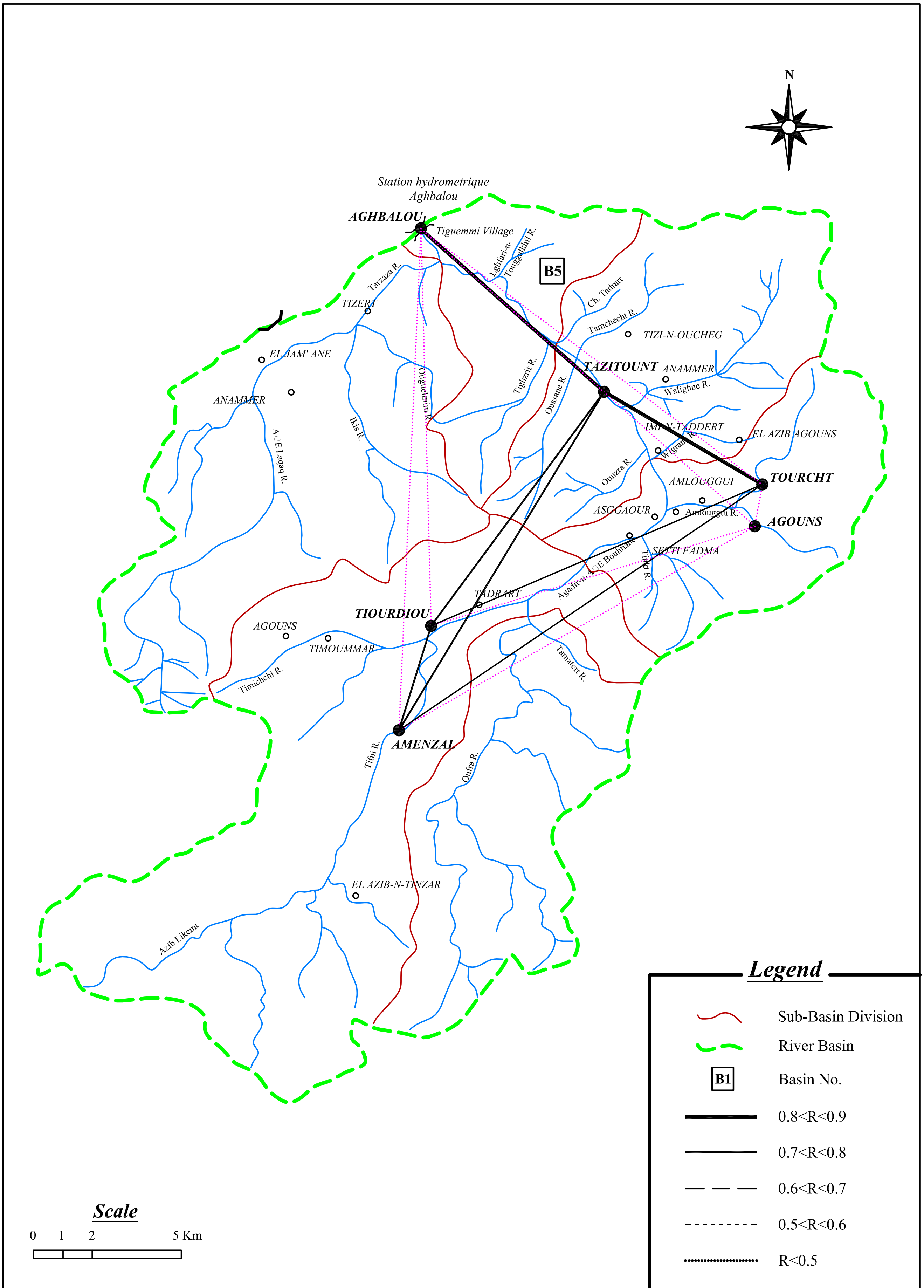
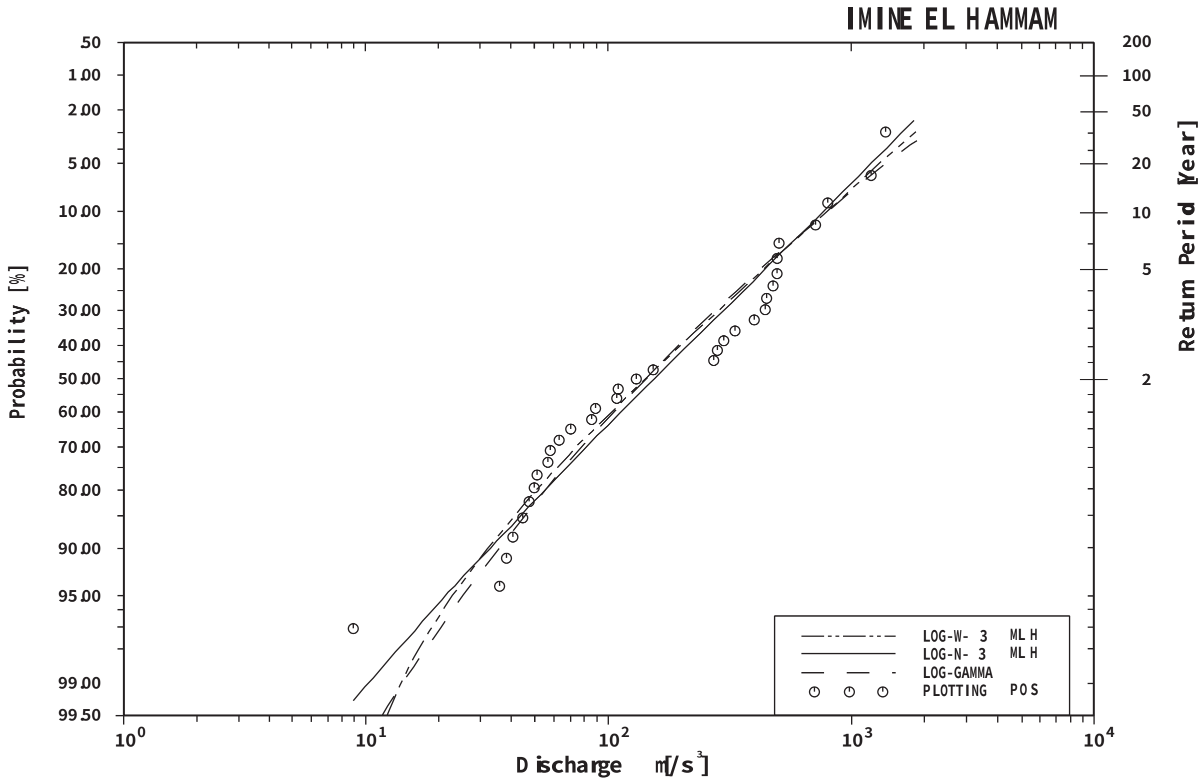
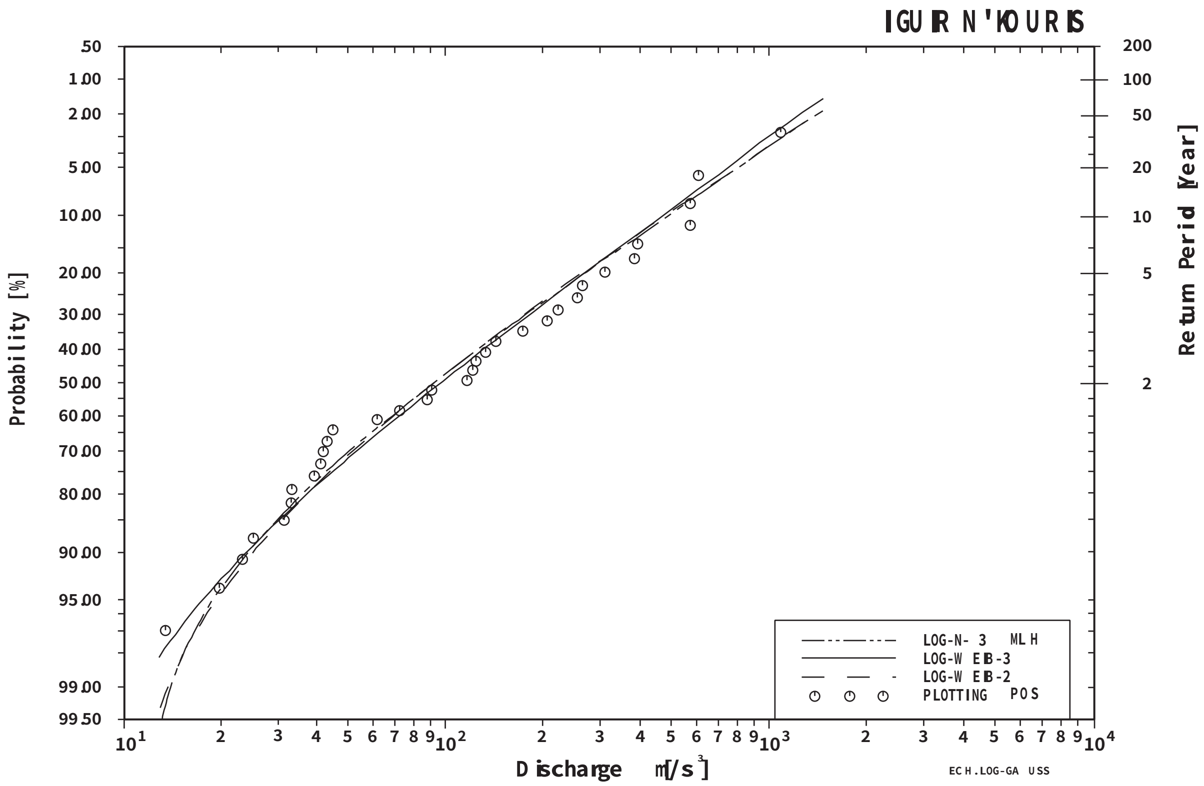


