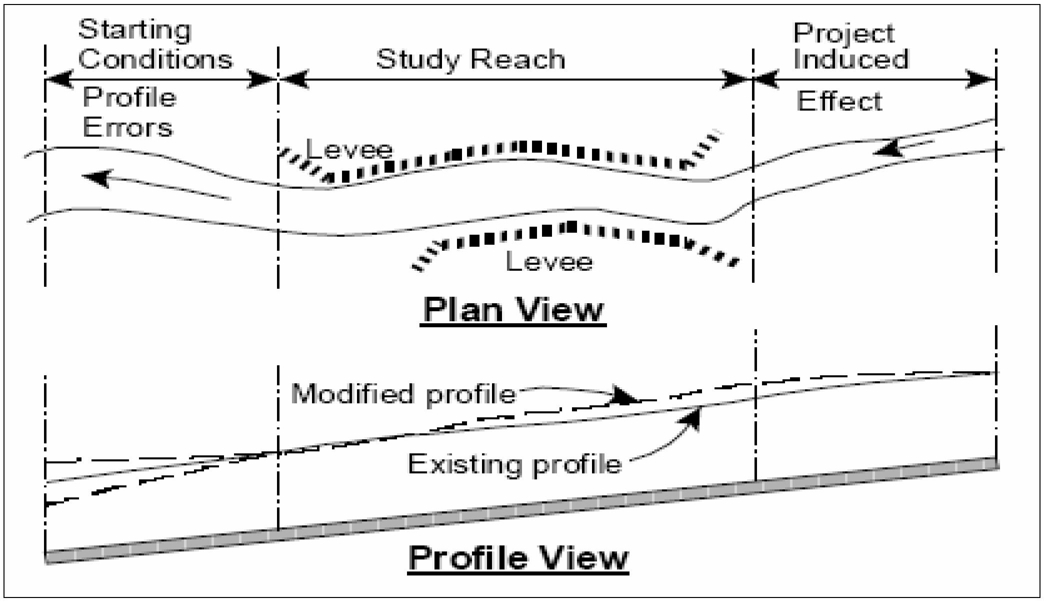
The first step in developing our hydraulic model in HEC RAS is to establish the directory and name of the project. This will bring up the new project window as shown in figure 1-1.



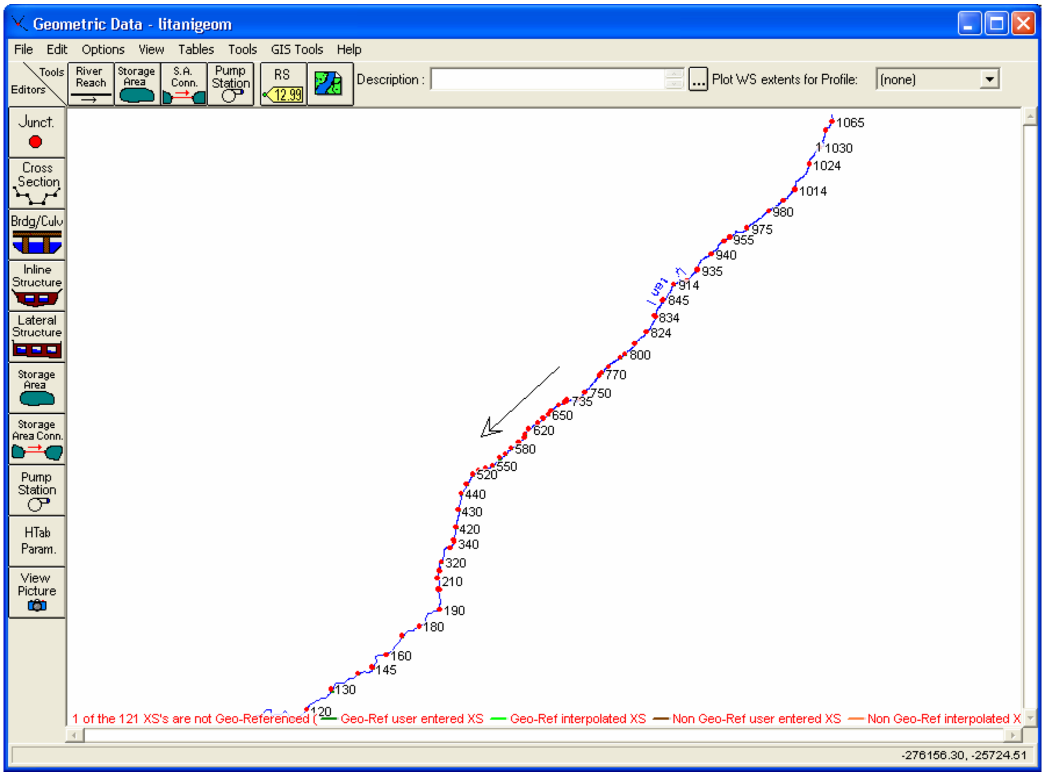
A.2 ENTERING GEOMETRIC DATA

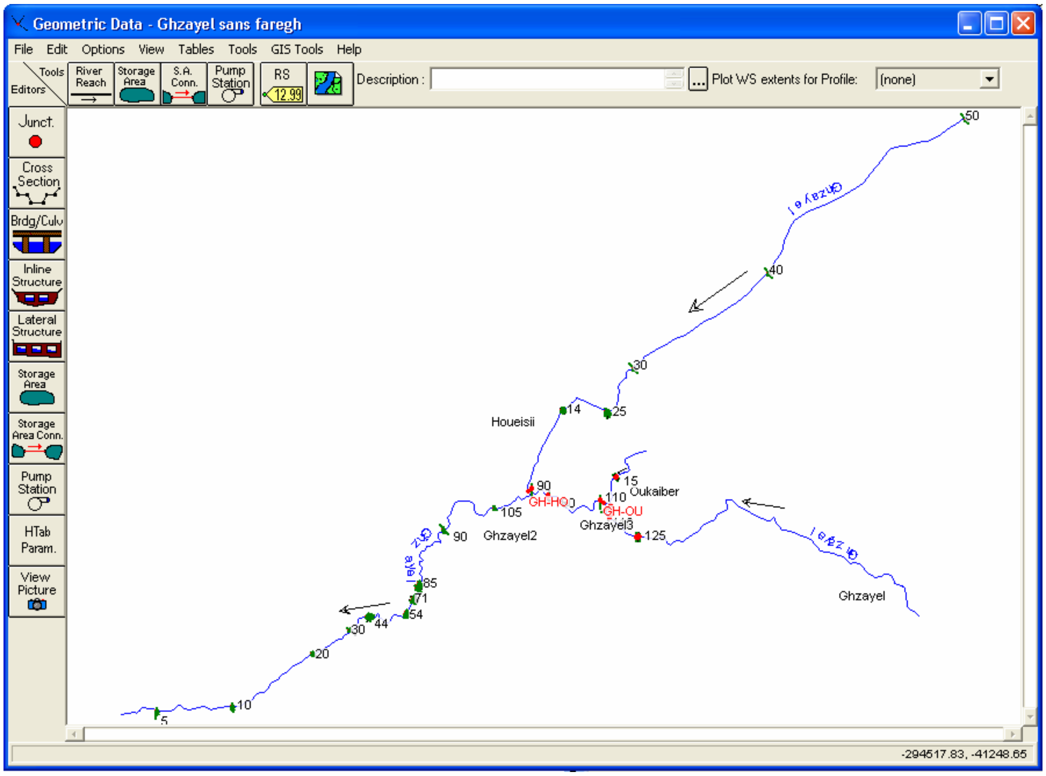
The next step is to enter the necessary geometric data, which consists of connectivity information of Litani River, cross section data and hydraulic structure data (bridges, culverts, weirs, etc.). The basic geometric data consists of establishing the connectivity of the river system; cross section data; reach lengths; energy loss coefficient (friction, contraction and expansion); and stream junction information.

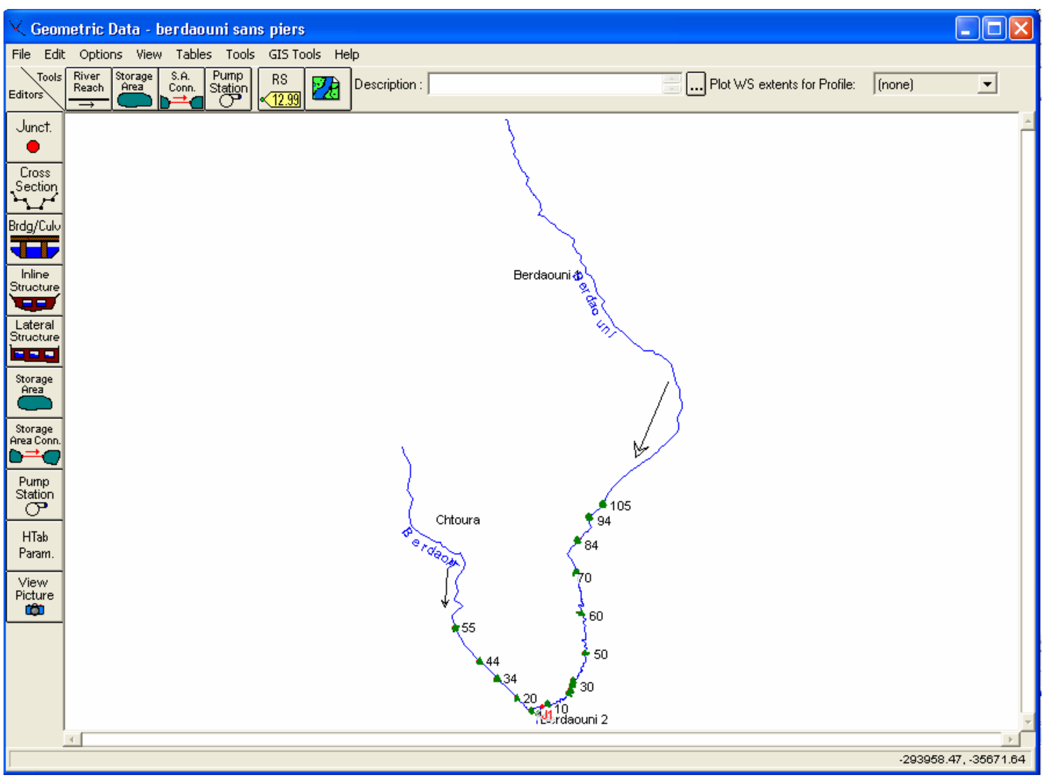
When performing a hydraulic study, it is normally necessary to gather data both upstream and downstream of the study reach. Gathering additional data upstream is necessary in order to evaluate any upstream impacts due to construction alternatives that are being evaluated within the study reach (figure 1-2). The limits for data collection upstream should be at a distance such that the increase in water surface profile resulting from a channel modification converges with the existing conditions profile. Additional data collection downstream of the study reach is necessary in order to prevent any user-defined boundary condition from affecting the results within the study reach.