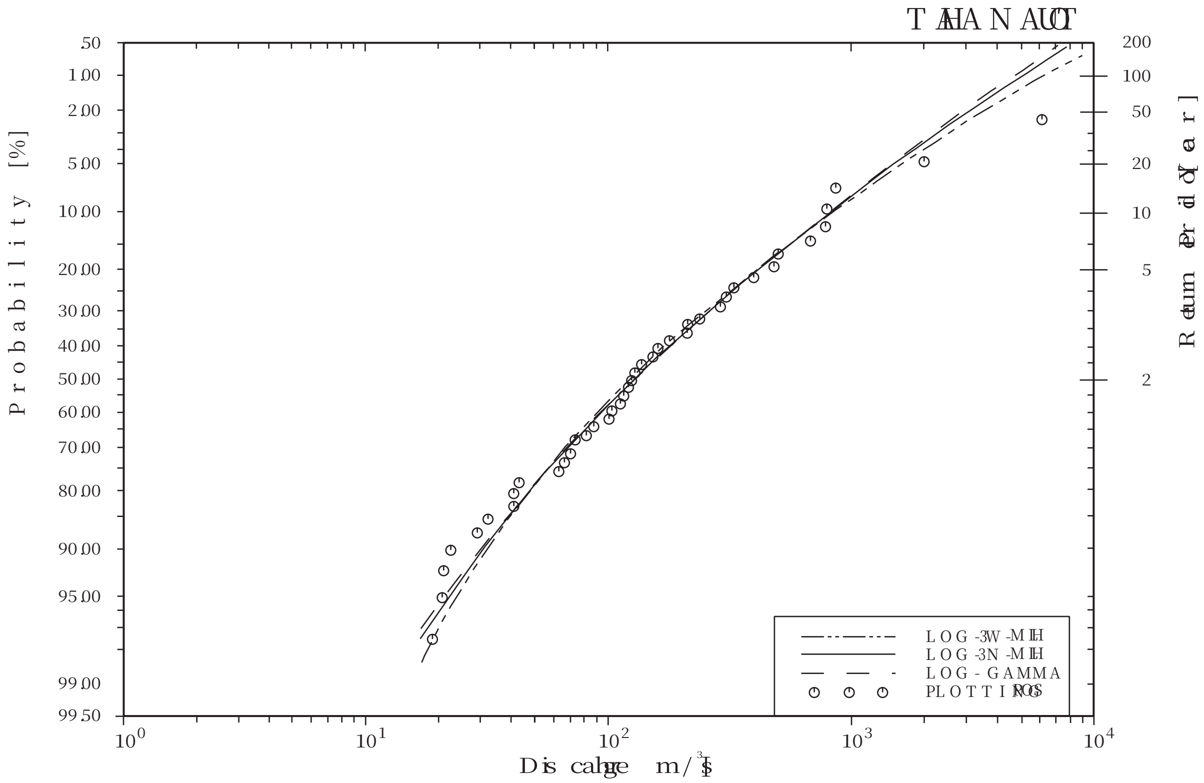
THE MASTER PLAN STUDY ON
FLOOD FORECASTING AND WARNING SYSTEM
FOR ATLAS REGION IN THE KINGDOM OF MOROCCO

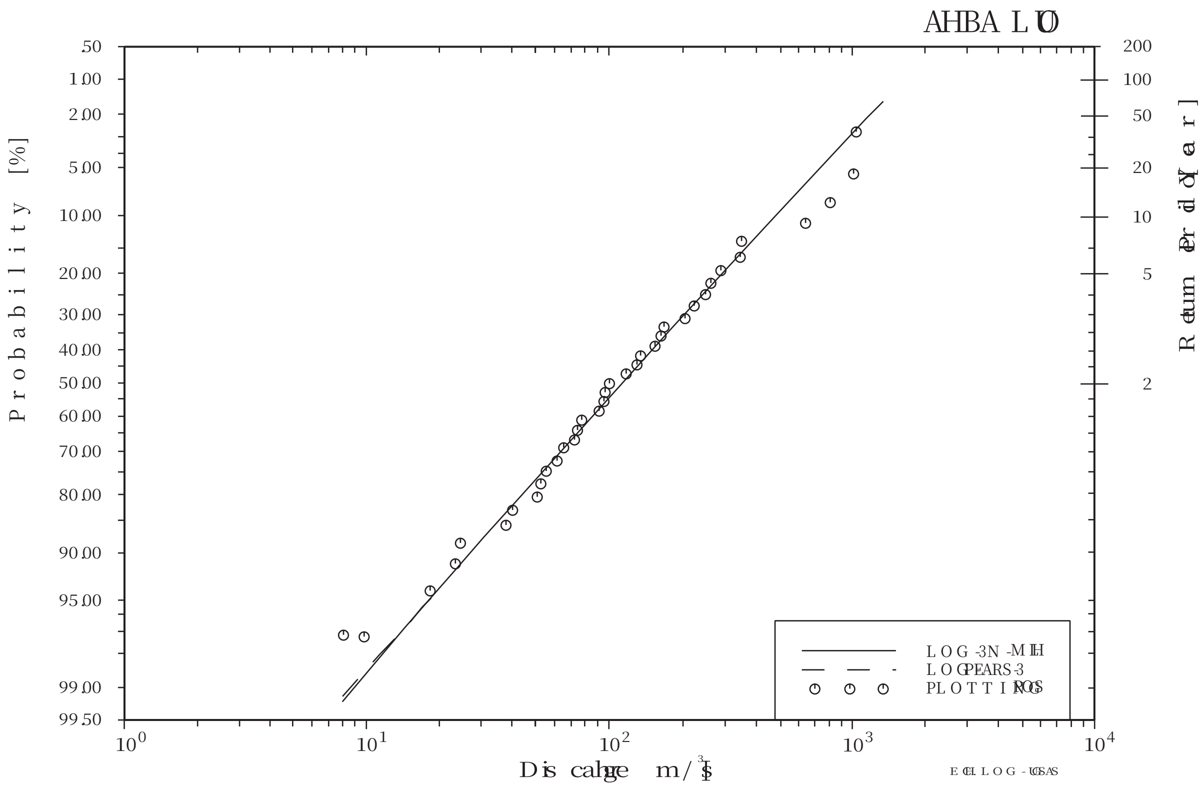
Fig. C.3.7 DAILY RAINFALL CORRELATION



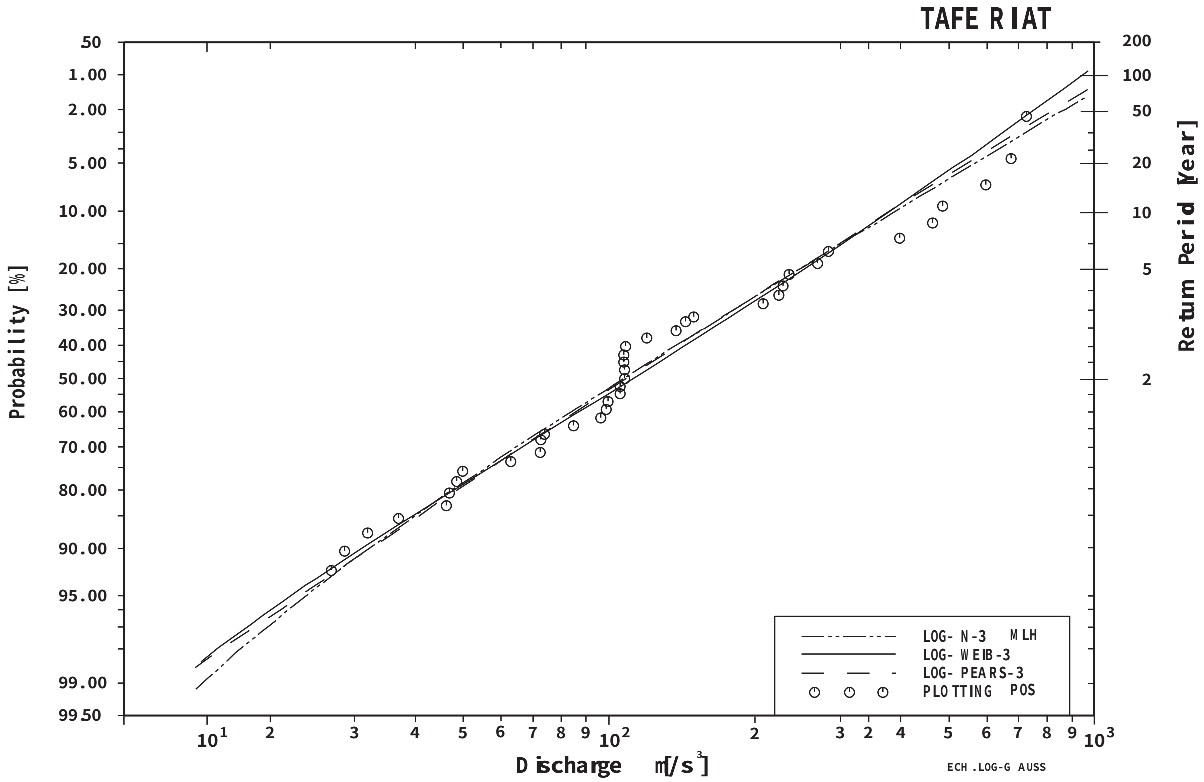


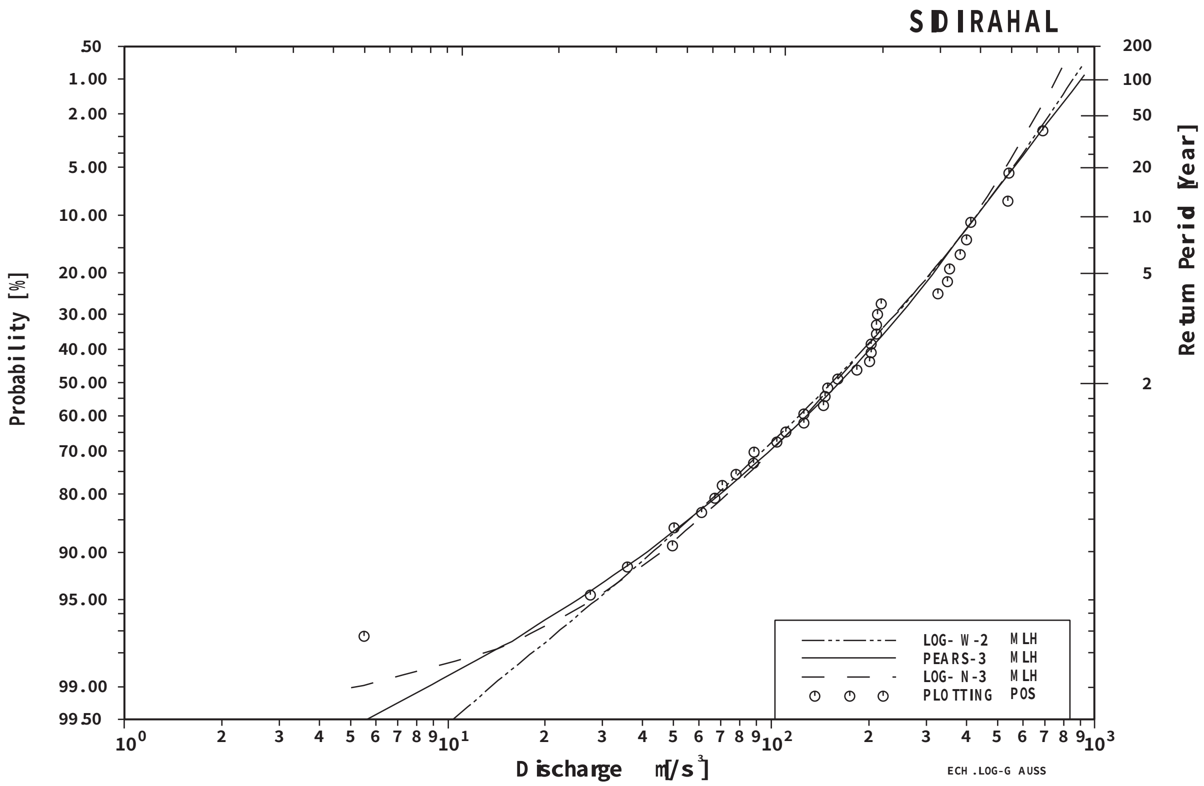
THE MASTER PLAN STUDTY ON FLOOD FORECASTING AND WARNING SYSTEM FOR ATLAS REGION IN KINGDOM OF MOROCCO	Fig. C.3.8 (1) PROBABLILITY OF MAXIMUM DISCHARGE





THE MASTER PLAN STUDTY ON FLOOD FORECASTING AND WARNING SYSTEM FOR ATLAS REGION IN KINGDOM OF MOROCCO	Fig. C.3.8 (2) PROBABLILITY OF MAXIMUM DISCHARGE





THE MASTER PLAN STUDTY ON FLOOD FORECASTING AND WARNING SYSTEM FOR ATLAS REGION IN KINGDOM OF MOROCCO	Fig. C.3.8 (3) PROBABLILITY OF MAXIMUM DISCHARGE

APPENDIX D

HYDRAULIC SIMULATION

THE MASTER PLAN STUDY ON
FLOOD FORECASTING AND WARNING SYSTEM
FOR ATLAS REGION IN THE KINGDOM OF MOROCCO

APPENDIX D HYDRAULIC SIMULATION

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APPENDIX D HYDRAULIC SIMULATION MODEL

CHAPTER 1. INTRODUCTION

1.1 Objective Flood Simulation

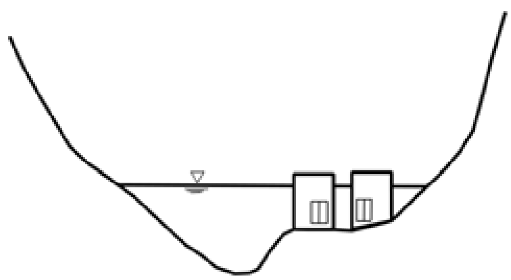
To identify probable flood inundation area along the N'fis, Rheraya, Ourika, R'dat, Zat and Issyl river basins, and to determine basic hydrological parameters for flood forecasting modeling, a flood simulation model is established for the objective six rivers.

1.2 Target Area for Modeling

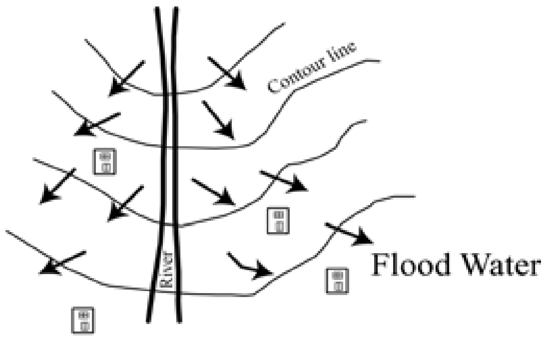
The target area was chosen with consideration of inundation and damaged area of the past flood and the location of infrastructure (mainly roads along the river) and houses. The target area was the same as topographic river survey area as shown in Fig. D.1.1. Fig. D.1.2 present the location of Cross-section survey

1.3 Selection of Software

Since the five rivers other than the Issyl all flow down in valley areas, flood water is confined in the rivers and the river banks. The Issyl River flows down in the alluvial fan area, in which floodwater spreads over.



Flood Inundation in a Valley
(5 rivers except Issyl River)



Flood Inundation in an Alluvial Fan
(Issyl River)

The selection of software for establishing a simulation model for these rivers shall be made in consideration of the above characteristics. The following software is selected for the six objective rivers.

Selected Software for inundation analysis

River	Type of Inundation	Proposed Software
5 Rivers other than Issyl River	Confined in valley	ISIS* (one-dimensional dynamic flow model)
Issyl River	Diffusive over fan	Two-dimensional dynamic flow model

(1) ISIS

ISIS is package software supplied by HR Wallingfort. ISIS software is suitable for a wide range of river engineering and environmental applications, from calculating simple backwater profiles to modeling entire catchments. The ISIS software is a modular software system for simulating flow, hydrology, water quality and sediment transport in canals, rivers, flood plains, estuaries and catchments. The core of software is summarized below.

ISIS Software Package

Available Module	Contents of Module	Use in this Study
ISIS Flow	Hydrodynamic modeling of open and converted channel system.	Yes
ISIS Steady	Backwater computation, including trans-critical flows	Yes
ISIS Routing	Flood Rooting	Yes
ISIS Hydrology	Rainfall-runoff modeling	Yes
ISIS Quality	Water quality process modeling	No
ISIS Sediment	Sediment transport modeling	No
ISIS WMS	Mapping module (Flood inundation area)	Yes

(2) Two-dimensional dynamic flow model

For the Issyl River, a two-dimensional dynamic flow model is applied. This model divides the flood plain into many square cells, every of which is given hydraulic attributes such as elevation and roughness. The dynamic flow equation is solved two-dimensionally. The ISIS hydrological module can be used for estimation of the boundary conditions.

CHAPTER 2. MODELING

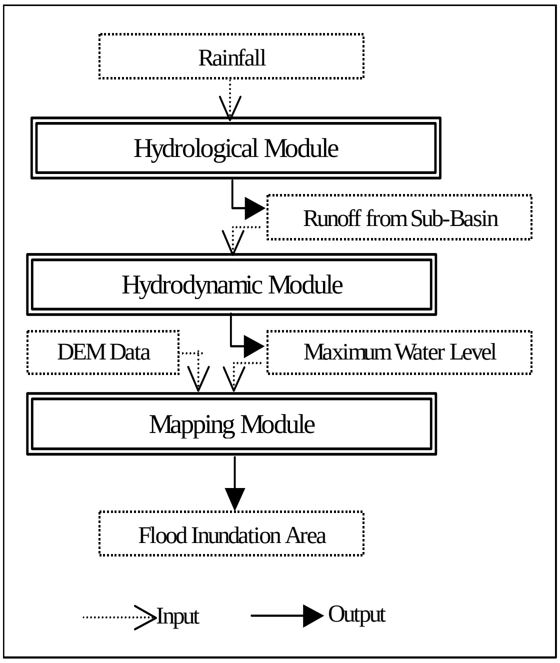
2.1 Introduction

In this section, the flood simulation model is established for each basin on the basis in consideration of the characteristics of basin, the condition of data stock etc. The modeling of the Ourika River is described in the section 2.2, the modeling of the Issyl River is expressed in the section 2.3 and the section 2.4 is about another basin.

2.2 Elaboration of Flood Inundation Simulation Model for Ourika River

First a flood simulation model has been elaborated for the Ourika River of which hydrological data accumulation is not sufficient but better than any other river basins. The following is a description of the elaboration of the simulation model for the Ourika River.

2.2.1 Model Structure



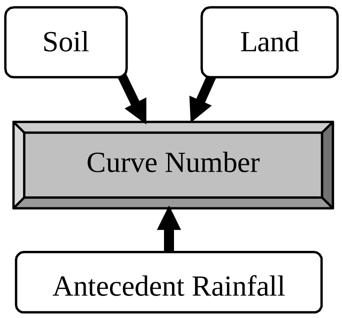
The hydrological module (rainfall-runoff module) based on the USSCS method calculates runoff generated in the sub-basins. The calculated runoff from the sub-basins is given to the dynamic flow module as the upstream end model boundary or lateral inflows from tributaries.

For the flood routing in the river channel, the hydrodynamic module is used. The hydrodynamic module is a one-dimensional dynamic flow model for which the Saint Venant Equation is applied. Hydraulic parameters such as water levels, velocities and discharges can be estimated at any points of the channels.

The calculated water levels are transferred to the WMS module for preparation of a flood map. The WMS module is a mapping module to define flood inundation areas and depths by comparing the river water levels with the ground elevations.

(1) Runoff from Sub-basin

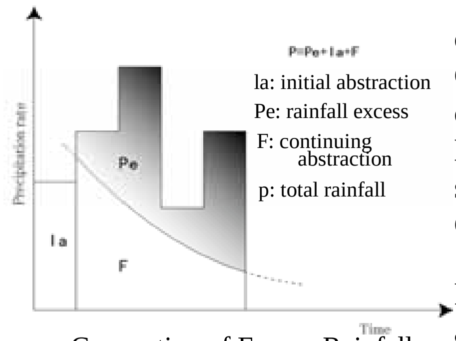
The USSCS method that is one of the runoff analysis models included in the hydrological module of ISIS has been applied for runoff analysis for the sub-basins. This USSCS model is a kind of the unit hydrograph method that was developed by the United States Soil Conservation Service.



Conception of CN

The Ourika River Basin is divided into six sub-basins, considering locations of major tributaries and topographical conditions. Fig. D.2.1 shows the topology, vegetation and lithology in the Ourika River Basin. The sub-basin boundary and a schematic diagram of the simulation model of the Ourika River Basin are shown in Figs. D.2.2 and D.2.3.

To determine a unit hydrograph for every sub-basin, the USSCS method is associated with the basin soil coefficient indexing CN, concentration time, lag time and catchment area. CN (Curve Number) value is express runoff characteristics (difference of runoff by Curve Number is shown in Fig. D.2.4) and is decided form soil, land use, and antecedent rainfall on the basis of CN standard table (Table D.2.1).



Conception of Excess Rainfall

Rainfall is separated loss for initial condition (initial abstraction) and infiltration into the underground (continuing abstraction). (2) Flood Routing

The flood routing is made along the 25km stretch from Setti Fadma to Tnine Bridge (about 8km downstream of the Aghbalau Station). 50 cross sections with an interval of 500m that were newly surveyed in this Study have been used for the hydraulic simulation.