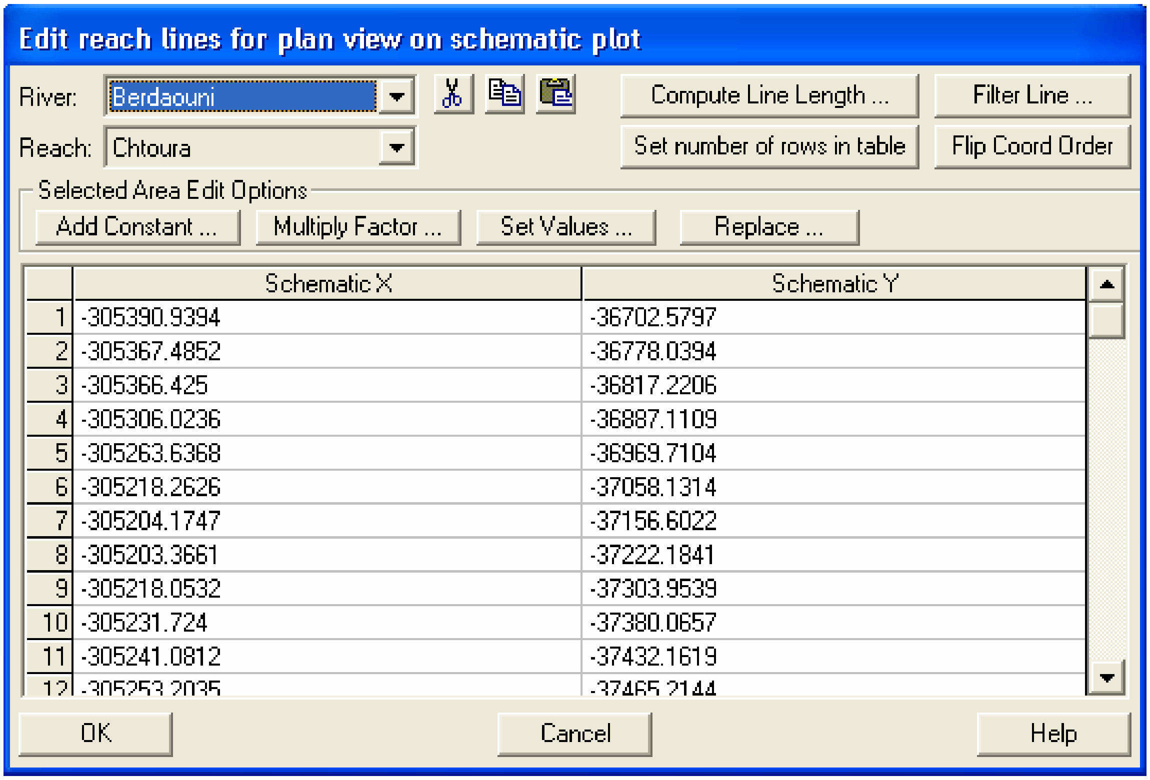
Geometric data are developed by first drawing the river system schematic. This is accomplished by drawing in a reach from upstream to downstream (in the positive flow direction).



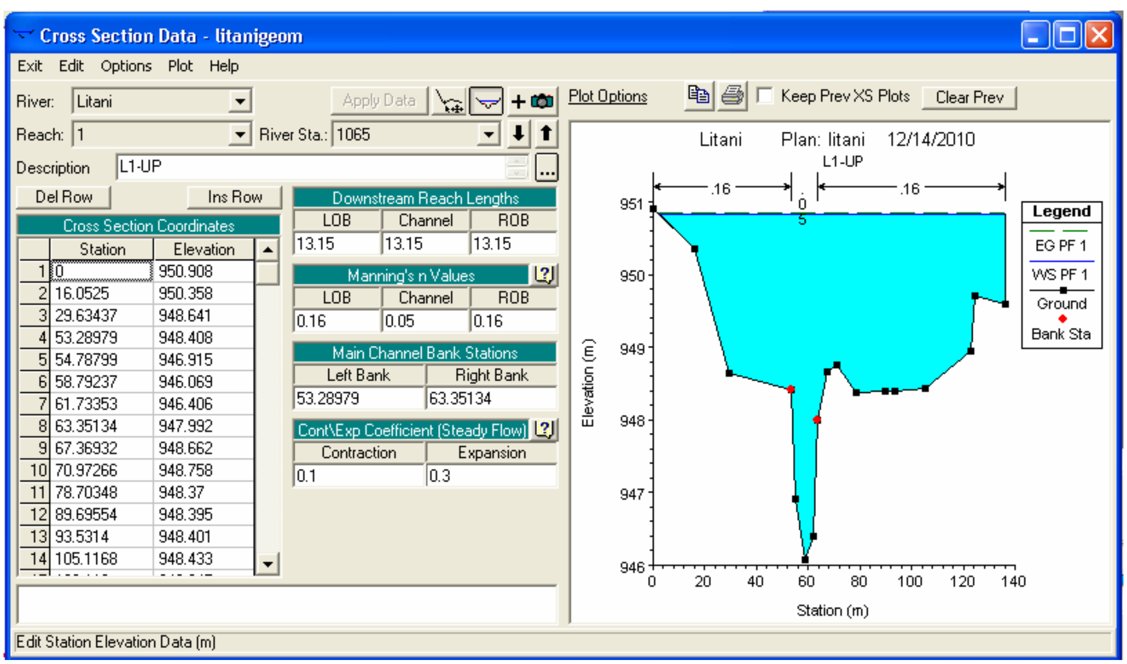

Geometric Data - Ghzayel sans faregh
File Edit Options View Tables Tools GIS Tools Help
Description :
Plot WS extents for Profile:
(none)
Junct.
Cross Section
Brdg/Culv
Inline Structure
Lateral Structure
Storage Area
Storage Area Conn.
Pump Station
HTab Param.
View Picture
Houeisii
Oukaiber
Ghzayel2
Ghzayel3
Ghzayel
-294517.83, -41248.65


Geometric Data - berdaouni sans piers
File Edit Options View Tables Tools GIS Tools Help
Description :
Plot WS extents for Profile:
(none)
Junct.
Cross Section
Brdg/Culv
Inline Structure
Lateral Structure
Storage Area
Storage Area Conn.
Pump Station
HTab Param.
View Picture
Berdaouni
Chtoura
-293958.47, -35671.64

After hand drawing the reach, the coordinates of the river reach are numerically edited by the Reach Invert Lines Table option.



After the river system schematic is drawn, cross section and hydraulic structure data are entered. The shape of each section is illustrated by stations and elevations for each station. Cross sections are ordered within a reach from the highest river station upstream to the lowest river station downstream.



The selection of an appropriate value for Manning's n is very significant to the accuracy of the computed water surface profiles. The value of Manning's n is highly variable and depends on a number of factors including: surface roughness; vegetation; channel irregularities; channel alignment; scour and deposition; obstructions; size and shape of the channel; stage and discharge; seasonal changes; temperature; and suspended material and bed load The values adopted of Manning Coefficient for each reach are:

- Litani River are 0.037 for the main channel and 0.16 for the flood plain from Mansourah village to the connection of Litani with Berdawni River and 0.05 at the part situated upstream for the main channel and 0.16 for the flood plain.
- Faregh River is 0.065 for the main channel and 0.16 for the flood plain.
- Chtaura Tributary and Berdawni River is 0.045 for the main channel and 0.16 for the flood plain.
- Hafir and Jaiir Tributary is 0.045 for the main channel and 0.16 for the flood plain.
- Ghzayel River is 0.05 and 0.07 for the main channel and 0.16 for the flood plain, as for Howayzek and Oqayber Tributary is 0.07 for the main channel and 0.16 for the flood plain.

Type of Channel and Description	Minimum	Normal	Maximum
A. *Natural Streams*			
1. **Main Channels**			
a. Clean, straight, full, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as "d" but more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy. deep pools	0.050	0.070	0.080
h. Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush	0.070	0.100	0.150
2. **Flood Plains**			
a. Pasture no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
2. Same as above, but heavy sprouts	0.050	0.060	0.080
3. Heavy stand of timber, few down trees, little undergrowth, flow below branches	0.080	0.100	0.120
4. Same as above, but with flow into branches	0.100	0.120	0.160
5. Dense willows, summer, straight	0.110	0.150	0.200
3. **Mountain Streams, no vegetation in channel, banks usually steep, with trees and brush on banks submerged**			
a. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. Bottom: cobbles with large boulders	0.040	0.050	0.070

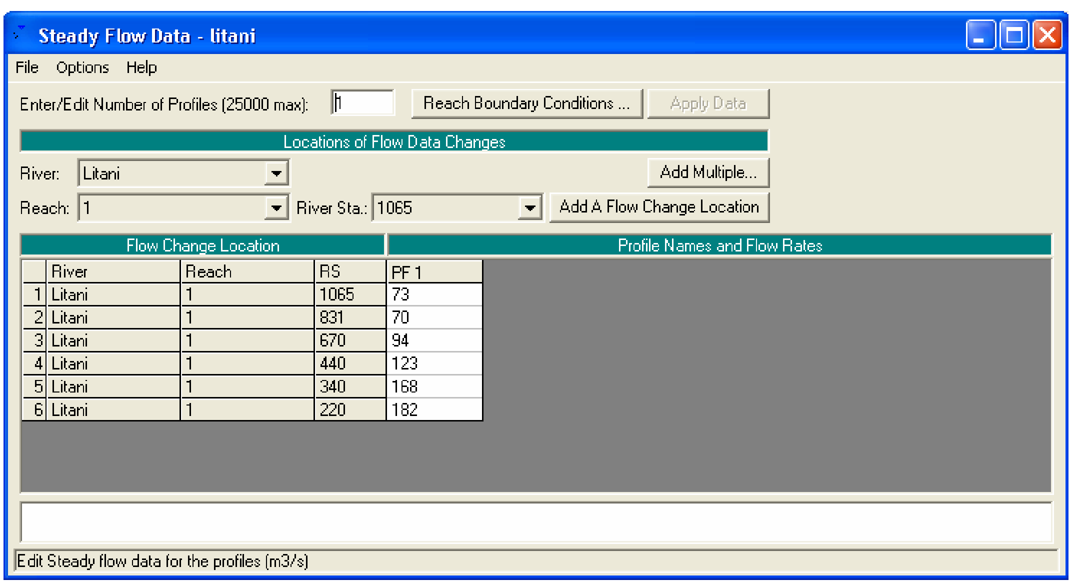
As for the contraction and expansion coefficients, contraction or expansion of flow due to changes in the cross section is a common cause of energy losses within a reach (between two cross sections). Where the change in river cross section is small, and the flow is subcritical, coefficients of contraction and expansion are typically on the order of 0.1 and 0.3, respectively. When the change in effective cross section area is abrupt such as at bridges, contraction and expansion coefficients of 0.3 and 0.5 are often used. On occasion, the coefficients of contraction and expansion around bridges and culverts may be as high as 0.6 and 0.8, respectively. Typical values for contraction and expansion coefficients, for subcritical flow, are shown in below.

Subcritical Flow Contraction and Expansion Coefficients

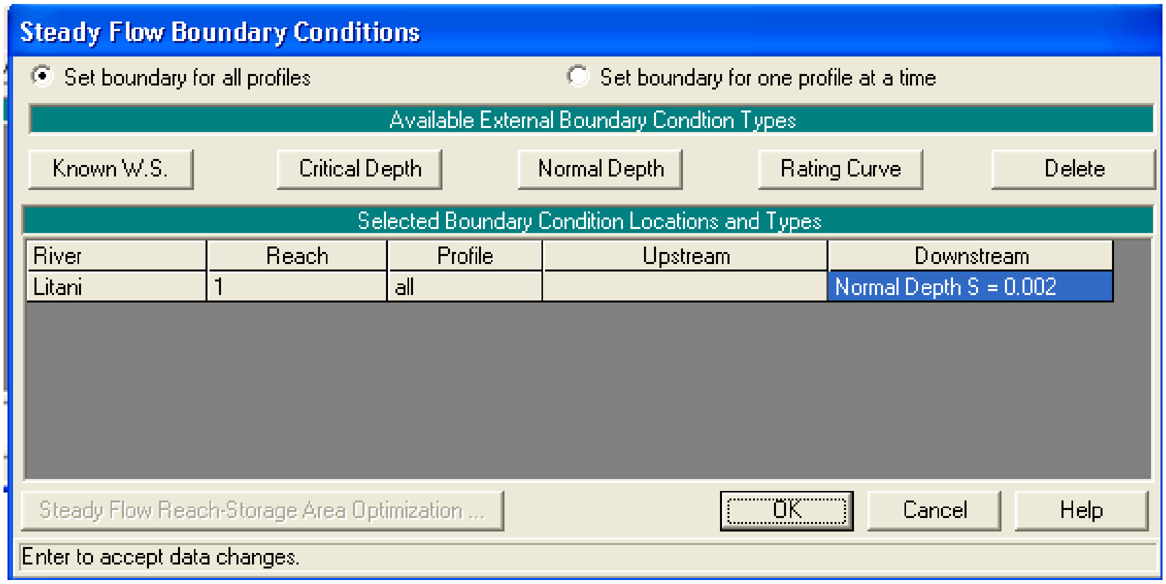
	Contraction	Expansion
No transition loss computed	0.0	0.0
Gradual transitions	0.1	0.3
Typical Bridge sections	0.3	0.5
Abrupt transitions	0.6	0.8

A.3 ENTERING FLOW DATA AND BOUNDARY CONDITIONS

Once the geometric data are entered, we entered our steady flow data. Profile computations begin at a cross section with known or assumed starting conditions and proceed upstream for subcritical flow or downstream for supercritical flow. Below are the flow data for each year.



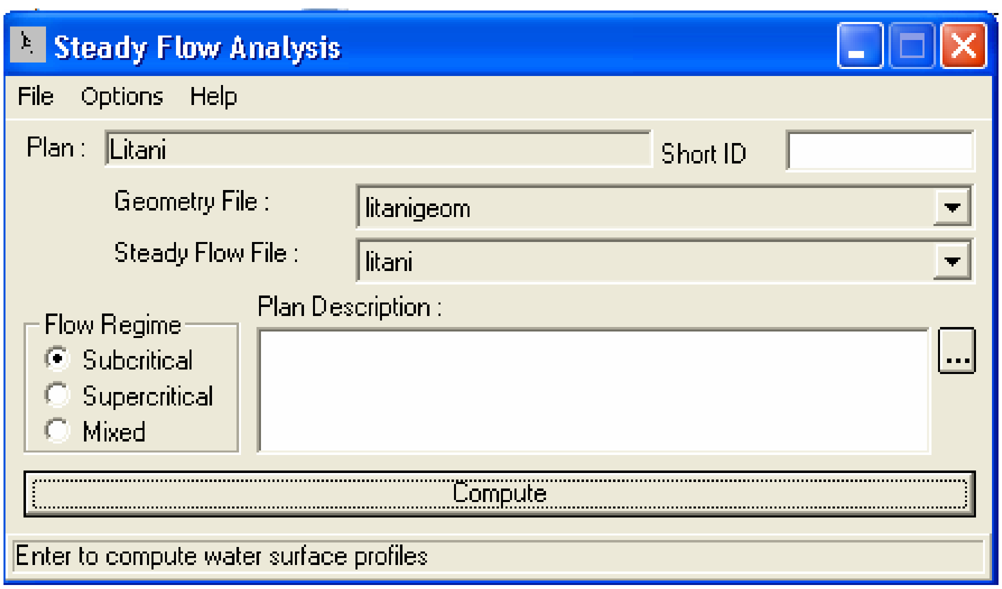
As for the reach boundary conditions we enter the normal depth that is 0.002 in our case.



Boundary conditions are necessary to establish the starting water surface at the ends of the river system. A starting water surface is necessary in order for the program to begin the calculations.

A.4 PERFORMING THE HYDRAULIC CALCULATIONS

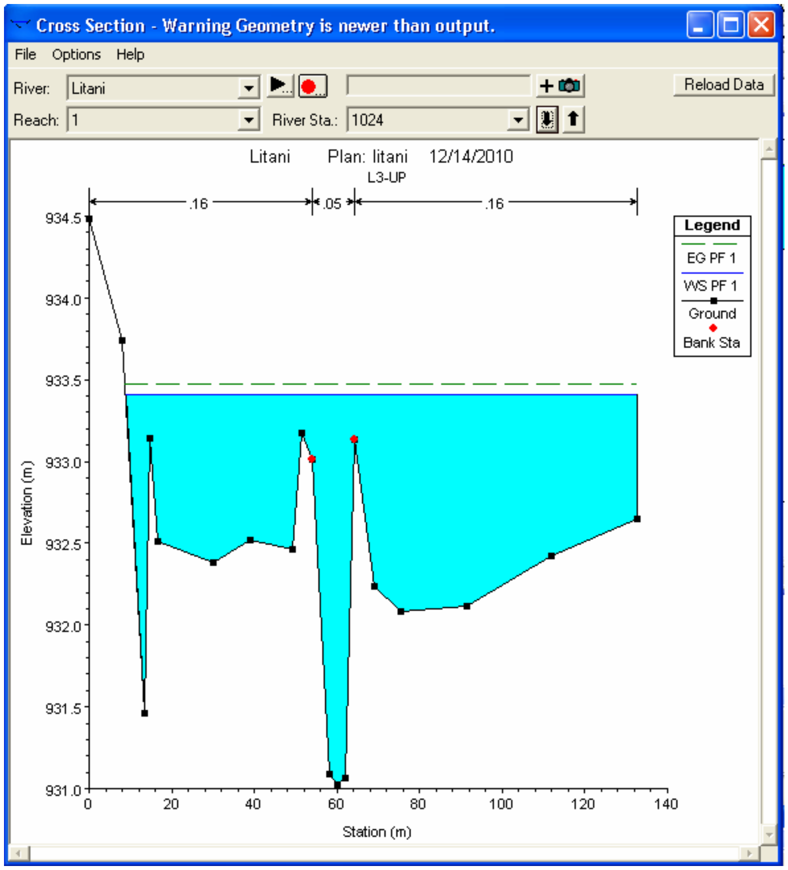
Once all of the geometric data and flow data are entered, the modeler can begin to perform the hydraulic calculations. There are five types of calculations: steady flow analysis, unsteady flow analysis, sediment transport/mobile boundary modeling, water quality analysis and hydraulic design functions. The calculation used is a steady flow analysis.

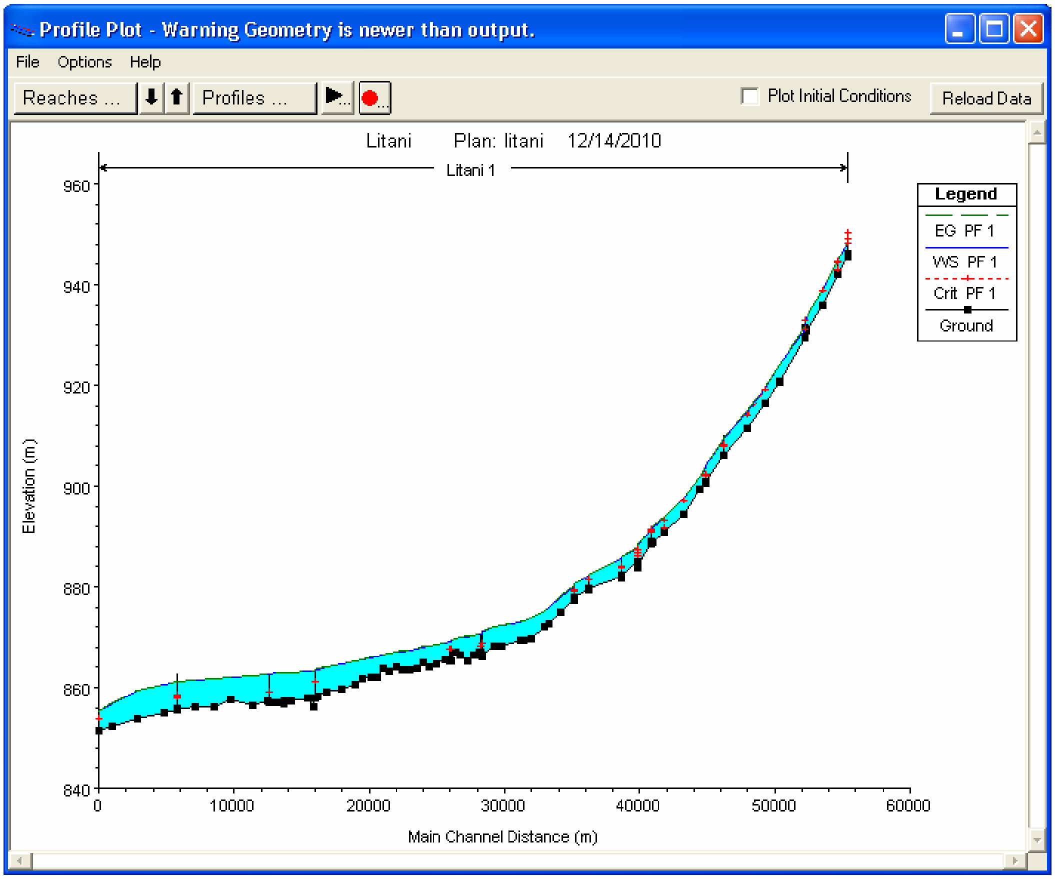


A.5 VIEWING AND PRINTING RESULTS

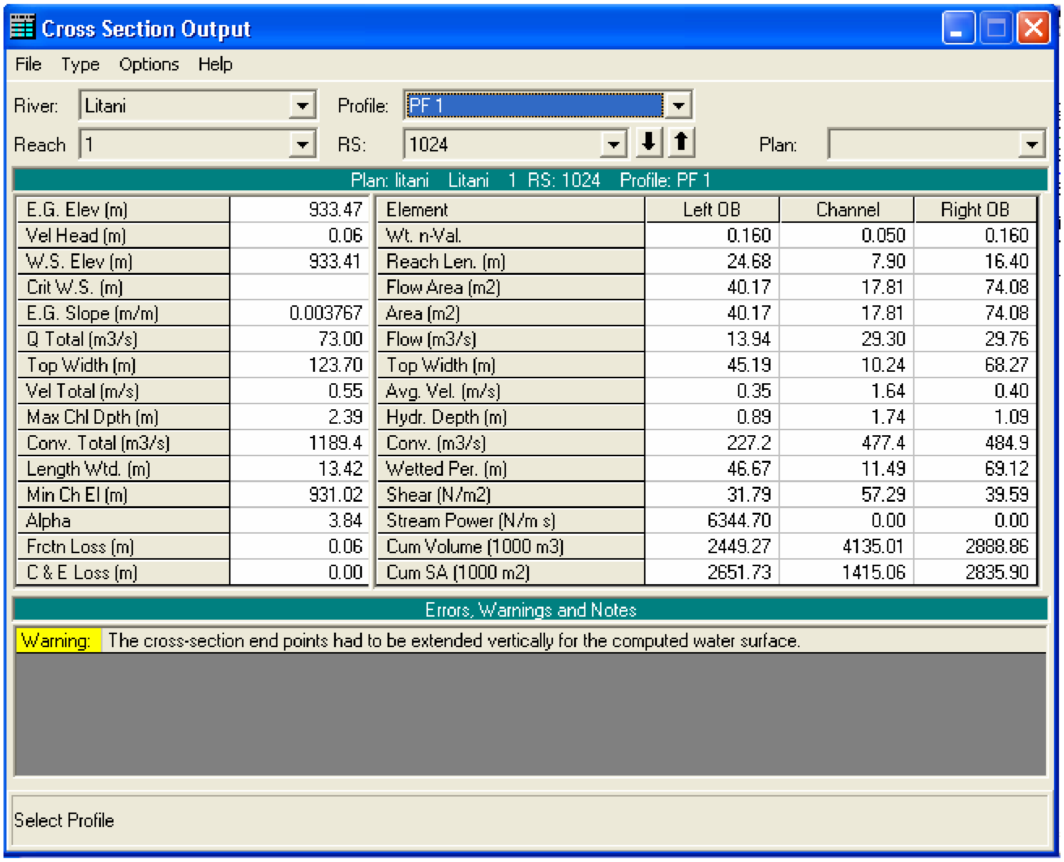
Once the model has finished all of the computations, we can begin viewing the results. These results include: cross section plots, rating curve plots, X Y Z perspective plots, hydrograph plots, tabular output at specific locations, tabular output for many locations and the summary of errors, warning and notes.

Below are some output results.