The governing equations of hydraulic simulation (Complete Saint-Venant Equation) are the continuity equation (a) and the momentum equation (b):

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (a)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{\beta Q^2}{A}\right) + gA\frac{\partial H}{\partial x} - gAS_f + q\frac{Q}{A}\cos\alpha = 0 \cdots\cdots (b)$$

where,
Q: Discharge (m^3/s)
A: Water Area (m^2)
q: Lateral Inflow (m^3/s)
H: Water Depth (m)
g: Gravity Acceleration (m/s^2)
S_f: Friction Slope

Saint-Venant Equations express conversation of mass and momentum. Conservation of mass leads to the continuity equation that establishes a balance between the rate of rise of water level and the storage in the wedge and prism channel (The wedge means that the cross-sectional shape is wedgelike and the prism means that the cross-sectional shape does not vary along the channel and the bed slope is constant). Conservation of momentum leads to the 'dynamic' equation that establishes a balance between inertia, diffusion, gravity and friction forces. Some other forces, such as the effect of wind or meanders, may also be included but usually these are small.

2.2.2 Model Calibration

(1) Target Flood

The flood on 28 October 1999 for which the most hydrological records are available among the past major floods, has been used for the target flood of the model calibration. In a strict sense, hydrological data, especially rainfall intensity data are still insufficient for the model calibration. However, through a close examination of the model parameters and rainfall distribution in space and time, the reproduction of the 1999 flood has been attained as discussed below:

(2) Rainfall distribution on October 1999 Flood

The record for observed rainfall is presented in Table D.2.2. The rainfall distribution for model calibration is arranged basically by using key station presented at the table below. The Isohyetal map for this flood is shown as Fig. D.2.5.

Table Key Station for Calibration of Ourika River Model

Key Station	Catchment Area (km^2)	Location (Sub basin No.)	1-day Rainfall (28/10)	Antecedent Rainfall (26/10-27/10)	Elevation (m)
Tiourdiou	154.1	1	57.6	6.6	1850
Amenzal	69.2	2	112.0	38.1	2230
Tourcht	42.9	3	109.3	37.9	1650
Tazzitount	98.4	4	0.0	17.7	1270
Aghbalau	25.6	5	40.8	12.5	1070
Agouns	104.8	6	26.6	0.0	2200

(a) Space Distribution

Basically, when the space distribution is assumed at a certain sub-basin, the rainfall record at the rainfall gauging station located inside the concerned sub-basin is used. However, the space distribution of the station has a bias to located at lower area, that is, the rainfall gauging station does not located at the area over the elevation of 2500m, which is over 50 % at the Ourika River basin. Thus, to use the rainfall record at the key station and to assume the space distribution rainfall caused flood, the following points should be taken into account.

- Sub-basin No. One (1)

  The spatial distribution of rainfall during flood at sub-basin of No. one (1) is determined referring to the rainfall recorded at Amenzal hydrological observation station which does not exist in this basin but locate at the average height of this basin. The rainfall record of Tiourdiou hydrological observation station that situate in this basin is used for only assuming time distribution because this station is located at low area and it can be assumed that it was heavy rain at the upper and middle of this basin more than low area. The accumulated depth of rainfall of sub-basin No. one (1) is calculated by using the relationship of daily rainfall between Amenzal and Tiourdiou.

- Sub-Basin No. two (2) and three (3)

  The spatial distribution of rainfall during flood at sub-basin of No. two (2) and three (3) are determined referring to the rainfall recorded at Amenzal and Tourcht hydrological observation station located in this basin respectively.

- Sub-Basin No. four (4) and five (5)

The spatial distribution of rainfall during flood at sub-basin of No. five (5) are determined referring to the rainfall recorded at Aghbalau hydrological observation station located in this basin. Concerning the sub-basin of No. four (4), it is determined by using the relationship of daily rainfall between Aghbalau and Tazzitount.

- Sub-Basin No. six (6)

In this basin, there is no rainfall gauging station that records the hourly rainfall data. Therefore, the trial for assumption of the spatial distribution is carried as the calibration result correspond the actual record.

(b) Time Distribution

During flood, the rainfall observation was normally carried out at even interval with one hour at the representative hydrological observation station manually. However, on 1999 flood, the interval of rainfall observation was sometimes changed as shown Fig. D.2.6, that is , there is the interval of no record of rainfall gauging. Thus, it is natural that there is the large gap between the actual discharge and the discharge of simulation result at representative hydrological observation stations when the series of observed rainfall data is used for model calibration.

Therefore, referring to the time series of hydrograph of discharge, to fill the missing rainfall data was carried out without changing total amount of rainfall settled at former section, so that the series (distribution) of rainfall data during 1999 flood is made for model calibration.

At last, taking the result of a few trial of calibration into account, the time distribution of rainfall was restructured through the process of model calibration. The restructured series of rainfall data during 1999 flood is shown in Fig. D.2.7.

(3) Discharge - Time Boundary at Upstream of Ourika River

The discharge boundary of upstream is calculated by the hydrological module inputted rainfall data, CN parameter and etc.

(4) Water Level - Time Boundary

The water level – time boundary, which is set at downstream, is made on the basis of actual discharge at the Aghbalau station and the relationship between discharge and water level at the bridge located at Tiguemmi village, which is estimated by the local consultant, INGEMA (refer to Subsection 4.2.2 of main report).

(5) Calibration Result

Quite a few trial runs were made until an acceptable accuracy was obtained, adjusting the model parameters and rainfall distribution. The table below presents the final USSCS such parameters obtained through the calibration.

Parameters for USSCS Method

No of Sub basin	Catchment Area (km^2)	CN*1			Concentration Time*2 (hour)
		CN I	CN II	CN III	
1	154.1	46	66	83	2.16
2	69.2	46	66	83	1.05
3	42.9	40	60	78	0.33
4	98.4	40	60	78	0.85
5	25.6	35	58	77	1.06
6	104.8	46	66	83	1.90

*CN Value estimated by standard curve number (refer to Table D.2.1)
*Concentration time is estimated by the Kirpich method.

Manning's roughness coefficients for the river stretch has been also determined between 0.045 and 0.055, so that the calculated river water levels could coincide with the observed maximum water level at the Aghbalau and Tazzitount Stations.

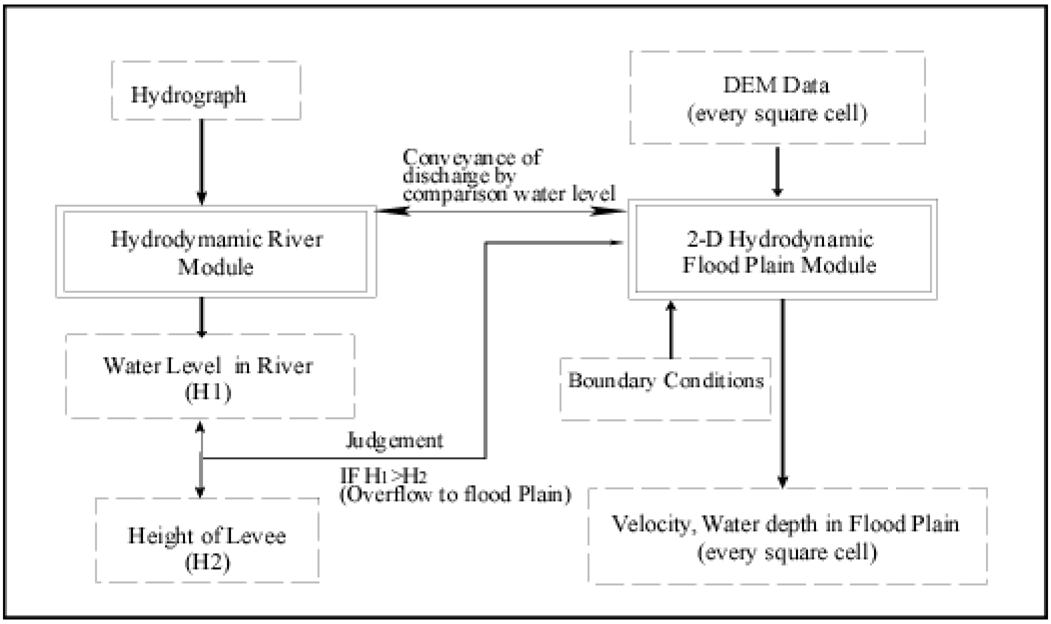
The simulated discharge hydrographs at the Aghbalau, and Tiourdiou Stations are presented in Fig. D.2.8. The reproduction result is generally good enough, although some gaps between the estimated and observed ones are seen in the recession stage of the Aghbalau and in the rising stage of the Tiourdiou. In conclusion, the simulation model is acceptable and applicable for the Ourika River.

2.3 Elaboration of Flood Inundation Simulation Model for Issyl River

Compared with the other basins, hydrological data accumulation in the Issyl River basin is so insufficient that no discharge observation station has been installed. Thus, the boundary condition is hypothetically presumed taking the past study in this basin into account. The following description explains the simulation model for the Issyl River basin.

2.3.1 Model Structure

The model is mainly divided into two parts. One part is the Hydrodynamic River Module which is a one-dimensional dynamic flow model for calculating water level in the river. The other part is the Hydrodynamic Flood Plain Module which is two-dimensional dynamic flow model. The flood plain module starts to calculate hydraulic parameters such as water level, velocity, and in-out discharge every square cell after the river water level gets over the height of levee. These two modules are linked together with conveyance of in-out discharge between the river and flood plain by comparison of the water level.



(2) Flood Routing inside River Channel

The flood routing in the Issyl River was carried out along the 40km stretch from the Rocado channel to the downstream of Memorial Bridge. Forty (40) cross sections with intervals of 500m as surveyed in this Study were used for the hydraulic simulation of the Issyl River.

Hydrograph derived from the model Hydrograph (refer to the report entitled “ETUDE DE GESTION DES RETENUES ET DE PRODUCTION DES BERGES MISSION I”) is presented at the upper edge of the river model.

(3) Two-Dimensional Dynamic Flow for Flood Plain

The schematic diagram of the simulation model of the Issyl River basin is shown in Fig. D.2.9. In this model, the flood plain is divided into 3,621 square cells with sides of 250m. Roughness coefficient, ground height, small channel, and banking are given into the cells.

(4) Afflux at the Bridges

There are bridges remarkably disturbing the flow of the Issyl River. In this analysis, the afflux at the bridge was calculated using the method developed by Hydraulics Research, Wallingford. This method for arched bridges has been developed from laboratory tests on model bridges and verified with data from prototype bridges in the UK.