Tabular output is available in two different formats. The first type of tabular output provides detailed hydraulic results at a specific cross section location illustrated as below

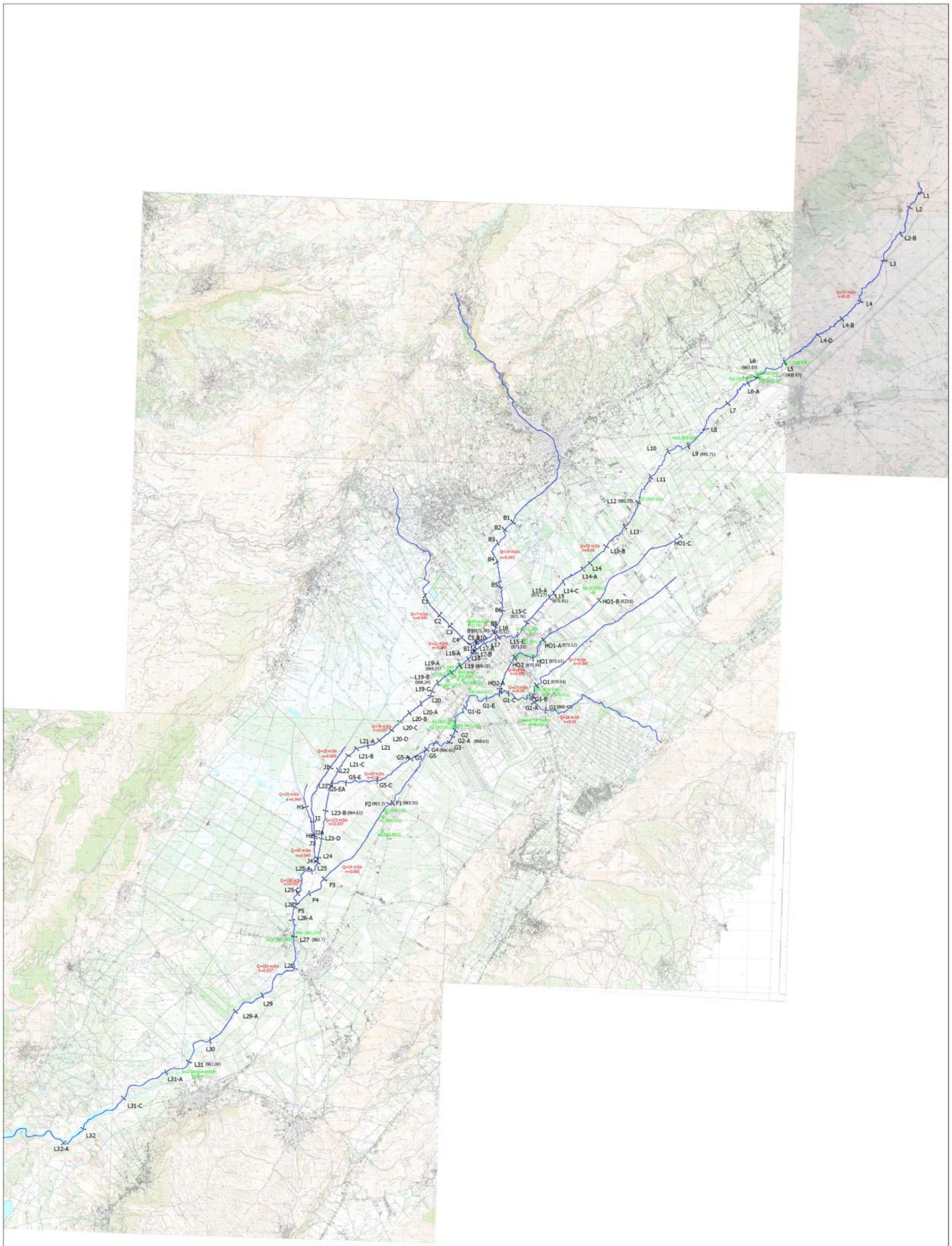


E.G. Elev (m)	933.47
Vel Head (m)	0.06
W.S. Elev (m)	933.41
Crit W.S. (m)	
E.G. Slope (m/m)	0.003767
Q Total (m3/s)	73.00
Top Width (m)	123.70
Vel Total (m/s)	0.55
Max Chl Dpth (m)	2.39
Conv. Total (m3/s)	1189.4
Length Wtd. (m)	13.42
Min Ch El (m)	931.02
Alpha	3.84
Frctn Loss (m)	0.06
C & E Loss (m)	0.00

Element	Left OB	Channel	Right OB
Wt. n-Val.	0.160	0.050	0.160
Reach Len. (m)	24.68	7.90	16.40
Flow Area (m2)	40.17	17.81	74.08
Area (m2)	40.17	17.81	74.08
Flow (m3/s)	13.94	29.30	29.76
Top Width (m)	45.19	10.24	68.27
Avg. Vel. (m/s)	0.35	1.64	0.40
Hydr. Depth (m)	0.89	1.74	1.09
Conv. (m3/s)	227.2	477.4	484.9
Wetted Per. (m)	46.67	11.49	69.12
Shear (N/m2)	31.79	57.29	39.59
Stream Power (N/m s)	6344.70	0.00	0.00
Cum Volume (1000 m3)	2449.27	4135.01	2888.86
Cum SA (1000 m2)	2651.73	1415.06	2835.90

The second type of tabular output shows a limited number of hydraulic variables for several cross sections and multiple profiles.