2.3.2 Simulation Result

In a strict sense, hydrological data accumulation is insufficient for the model calibration. In this basin, discharge and rainfall intensity has not been observed. Only the peak discharge of 90m^3/s calculated by simple method at the Marrakech in the 1997 flood is known. Therefore, the simulation is carried out with the model hydrograph given the peak discharge of 90m^3/s on trial. The simulation result is shown in Fig. D.2.10 In this simulation, the roughness coefficient for each cell is compounded for each land use, namely, Agricultural area (0.060), Road (0.047), and Others (0.050). Manning's roughness coefficient of the river channel is 0.040.

2.4 Elaboration of Flood Inundation Simulation Model for Other Rivers

It is difficult to construct a hydrodynamic model without the many gaps between calculation result and actual data because rainfall intensity has not been observed at the N'fis, Wirgane, Rheraya, Zat and R'dat river basins. For these 5 rivers the model was made of the ISIS Flow module. This module carried out non-uniform flow calculation with distribution of discharge (without time series data) and calculated the water level at any point. Manning's roughness coefficient had the same value (0.045-0.055) as the Ourika River.

CHAPTER 3. FLOOD INUNDATION ANALYSIS

3.1 Preparation of Flood Map

Flood Map was prepared for every discharge probability in this study. For the flood map at the six river basins (except Issyl), the result of non-uniform flow was used because hydrological data has been stocked insufficiently for use of the hydrodynamic method that need the time series data by discharge probability. It is better to use the non-uniform flow rather than the hydrodynamics method including the many gaps generated when many prerequisite conditions are assumed. For the Issyl River basin, the two-dimensional dynamic method could be used with the information on the boundary conditions such as hydrograph pattern DRHT decided.

3.1.1 Preparation of DEM

A DEM (Digital Elevation Model) is essential for flood simulation. In this study, the DEM for the target area was prepared as spot elevations in every 5m square. These spot elevations were digitized when ortho-photo-maps with counters were made. The flood inundation area can be analyzed by comparing the water level with the spot elevations.

3.1.2 Prerequisite Condition

(1) N'fis, Rheraya, Ourika, R'dat and Zat River

(a) River Channel

The cross sections prepared with the interval of about 500m by topographic survey in this study were used. The cross sections were measured taking the bottleneck points into consideration.

(b) Distribution of Discharge and Manning's Roughness Coefficient

Generally, the river discharge increases downwards in the mountain area by collecting discharge from the tributaries. The discharge distribution of the river at every probability, which is summarized in Table D.3.1, was determined based on the observed discharge data at the principal stations in the past and specific discharge estimated from Creager Curve (See Fig. D.3.1).

(c) Water Depth at the Starting Point of Calculation

The river section at the starting point of calculation was assumed to give the hydraulic critical water depth, taking into consideration the steep riverbed slope at this river section. The water levels corresponding to various discharges at this point were determined by a hydraulic formula.

(2) Issyl River

(a) Hydrographs at the Boundary

Hydrographs were given for every probability with consideration of the hydrographs determined in the DRHT report entitled "ETUDE DE GESTION

DES RETENUES ET DE PRODUCTION DES BERGES MISSION I ”. The hydrograph is shown in Fig. D.3.2.

(b) Bridges

At the downstream from Sidi Youssef Ben Ali, there are three arched bridges that are obstacles to the flow of Issyl River. In addition, a bridge where Road N9 intersects the Issyl River reduces the flow capacity of this river. These bridges are shown in Fig. D.3.3.

3.2 Flood Map

(1) N’fis River

Fig. D.3.4(1) shows the inundation area of a 100-year flood. The relative height of the road (Route 203) and houses to the river surface is so large that its hardly suffers from flood of the N’fis River. According to the Fig. D.3.4 (2), in the upper basin of the N’fis River, the probable inundation areas of a 100-year flood are the Ijyoukak and Talat-n-Yaquob villages. These villages are partly inundated when a 100-year flood occurs but not when the flood of less than 50-year occurs at Talat-n-Yaquob.

At the Wirgane River, a tributary of the N’fis River, the place near the arched bridge where Route 203 intersects is inundated in 50-year and 100-year floods. There is a possibility of inundation of houses in a 100-year flood.

(2) Rheraya River

The inundation area of a 100-year flood in the Rheraya River basin is shown Fig. D.3.5 (1). Especially, Route 203 between May Brahim and the Asni village and Route 2015 near the downstream of Imlil Village are remarkable areas of flood inundation. The difference in height between Route 203 and the riverbed is in the range of less than 1m to 1.5 in this area. Part of Route 2015 is close to the riverbed.

Fig. D.3.5 (2) shows the flood map around May Brahim, Asni, Imlil village. This flood map shows the following. Route 203 downstream of Asni village and near the Moulay Brahim is inundated in a 10-year flood, but Asni village is partly inundated even in a 100-year flood in spite of being close to the river. Imlil village has the probability of inundation in a 10-year flood. Route 2017, which is close to the riverbed near the downstream of Imlil village, is inundated in a 5-year flood and submerges 700m in a 100-year flood.

(3) Ourika River

Route 2017 along the Ourika River is submerged for an extent of about 6km in a 100-year flood (see Fig. D.3.6). Fig. D.3.7 (1/5-6/5) shows the flood map near the Tnine Bridge, upstream of the Aghbalau village, near the Iraghf village (upstream and downstream), and near the Tazzitount village, respectively.

Fig. D.3.7 (1/5) presents the flood map near the Tiguemmi-n-Oumzil village. This figure shows that the village near the right bank of the Tnine Bridge is partly inundated in a 5-year to 10-year floods and completely inundated in a flood of over 20-year probability. On the other hand, the village situated at the left bank is partly inundated in a 100-year flood.

Fig. D.3.7 (2/5) shows the flood map at the upstream of Aghbalau village. In this area, about 1km of Route 2017 is submerged in a 100-year flood and this area has the possibility of inundation in a 5-year flood.

Fig. D.3.7 (3/5) shows the flood map at the downstream of Iraghf village. This figure shows that Route 2017 nearby is submerged in 10-year and 20-year floods. Fig. D.3.7 (4/5), which is the flood map near the upstream of Iraghf village, shows that a 5-year flood submerges part of Route 2017, and the area where people gather for camping, swimming and lunch is inundated in a 2-year flood.

Fig. D.3.7 (5/5) is the flood map near the Setti Fadma village. In this area, Route 2017 and houses are partly submerged in a 2-year flood.

(4) Zat River

In the Zat River basin, the relative height of the road and village to the riverbed is so high that submergence by even a 100-year flood is difficult. Thus even the 100-year flood submerges the secondary road along this river with only 100m (see Fig. D.3.8). However, there is a very large agricultural area along the river and this agricultural area suffers from a 2-year flood.

(5) R'dat River

Fig. D.3.9 (1) shows the submerged area of Route N9 in a 100-year flood. Some two (2) km of this route is submerged. The flood map shows that houses are also inundated in a 100-year flood, however, only a few houses are inundated except around the junction of the Tazilida tributary because they are mostly situated at more than 4m from the riverbed (the depth of this river in a 100-year flood is 3.0m on average). The houses at the village near the junction of the Tazilida tributary are inundated when the flood of over 20-year occurs (see Fig. D.3.9 (2)).

(6) Issyl River

The 10, 20, 50 and 100-year flood map in the Issyl River basin is given in Fig. D.3.10. The flood map shows the different flood characteristics between the left and right banks of the Issyl River due to the topographical condition. In the right bank, the flood diffuses widely at shallow depths due to the even flood plain, while the flood goes down through the thalweg along the river narrowly at the left bank. As a result, the inundation on the left bank is deeper than on the right bank. The maximum depth of flood is about 2.0m near the bridge where Route N9 intersects the Issyl River at Sidi Youssef Ben Ali.

CHAPTER 4. HYDRAULIC STUDIES BY USING CALIBLATION MODEL

By using the elaborated simulation model, some studies have been also conducted for the rivers in the study area.

4.1 Examination of Muskingum Method

The Muskingum Method is a world-famous flood routing method that can be easily applied. The method is very common in Morocco too, as understood by the fact that this method was applied to elaborate the simple deterministic flood-forecasting model by the local consultant, INGEMA (refer to Subsection 4.2.2 of main report). Here, an examination has been made to confirm whether the Muskingam method is applicable or not as a flood routing model in place of the hydrodynamic model.

Fig. D.4.1 compares two discharge hydrographs for the 1999 flood that have been obtained from the hydrodynamic model and the Muskingam Method. Very good agreement is seen between them. Thus, it can be said that the Muskingam Method is good enough to be applied for the Ourika River. This result might allow application of the Muskingam Method for the flood-forecasting model as discussed in Subsection 6.2.2. The calibrated parameters are given as below:

Parameters of Muskingam Method

Section	K (hour)	X
Setti Fadma – Amlouggui	0.29	0.25
Amlouggui – Tighazrit	0.65	0.25
Tighazrit – Aghbalau	0.65	0.25

4.2 Estimation of Flood Propagation Velocity

Flood propagation velocity is one of the most important factors for planning a flood watch station network. In this sense, travel time of flood flow has been studied for the Ourika River through a hydraulic simulation and an interview survey on the actual 1995 flood. Consequently the flood propagation velocity is estimated at 4 m/s, considering the results of the two methods as discussed below:

4.2.1 Travel Time by Hydraulic Simulation

The travel time of flow from Setti Fadma to the Aghbalau Station (the distance is about 16 km) is estimated about 1.2 hour by using the dynamic flow model calibrated with observed data in 1999 flood as shown in Fig. D.4.2. The travel time corresponds to 3.8 m/s of velocity.

4.2.2 Interview Survey on Flood Peak Time

On the other hand, the result of interview survey that was made to local inhabitants on the time of the flood peak at different locations reveals that the flood took about 1.7 hours to be propagated down 24 km from Anfli to Aghbalau. The travel time corresponds to 4.0 m/s of velocity.

4.3 Estimation of Flow Capacity

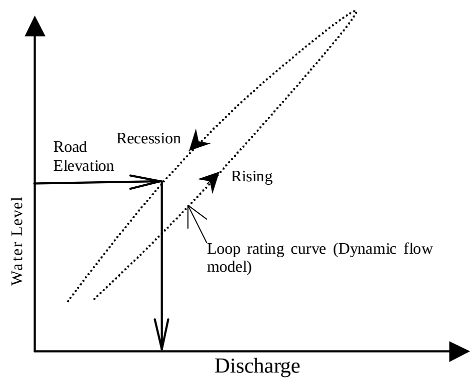
The flow capacity of the major rivers (Ourika, N'fis, Rheraya, R'dat, Zat, and Issyl) in the study area has been estimated in this section. The elevation of the road along the river has been applied as the maximum water levels for calculating the river capacity. This setting seems reasonable because many restaurants and shops stand along the road and people probably evacuate on the road during a flood.