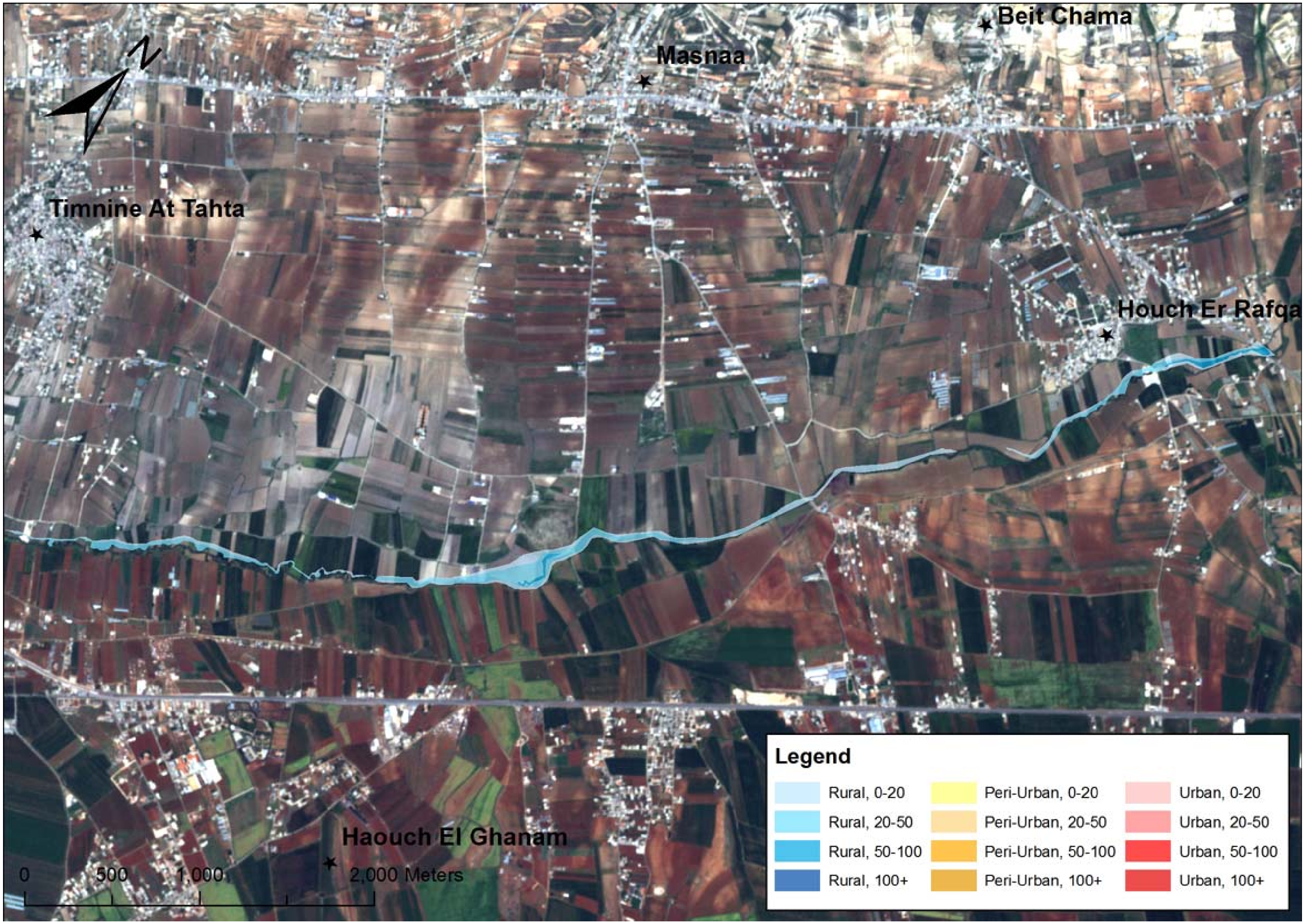
APENDIX B
GENERAL PLAN VIEW

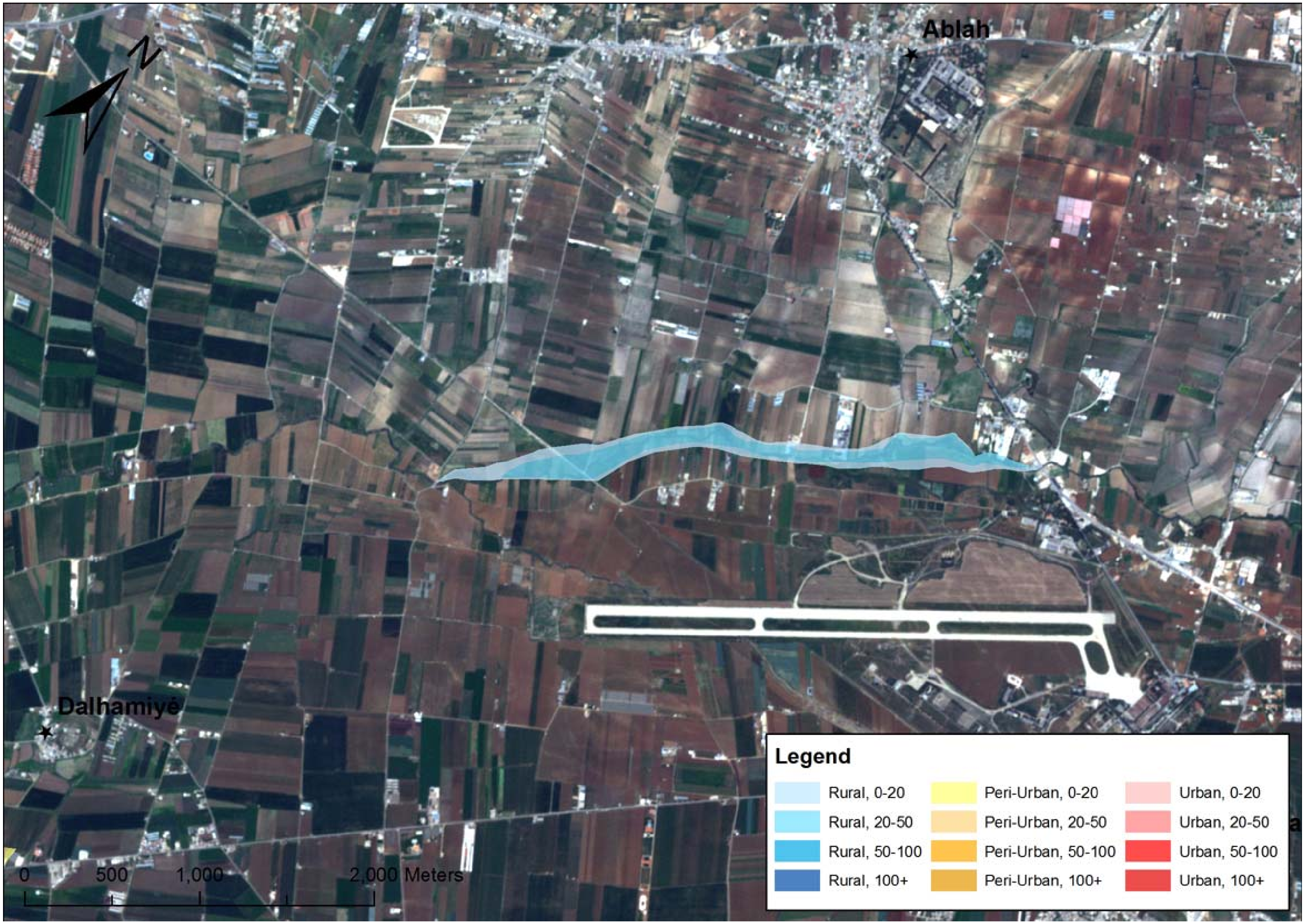


APPENDIX B
GENERAL PLAN VIEW

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

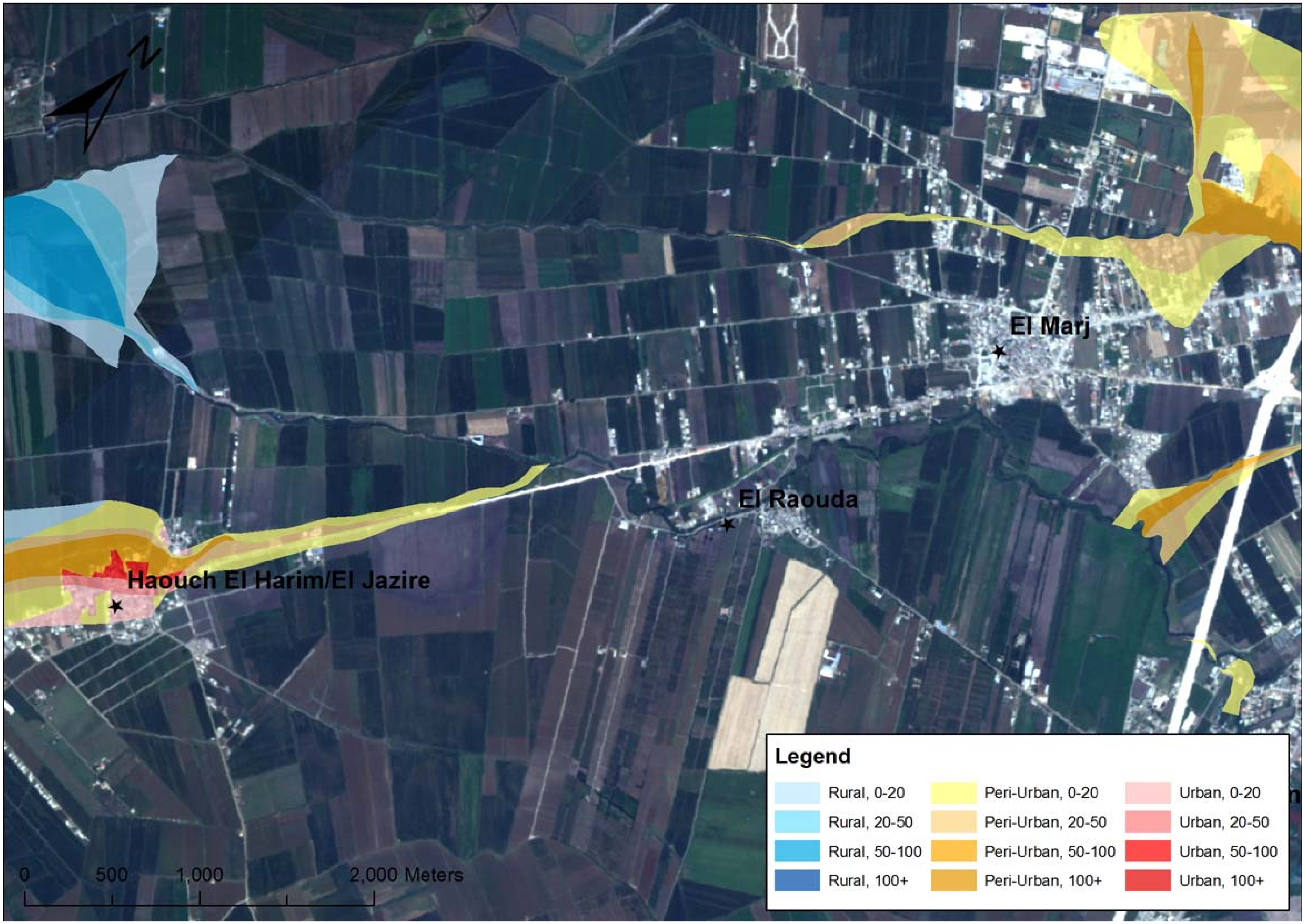
APENDIX C
FLOOD MAPS

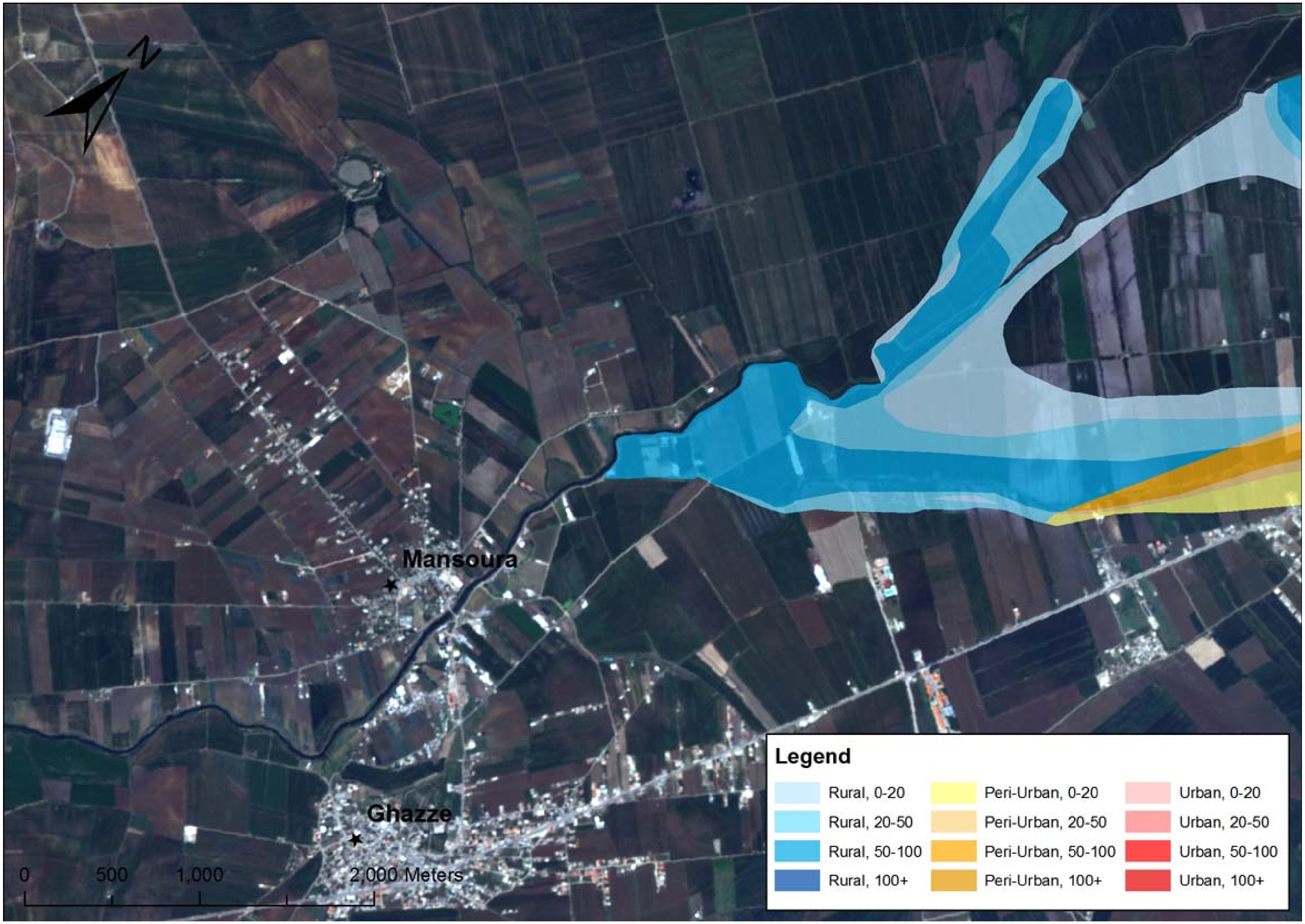

Beit Chama
Masnaa
Timnine At Tahta
Houch Er Rafqa
Haouch El Ghanam
0
500
1,000
2,000 Meters
Legend
Rural, 0-20
Rural, 20-50
Rural, 50-100
Rural, 100+
Peri-Urban, 0-20
Peri-Urban, 20-50
Peri-Urban, 50-100
Peri-Urban, 100+
Urban, 0-20
Urban, 20-50
Urban, 50-100
Urban, 100+



N
Ablah
Dalhamiyé
0
500
1,000
2,000 Meters
Legend
Rural, 0-20
Rural, 20-50
Rural, 50-100
Rural, 100+
Peri-Urban, 0-20
Peri-Urban, 20-50
Peri-Urban, 50-100
Peri-Urban, 100+
Urban, 0-20
Urban, 20-50
Urban, 50-100
Urban, 100+

Barr Elias
Legend
Rural, 0-20
Rural, 20-50
Rural, 50-100
Rural, 100+
Peri-Urban, 0-20
Peri-Urban, 20-50
Peri-Urban, 50-100
Peri-Urban, 100+
Urban, 0-20
Urban, 20-50
Urban, 50-100
Urban, 100+
0
500
1,000
2,000 Meters


El Marj
El Raouda
Haouch El Harim/El Jazire
Legend
Rural, 0-20
Rural, 20-50
Rural, 50-100
Rural, 100+
Peri-Urban, 0-20
Peri-Urban, 20-50
Peri-Urban, 50-100
Peri-Urban, 100+
Urban, 0-20
Urban, 20-50
Urban, 50-100
Urban, 100+
0
500
1,000
2,000 Meters


N
Mansoura
Ghazze
0
500
1,000
2,000 Meters
Legend
Rural, 0-20
Rural, 20-50
Rural, 50-100
Rural, 100+
Peri-Urban, 0-20
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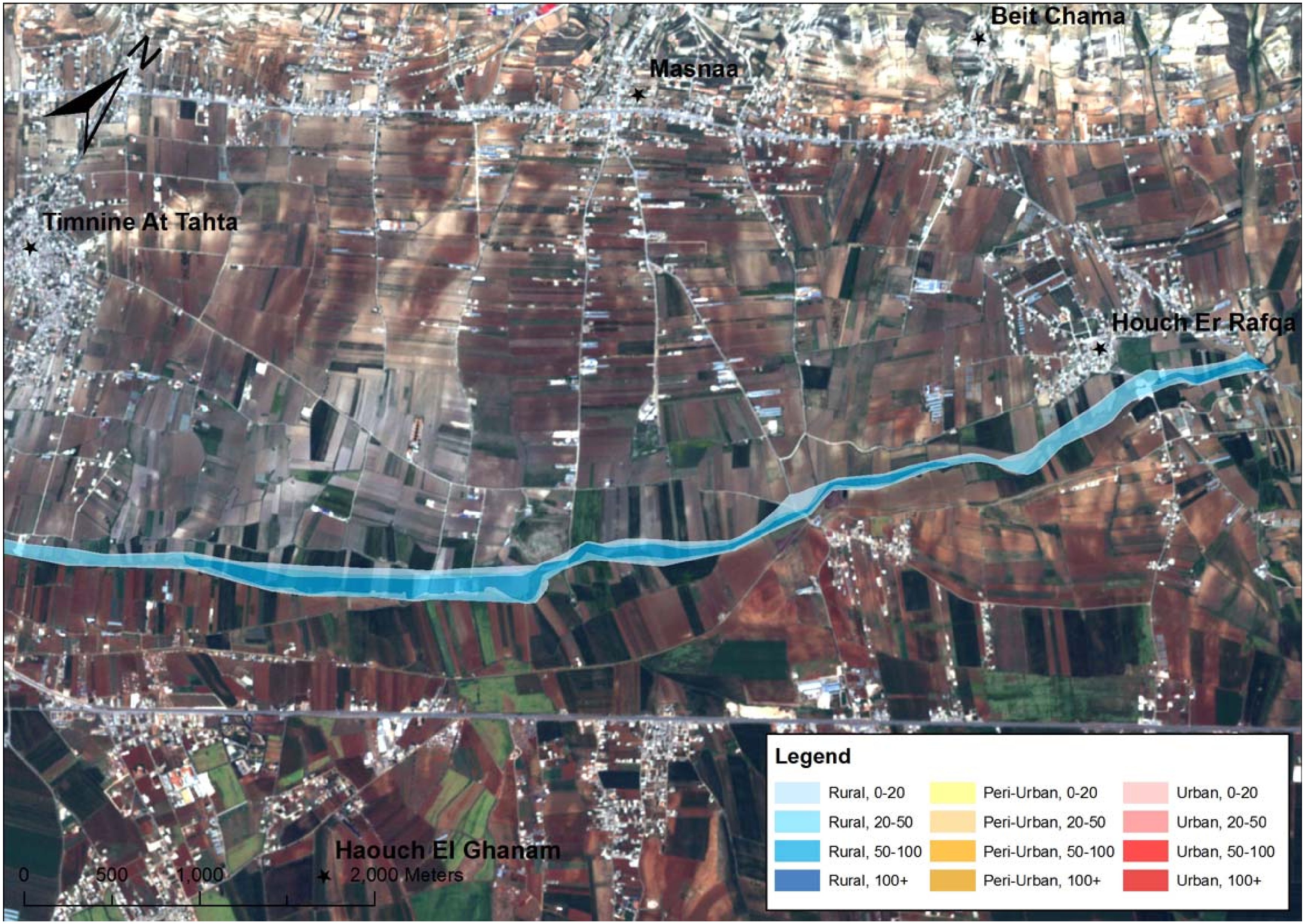
Urban, 50-100
Urban, 100+


N
Beit Chama
Masnaa
Timnine At Tahta
Houch Er Rafqa
Haouch El Ghanam
0
500
1,000
2,000 Meters
Legend
Rural, 0-20
Rural, 20-50
Rural, 50-100
Rural, 100+
Peri-Urban, 0-20
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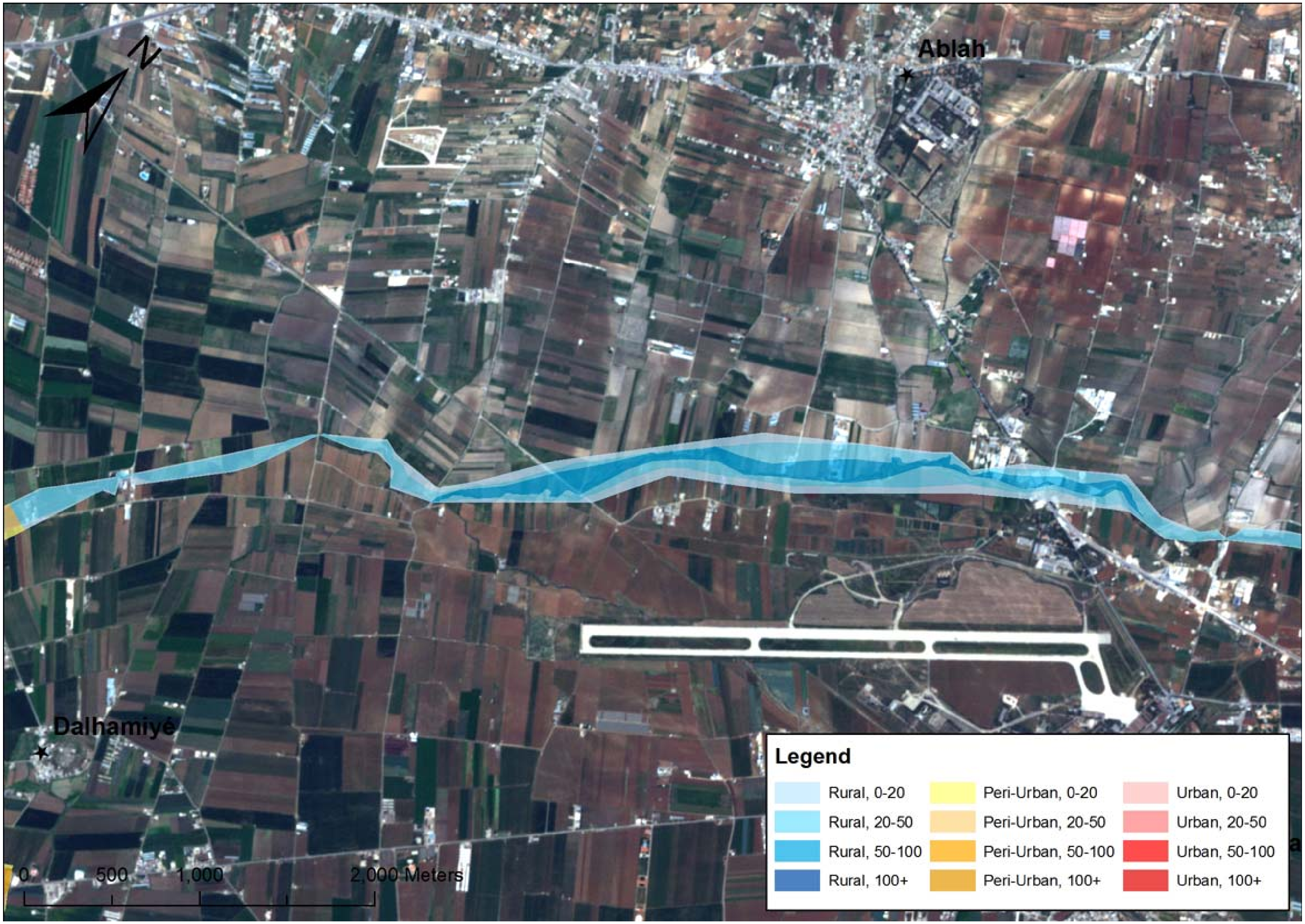

N
Ablah
Dalhamiyé
0 500 1,000 2,000 Meters
Legend
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Rural, 50-100
Rural, 100+
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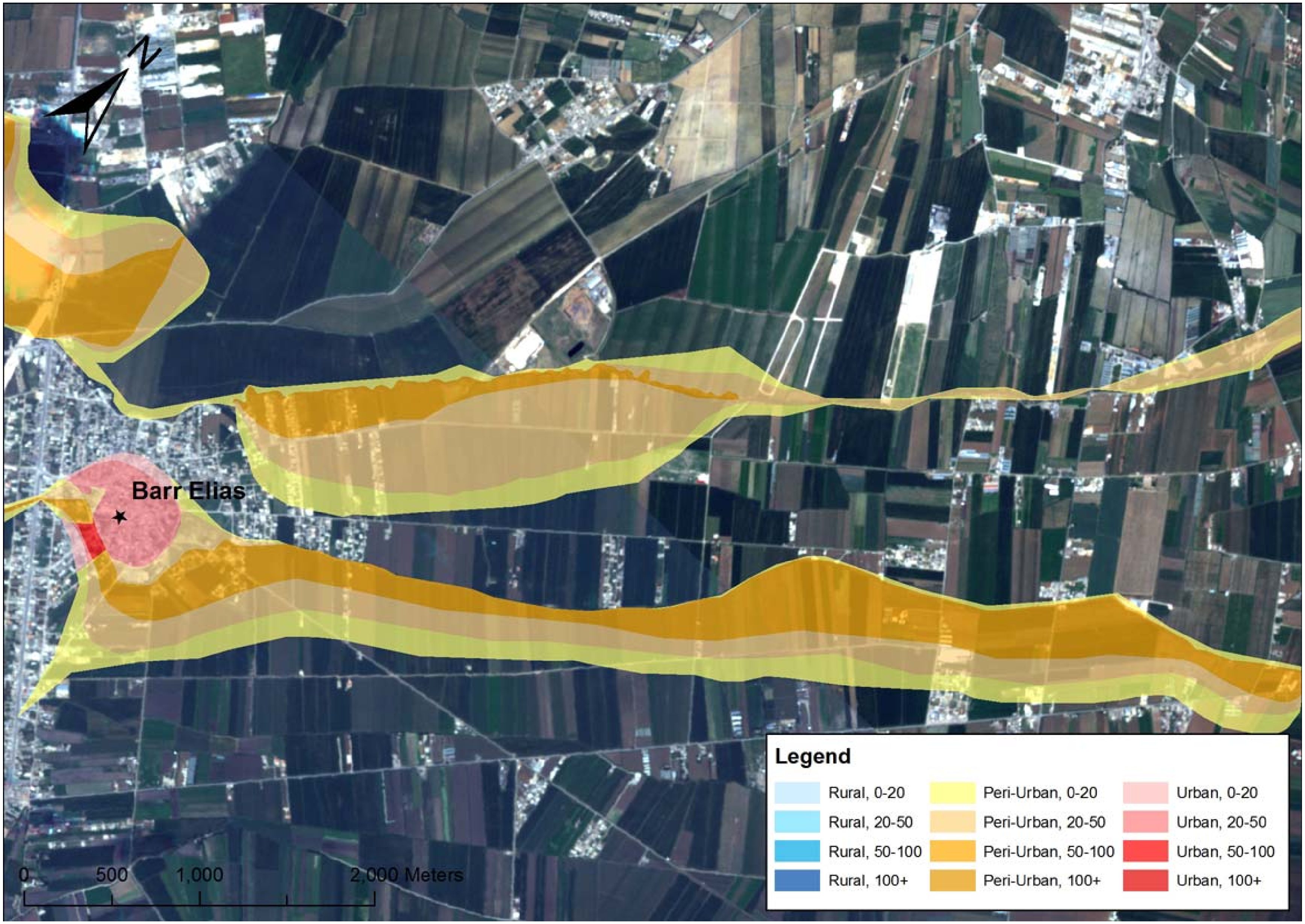