Unfortunately, the estimation was limited to the locations with available cross section data. In order to know the flooding condition of the whole area along the river, the flood maps mentioned in Section 3.2.4 should be made as reference.

4.3.1 Ourika River

The flow capacity of the Ourika River has been calculated from the relationship between water levels and discharges obtained for the 1999 flood simulation. The elevation of the road P2017 that runs on the left bank has been applied as the maximum water levels for calculating the river capacity.

The flow capacities at all the cross sections of the 25km stretch from Setti Fadma to the Tnine Bridge have been estimated as shown in Fig. D.4.3 (1). In the figure, the estimated capacities are compared with probable discharges with return periods of 10 and 20 years that have been roughly estimated based on the discharge records at the Aghbalau Station.



Estimation of Flow Capacity

The flow capacity at the Tnine Bridge is 650 m^3/s, which is between the 10 and 15-year discharges. This section is a critical point that is narrowed by expansion of the Tiguemmi-n-Oumzil village on both the banks. Between Tnine Bridge and the Aghbalau Station, the road elevation is very high and the flow capacities exceed the 100-year discharge. However, large agricultural areas that spread over the riverbed are exposed to a flood discharge of 20-year or over. In fact this area was damaged in the 1999 flood that had a peak discharge of 760 m^3/s at the Aghbalau Station (corresponding to the 20-year discharge).

In the upstream from the Aghbalau Station, the flow capacities are less than the 20-year discharges at some sections. Among them the flow capacity at Iraghf is as small as 160 m^3/s, corresponding to the 3-year discharge. At the upstream end the road runs in the river, and the flow capacity is almost nil.

4.3.2 Other Rivers

The flow capacity of the other rivers has been calculated from the relationship of water level to various discharges obtained for the non-uniform flow simulation. The flow capacity is described as follows:

(1) Rheraya River

Road P2017 along the left bank of the Rheraya River was applied as the maximum water level for the calculation of flow capacity. The flow capacity at all sections of this river is shown in Fig. D.4.3(2). This figure shows the area around the downstream of Imlil, the nearby downstream of Asni village and the upstream of the Tahanaout Station. The minimum flow capacity nearby the downstream of Imlil, where the road is close to the riverbed, is 28.5 m^3/s which is between a 2-year and 5-year discharge. Near the downstream of Asni Village, the minimum discharge is 300m^3/s which is between a 50-year and 20-year discharge. The Tahanaout Station section has the flow capacity of only 240m^3/s which is about a 20-year discharge.

(2) N'fis River, R'dat River and Zat River

The route along these rivers has enough relative height and hardly inundated except for a few points in a 100-year flood. The flood condition in such areas should be referred to the flood map.

(3) Issyl River

The bank of the Issyl River was applied as the maximum water level for the calculation of flow capacity. The flow capacity at each section of this river is shown in Fig. D.4.2 (2). The Issyl River has two bottleneck points. One point is around the junction with the Tassoltante tributary that has a narrow section (flow capacity is 45.8m^3/s) compared with the downstream and upstream sections (flow capacity is over 200m^3/s). The other point is the bridge where Route N9 intersects the Issyl River, which point has the flow capacity of 75.4m^3/s (under 10-year discharge). In addition to these points, there is the arched bridge with a small flow area having the flow capacity of under a 10-year discharge at Marrakech.

TABLES

Table D.2.1 (1/4) STANDARD CURVE NUMBER (CLASSIFICATION OF SOIL GROUP)

Soil Group	Minimum Infiltration Rate (mm /hr)	Sort of soil
A	7.5 to 11.5	deep sand, deep loess, aggregated
B	3.8 to 7.5	shallow loess, sandy loam
C	1.3 to 3.8	clay, loams, shallow sandy loam, soils
D	0 to 1.3	Others

The SCS soil group can be identified by:

1. Soil characteristics as described above sort of soil.
2. Soil survey (if available).
3. Minimum infiltration rates as shown below.

Table D.2.1 (2/4) STANDARD CURVE NUMBER (RESIDENTIAL, ROAD, COMMERCIAL / BUSINESS AREA AND ETC.)

	Average lot size	Average Percent Impervious	CN for Hydrologic Soil Groups			
			A	B	C	D
Residential	1/8 acre or less	65	77	85	90	92
	1/4 acre	38	61	75	83	87
	1/3 acre	30	57	72	81	86
	1/3 acre	25	54	70	80	85
	1 acre	20	51	68	79	84
Paved Parking Lots, Roofs, Driveways, etc.			98	98	98	98
Street and Roads	Paved with curbs and storm sewers		98	98	98	98
	Gravel		76	85	89	91
	Dirt		72	82	87	89
Commercial/Business Areas (85% Impervious)			89	92	94	95
Industrial Districts (72% Impervious)			81	88	91	93
Open spaces, Lawns, Parks, Golf Courses, Cemeteries etc.	Good condition: grass cover on > 75% of area		39	61	74	80
	Poor condition: grass cover on 50 to 75% of area		49	69	79	84

Table D.2.1 (3/4) STANDARD CURVE NUMBER (FRAM LAND)

Land Use	Treatment	Hydraulic Condition	CN for Hydrologic Soil Groups			
Fallow	Straight row	-	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	89
	Contoured	Good	65	75	82	86
	Contoured & terraced	Poor	66	74	80	82
	Contoured & terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured & terraced	Poor	61	72	79	82
	Contoured & terraced	Good	59	70	78	81
Close-seeded	Straight row	Poor	66	77	85	89
Legumes or Rotation	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
Meadow	Contoured & terraced	Poor	63	73	80	83
	Contoured & terraced	Good	51	67	76	80
Pasture or Range	Un-contoured	Poor	68	79	86	89
	Un-contoured	Fair	49	69	79	84
	Un-contoured	Good	39	61	74	80
	Contoured	Poor	47	67	74	80
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow	-	Good	30	58	71	78
Woods or Forest	-	Poor	45	66	77	83
	-	Fair	36	60	73	79
	-	Good	25	55	70	77
Farmsteads	-	-	59	74	82	86

Table D.2.1 (4/4) STANDARD CURVE NUMBER (ANTECEDENT SOIL MOISTURE CONDITION)

AMC	Dormant season	Growing season
I	<13	<35
II	13 to 28	35 to 53
III	>28	>53

Condition I Soils are dry but not to wilting point; satisfactory cultivation has taken place.

Condition II Average conditions.

Condition III Heavy rainfall, or light rainfall and low temperatures have occurred within the last 5 days; saturated soil.

CN for AMC II	Corresponding CN for	
	AMC I	AMC III
100	100	100
95	87	98
90	78	96
85	70	94
80	63	91
75	57	88
70	51	85
65	45	82
60	40	78
55	35	74
50	31	70
10	4	22
5	2	13
0	0	0

The following table can be used to adjust the CN from the average conditions referenced in the above CN tables to Antecedent Moisture Conditions I and III.

Table D.2.2 OBSERVED RAINFALL DURING 1999 FLOOD

(mm)

Time		Ilmil	Agouns	Tiourdiou	Amenzal	Tourcht	Tazitounte	Aghbalau	Marrakech	Iguir N'kouris	Takerkoust
1999/10/26 7:00		0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0
1999/10/26 11:00		0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1999/10/26 15:00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1999/10/26 17:00		2.3	0.0	0.0	0.0	3.7	3.0	0.2	0.0	0.0	0.0
1999/10/26 20:00		13.1	0.0	2.3	0.0	3.6	0.0	3.2	0.4	2.2	1.0
1999/10/27 7:00		27.6	0.0	4.3	38.1	30.6	14.7	9.1	2.7	13.8	7.6
1999/10/27 11:00		0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1999/10/27 15:00		1.3	3.0	0.0	0.0	3.9	2.9	3.1	0.0	0.0	0.0
1999/10/27 17:30		1.6	11.3	3.1	0.0	0.0	0.0	2.0	0.0	0.0	0.7
1999/10/28 7:00		22.9	6.6	12.6	8.2	1.3	0.0	8.6	11.2	38.0	7.6
1999/10/28 11:00		33.9	10.0	11.8	28.9	17.4	0.0	9.1	1.7	24.0	3.0
1999/10/28 12:00		0.0	0.0	8.5	17.2	10.0	0.0	3.2	0.0	3.4	0.0
1999/10/28 15:00		15.5	10.0	15.9	32.5	37.1		9.8	4.5	13.7	2.4
1999/10/28 16:00		0.0	0.0	0.0	12.5	0.0	0.0	6.8	0.0	1.0	0.0
1999/10/28 17:00		15.3	0.0	8.8	6.7	32.2	0.0	2.0	1.5	3.5	0.0
1999/10/28 18:00		0.0	0.0	0.0	2.3	7.9	0.0	1.0	0.0	1.6	0.0
1999/10/28 19:00		16.7	0.0	0.0	0.0	1.7	0.0	0.3	0.0	0.0	0.0
1999/10/28 20:00		0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0
1999/10/29 7:00		0.2	0.0	0.0	3.7	0.0	0.0	0.0	0.2	0.0	0.8
1999/10/29 15:00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1999/10/29 17:00		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	26-Oct-99	43.2	0.0	6.6	38.1	37.9	17.7	12.5	3.1	16.0	8.6
	27-Oct-99	25.9	20.9	15.7	8.2	5.2	2.9	13.7	11.2	38.0	8.3
	28-Oct-99	81.6	20.0	45.0	103.8	108.0	0.0	32.2	7.9	47.2	6.2

Table D.3.1 DISCHARGE DISTRIBUTION

Ourika (m^3/s)

Required point	CA (km2)	Distribution of Discharge					
		1/100	1/50	1/20	1/10	1/5	1/2
Aghbalau	495	1,650	1,200	750	490	300	115
Tazzitount	347	1,367	993	622	404	248	96
Setti Fadma	156	1,071	778	487	317	194	75
Tiourdiou	134	795	578	362	235	144	56
Amenzal	49	421	306	191	124	76	29

N'fis (m^3/s)

Required point	CA (km2)	Distribution of Discharge					
		1/100	1/50	1/20	1/10	1/5	1/2
Imin El Hammam	1256	2,880	2,040	1,220	770	440	150
N'kouris	848	2,200	1,500	850	520	280	100
Ijoukak	547	1,912	1,358	813	512	275	94
Ait Barahi	518	1,860	1,321	790	498	267	92
Mzouzit	454	1,736	1,233	738	465	249	86

Rheraya (m^3/s)

Required point	CA (km2)	Distribution of Discharge					
		1/100	1/50	1/20	1/10	1/5	1/2
May Brahim	221	560	390	230	150	90	40
Asni	193	518	360	212	139	83	33
Tansghalt	183	502	349	206	135	80	32
Imi Oughlad	85	315	220	129	85	51	20
Imlil	56	242	169	99	65	39	15
Aroumd	33	169	118	69	46	27	11

Zat (m^3/s)

Required point	CA (km2)	Distribution of Discharge					
		1/100	1/50	1/20	1/10	1/5	1/2
Taferiat	528	1,100	840	560	390	250	110
tassourt	390	939	715	477	332	212	93
Tighedoune	361	900	686	458	318	203	89
Ait shmane	297	810	618	412	287	183	80

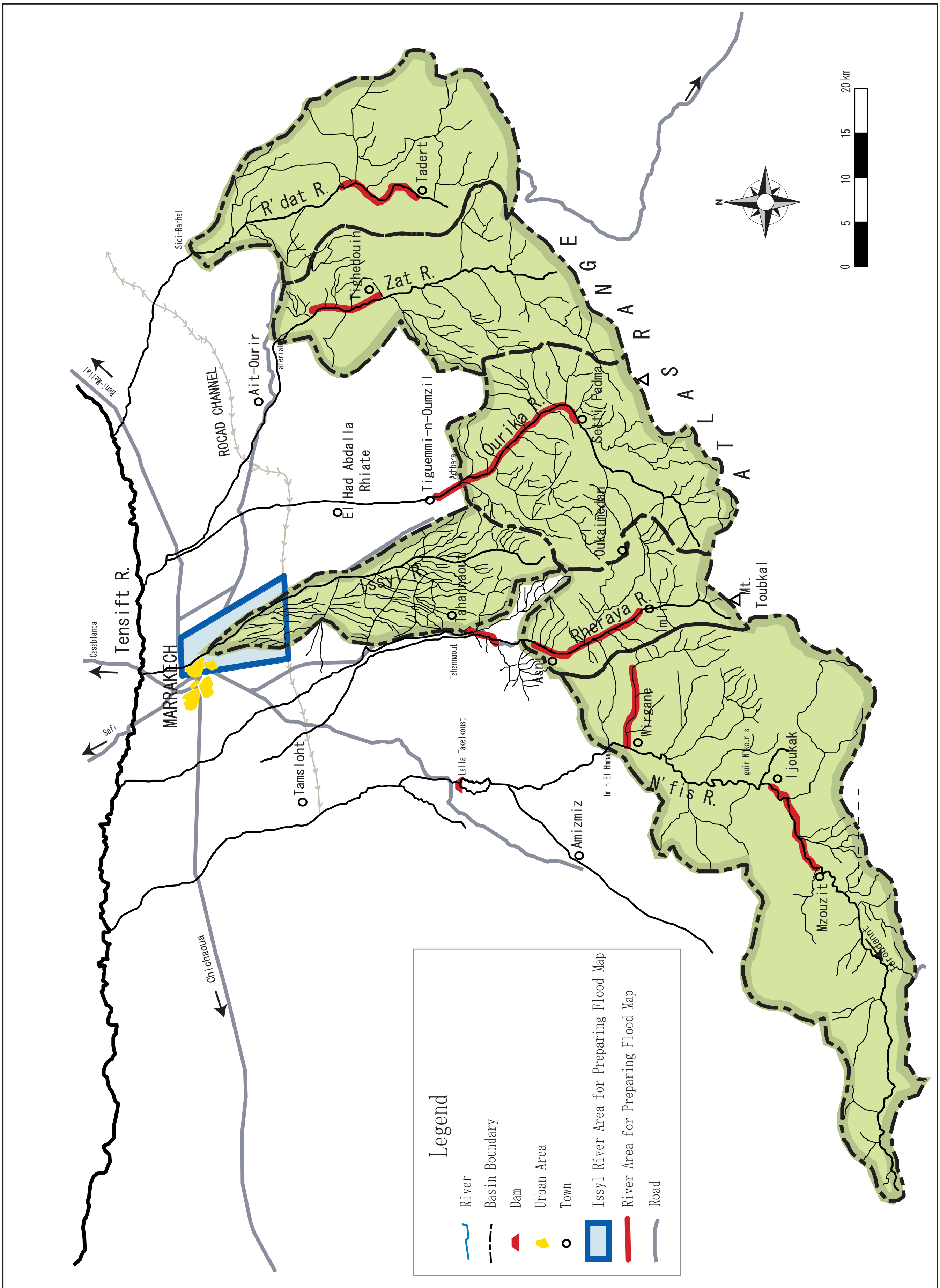
R'dat (m^3/s)

Required point	CA (km2)	Distribution of Discharge					
		1/100	1/50	1/20	1/10	1/5	1/2
Sidi Rahal	532	900	740	550	420	300	150
Jeddint	140	428	353	260	200	141	71
Ait Mancour	129	408	336	248	191	135	67
Tilnif	75	292	240	177	136	96	48
Tadert	52	229	189	139	107	76	38

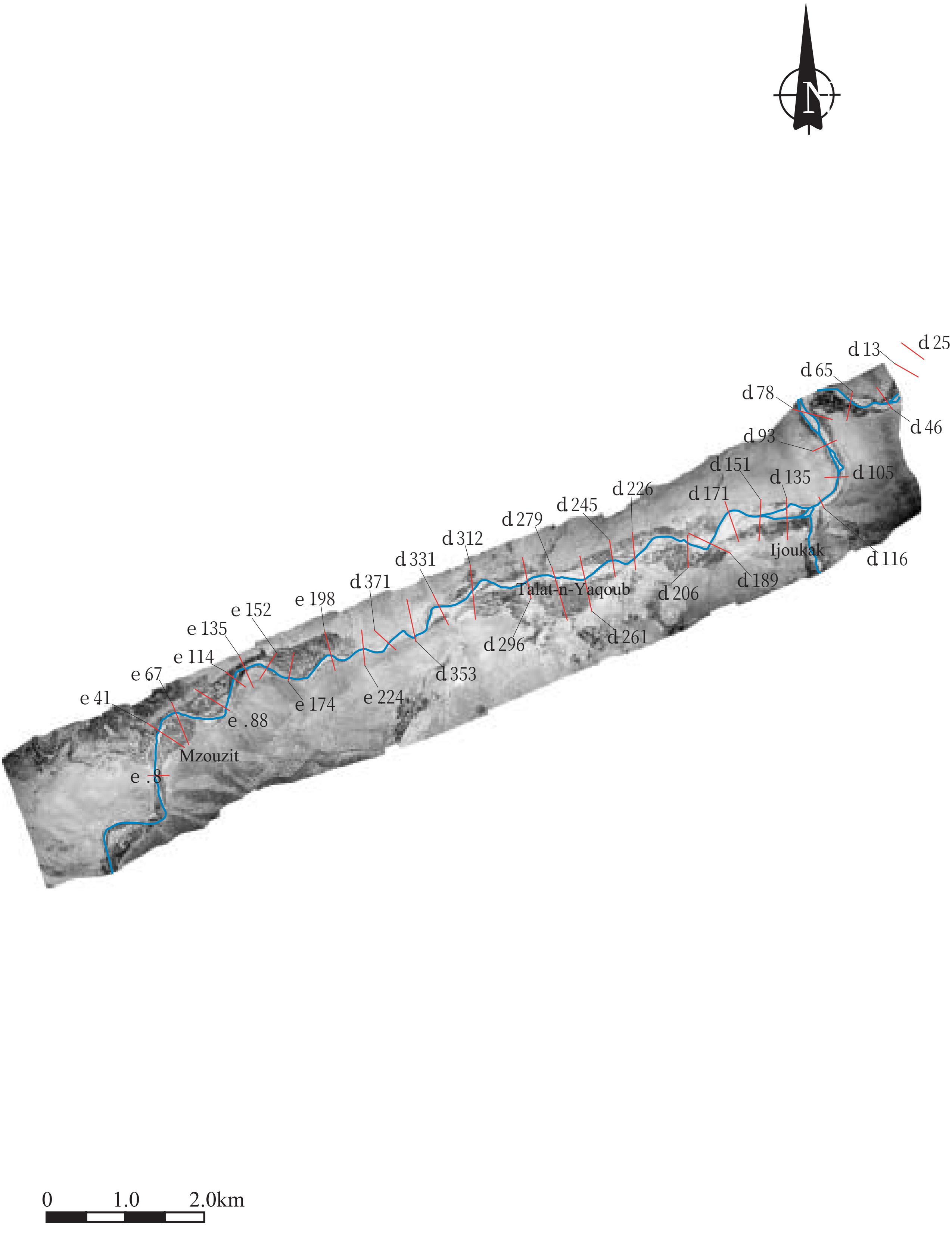
Wirgane (m^3/s)

Required point	CA (km2)	Distribution of Discharge					
		1/100	1/50	1/20	1/10	1/5	1/2
Wirigane	92	211	150	90	57	30	10
Tassa Wirgane	64	146	104	62	39	21	7