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Barr Elias
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Legend
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Rural, 50-100
Rural, 100+
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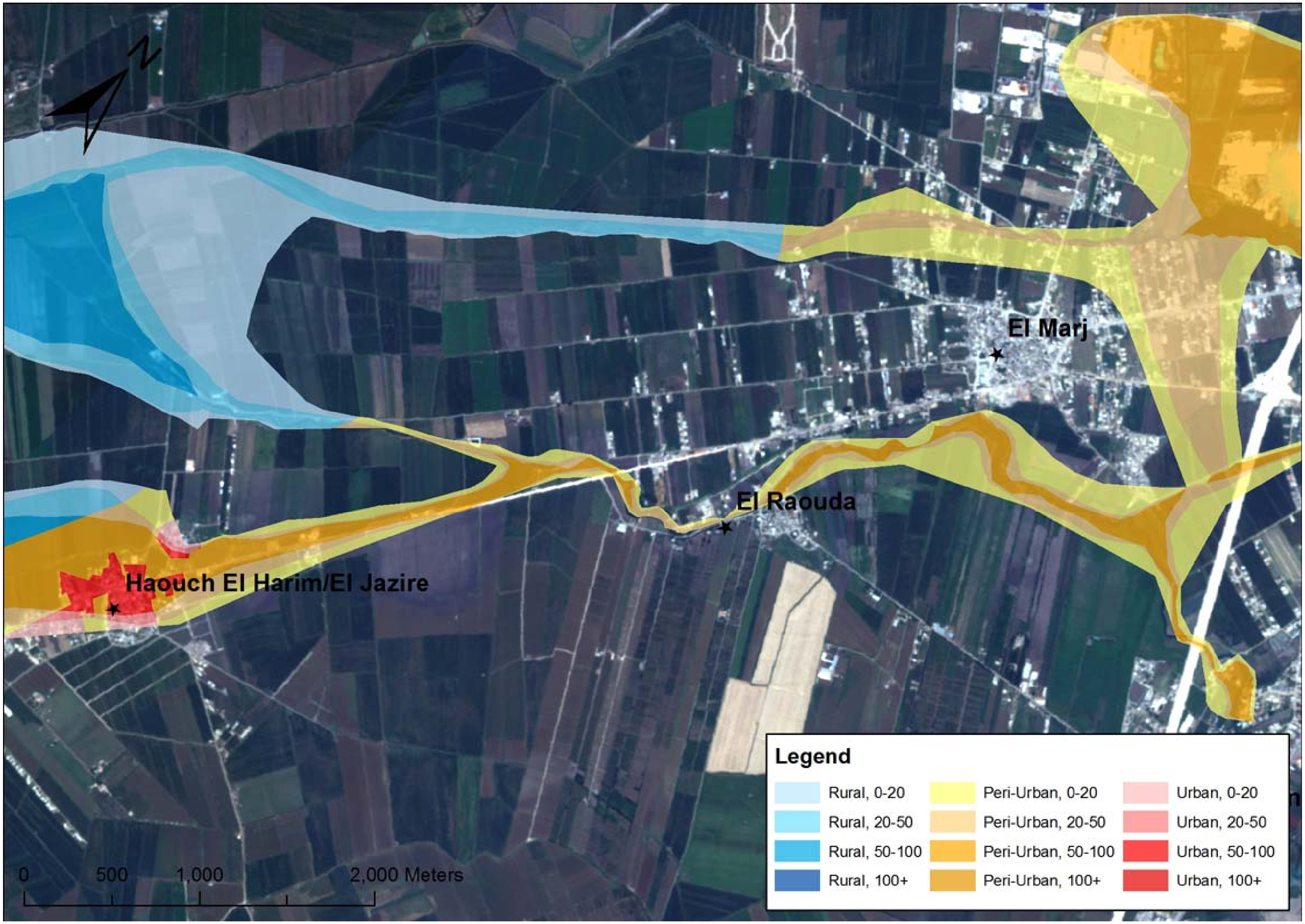
N
El Marj
El Raouda
Haouch El Harim/El Jazire
0 500 1,000 2,000 Meters
Legend
Rural, 0-20
Rural, 20-50
Rural, 50-100
Rural, 100+
Peri-Urban, 0-20
Peri-Urban, 20-50
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Peri-Urban, 100+
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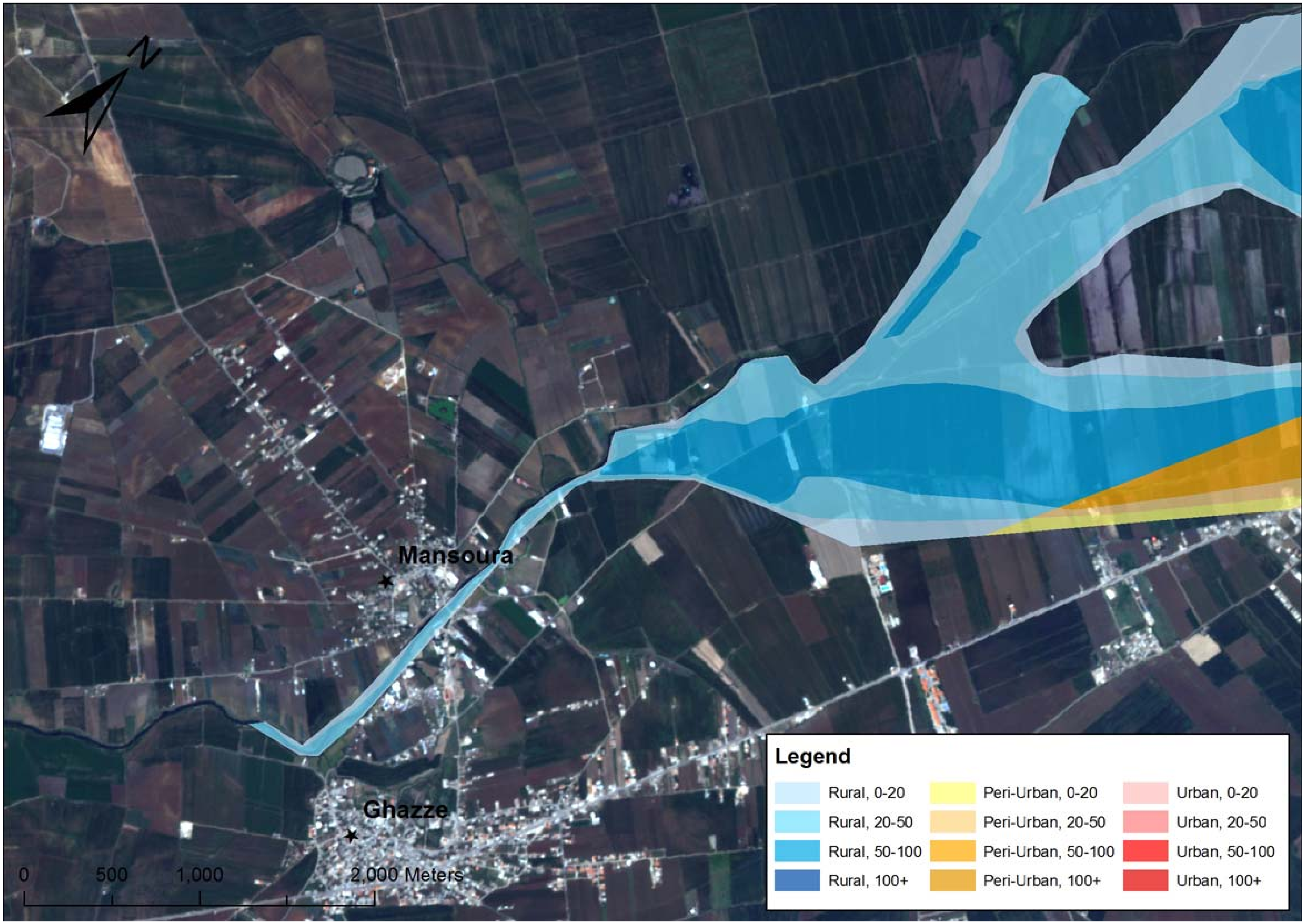
Urban, 20-50
Urban, 50-100
Urban, 100+


N
Mansoura
Ghazze
0
500
1,000
2,000 Meters
Legend
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Rural, 20-50
Rural, 50-100
Rural, 100+
Peri-Urban, 0-20
Peri-Urban, 20-50
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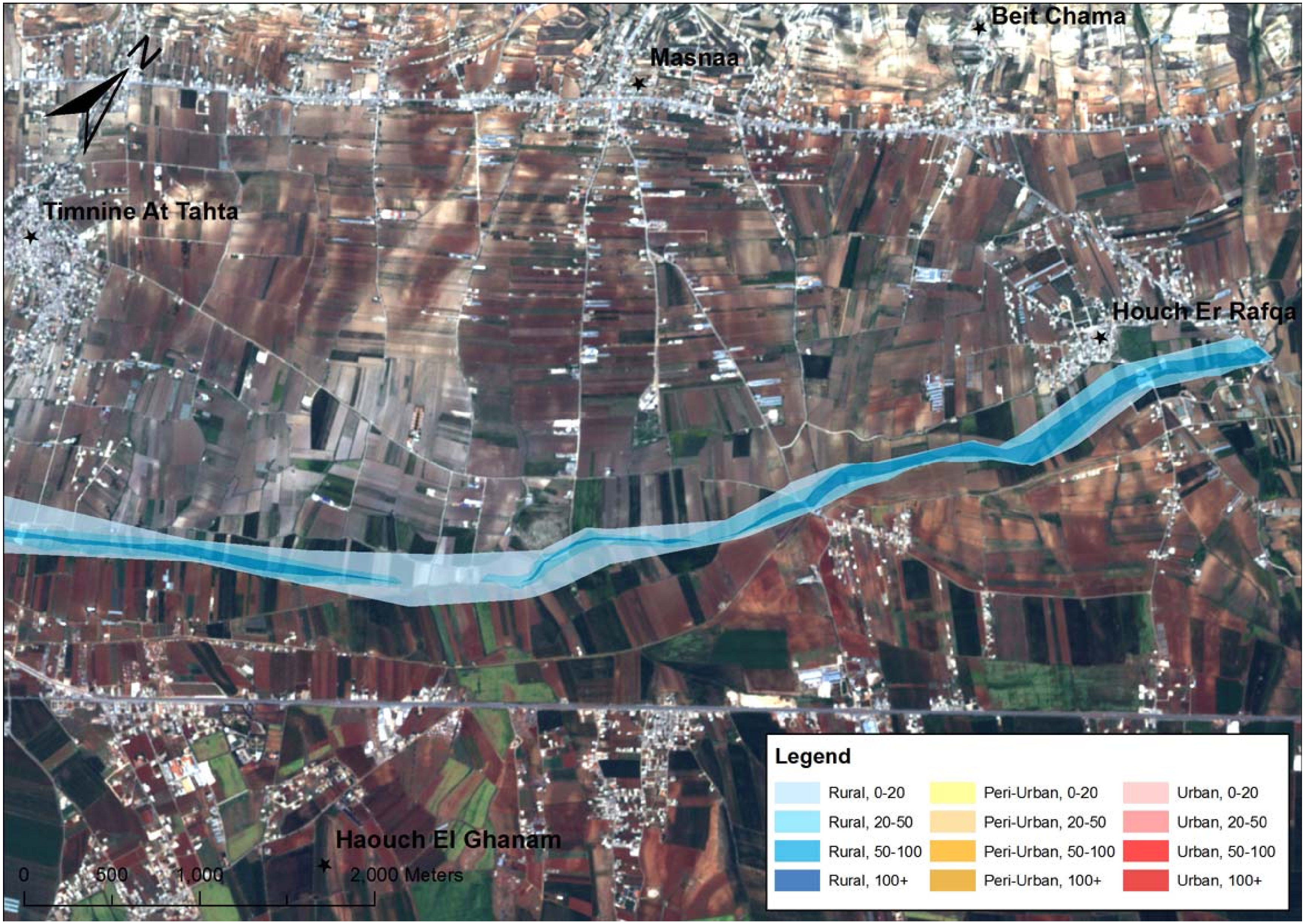

N
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Masnaa
Timnine At Tahta
Houch Er Rafqa
Haouch El Ghanam
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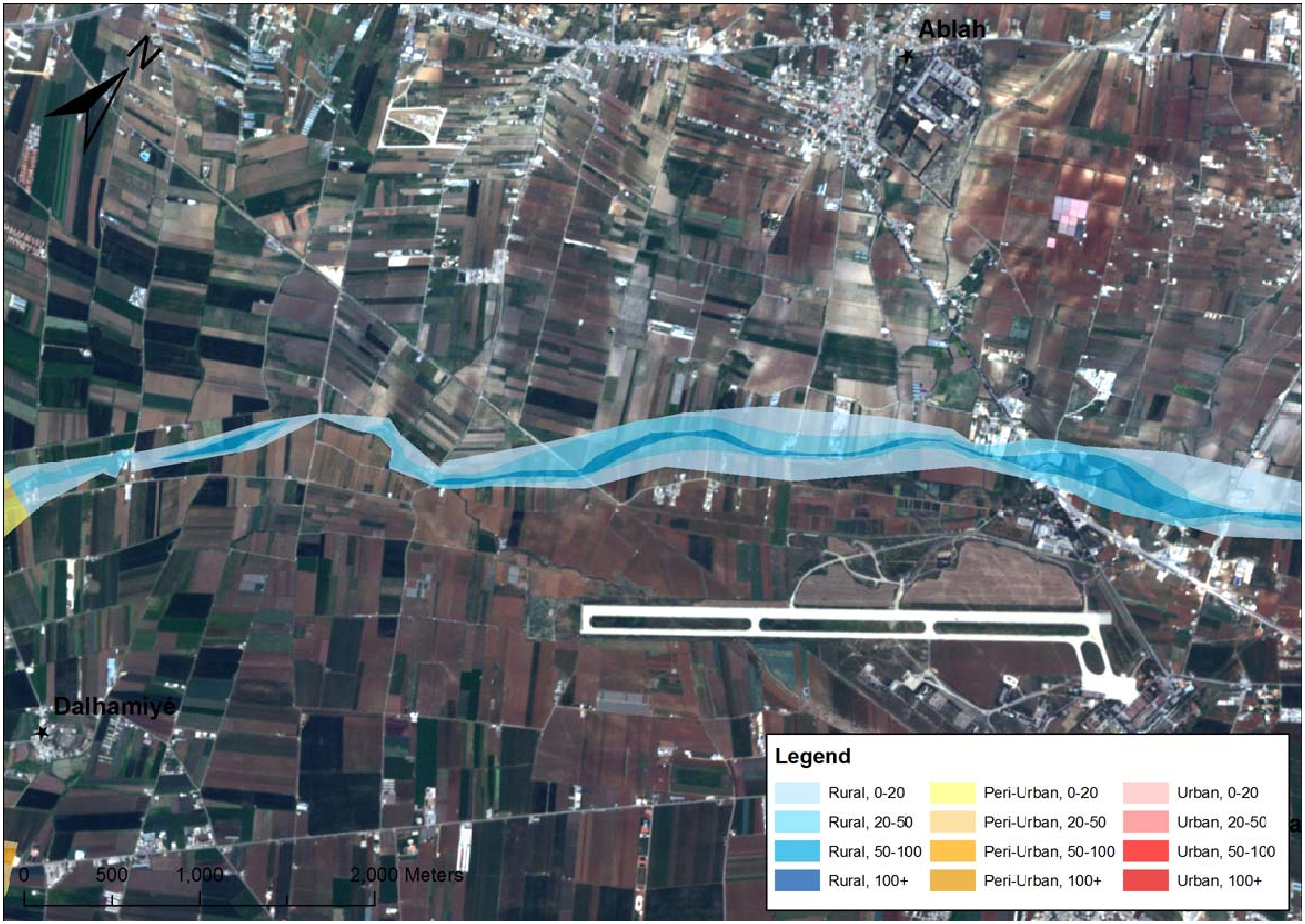

N
Ablah
Dalhamiyé
0
500
1,000
2,000 Meters
Legend
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Rural, 50-100
Rural, 100+
Peri-Urban, 0-20
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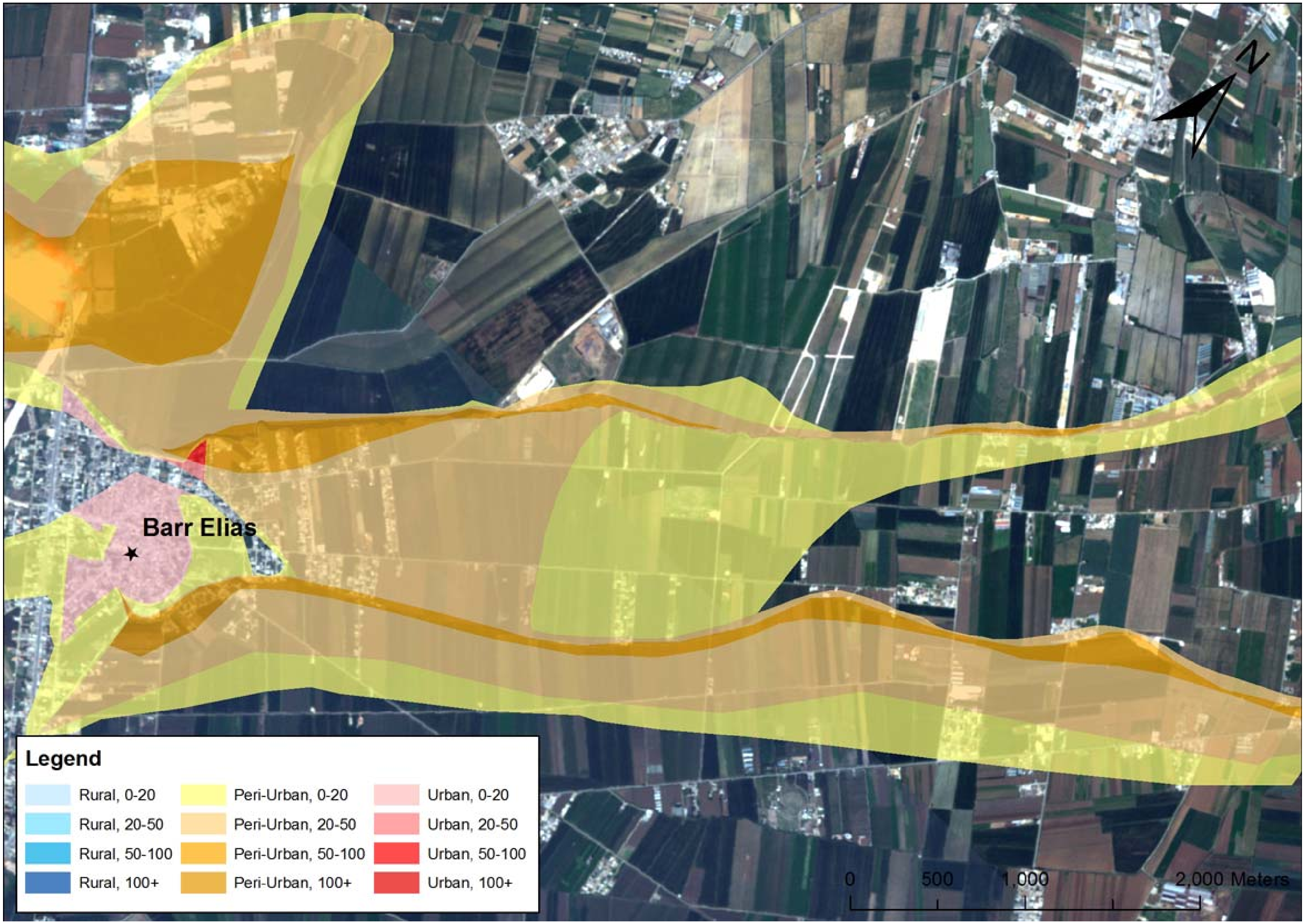

Barr Elias
Legend
Rural, 0-20
Rural, 20-50
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Peri-Urban, 0-20
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Peri-Urban, 50-100
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Urban, 50-100
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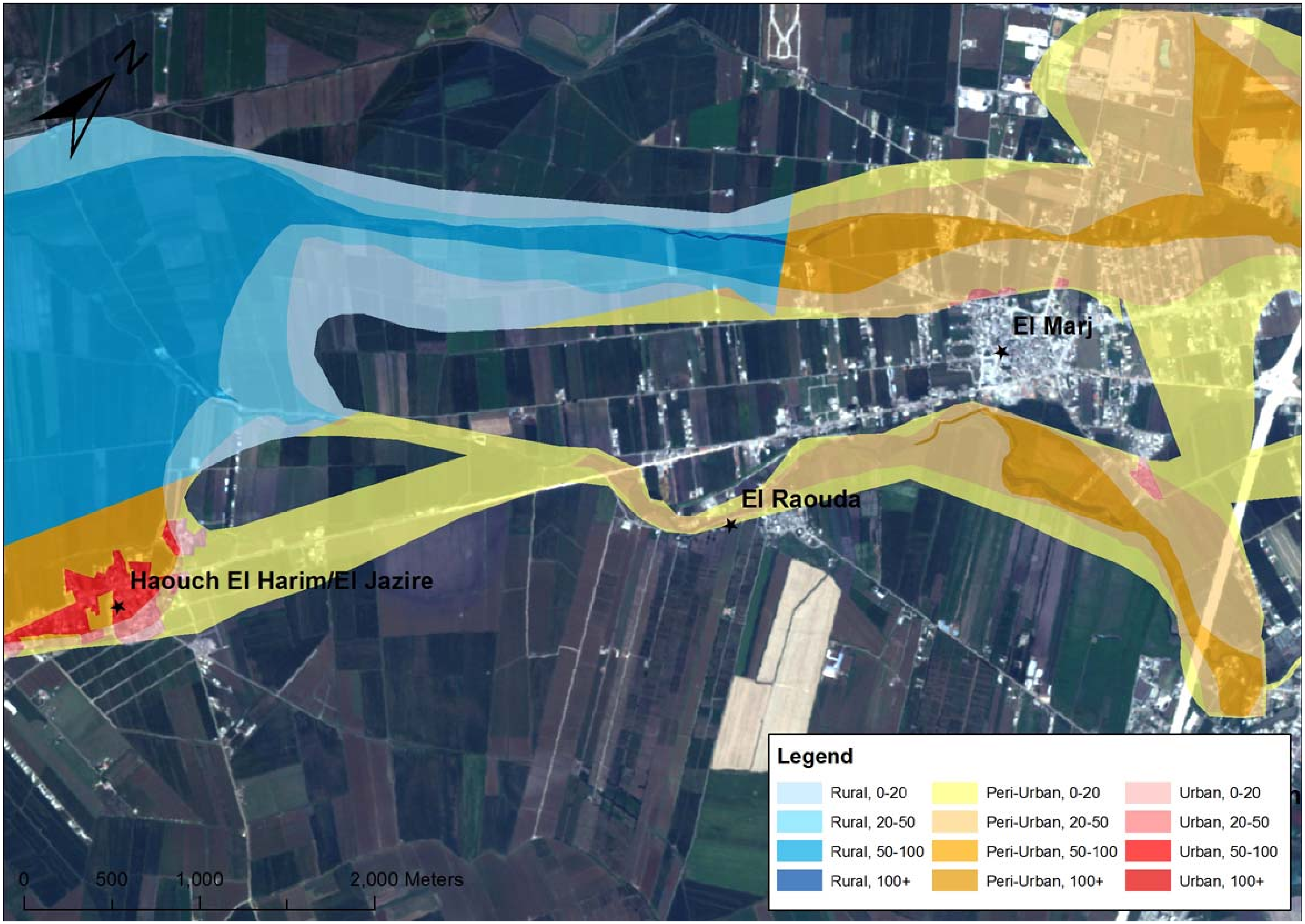
0
500
1,000
2,000 Meters
N


N
El Marj
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Haouch El Harim/El Jazire
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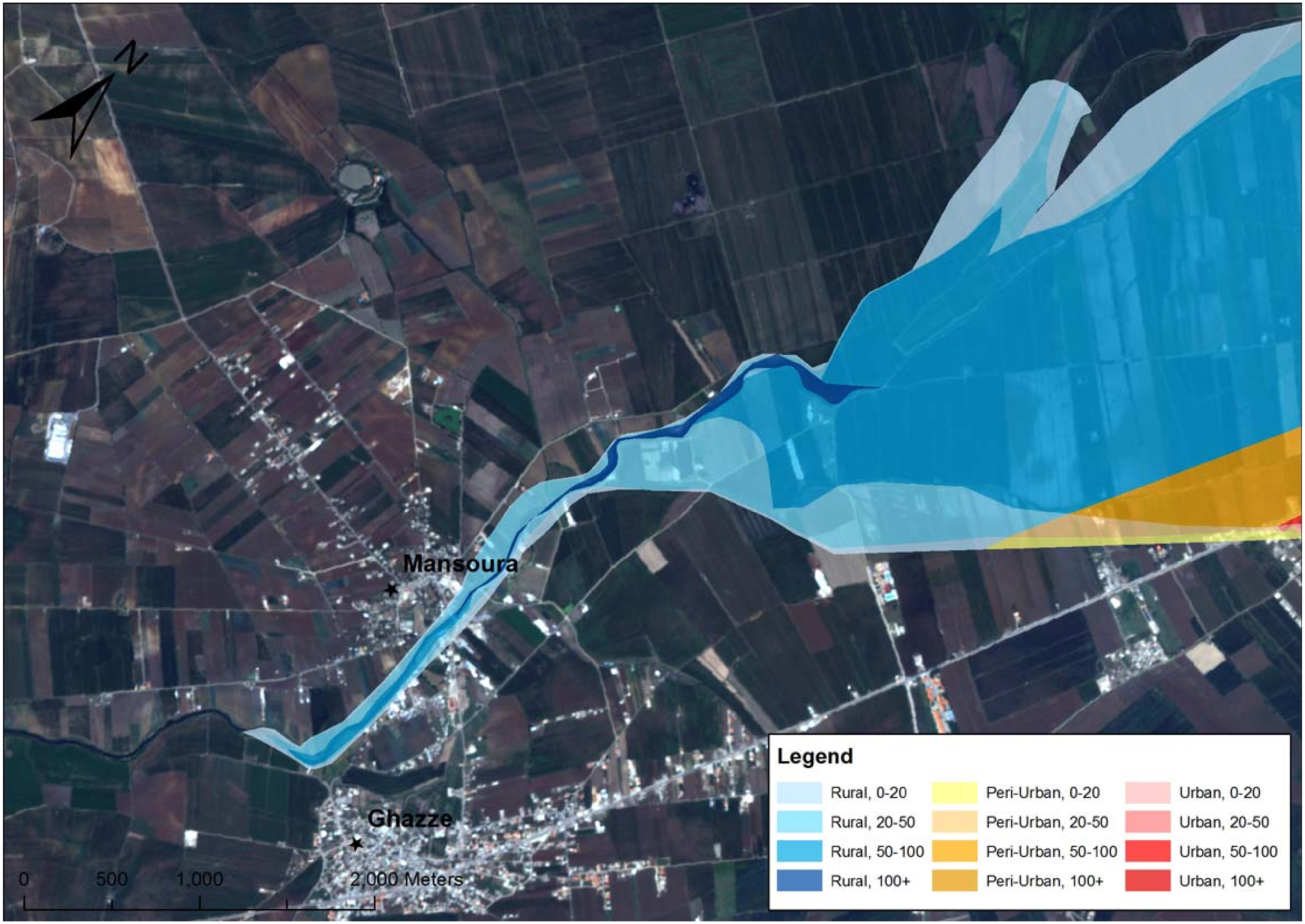

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Mansoura
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Peri-Urban, 50-100
Peri-Urban, 100+
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Urban, 20-50
Urban, 50-100
Urban, 100+

U.S. Agency for International Development
1300 Pennsylvania Avenue, NW
Washington, DC 20523
Tel: (202) 712-0000
Fax: (202) 216-3524
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