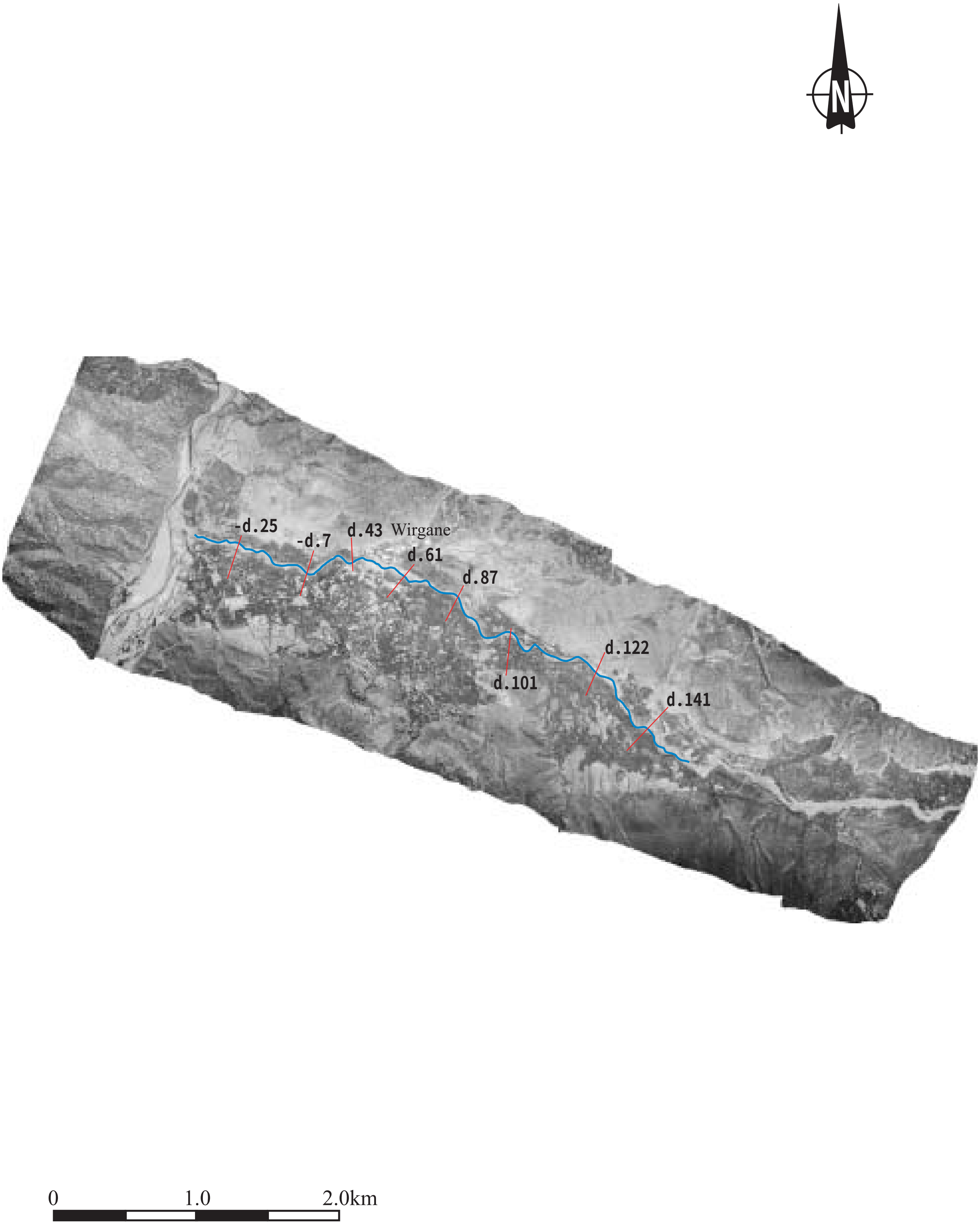
FIGURES



THE MASTER PLAN STUDTY ON FLOOD FORECASTING AND WARNING SYSTEM FOR ATLAS REGION IN KINGDOM OF MOROCCO	Fig. D.1.1 TARGET AREA FOR FLOOD MAP

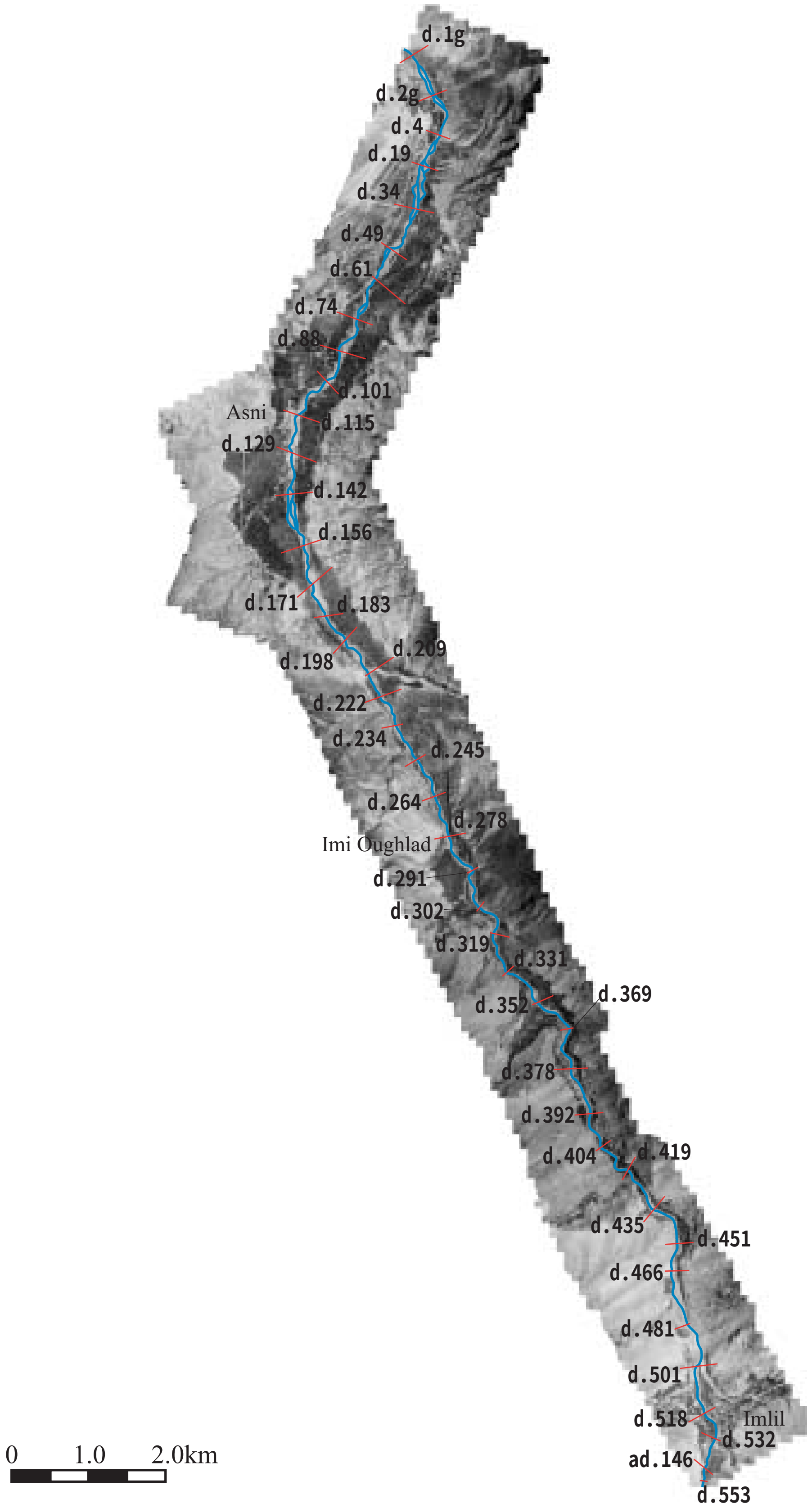


THE MASTER PLAN STUDTY ON FLOOD FORECASTING AND WARNING SYSTEM FOR ATLAS REGION IN KINGDOM OF MOROCCO	Fig. D.1.2 (1/8) LOCATION OF CROSS-SECTION SURVEY (N'FIS RIVER)

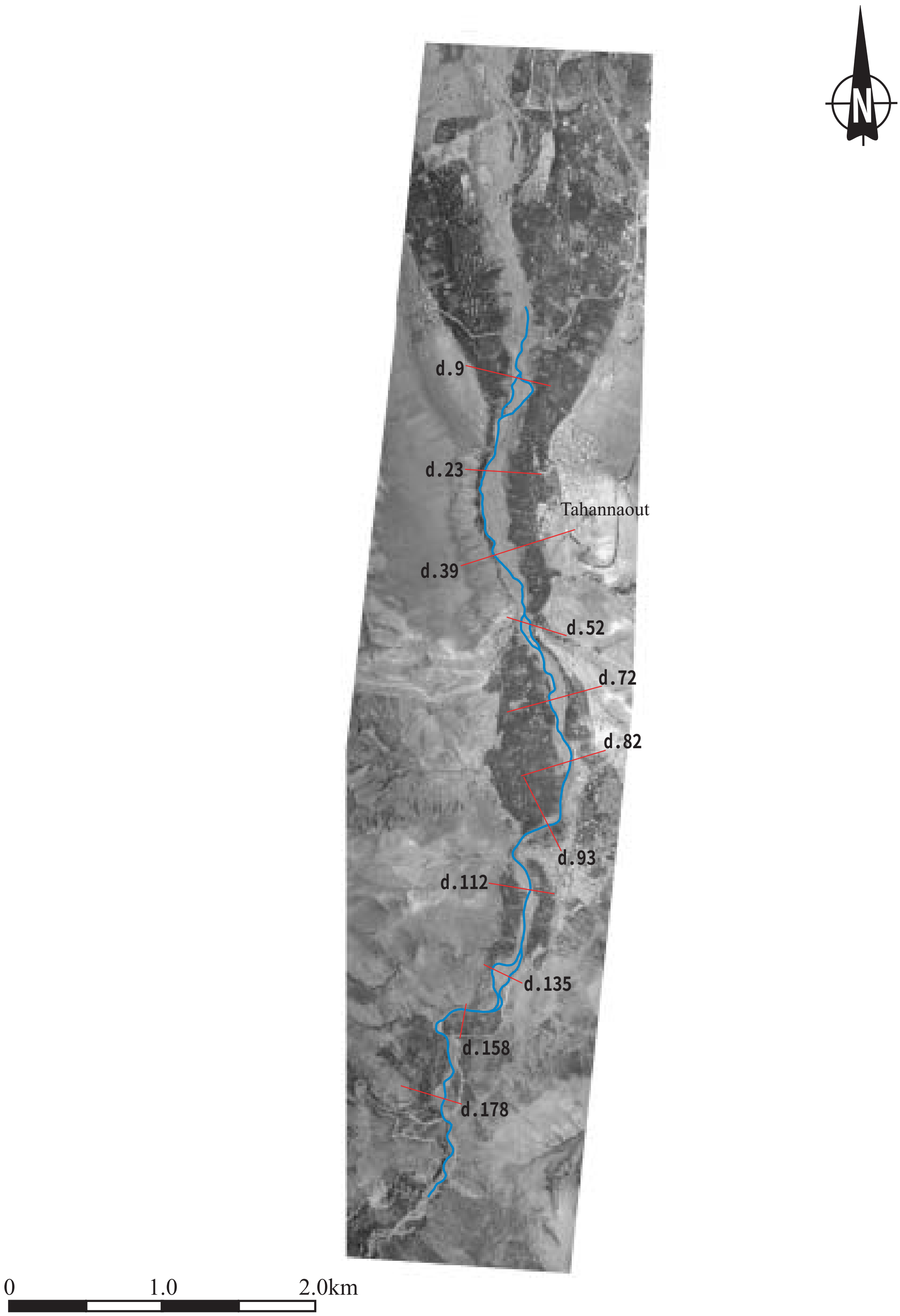


THE MASTER PLAN STUDTY ON
FLOOD FORECASTING AND WARNING SYSTEM
FOR ATLAS REGION IN KINGDOM OF MOROCCO

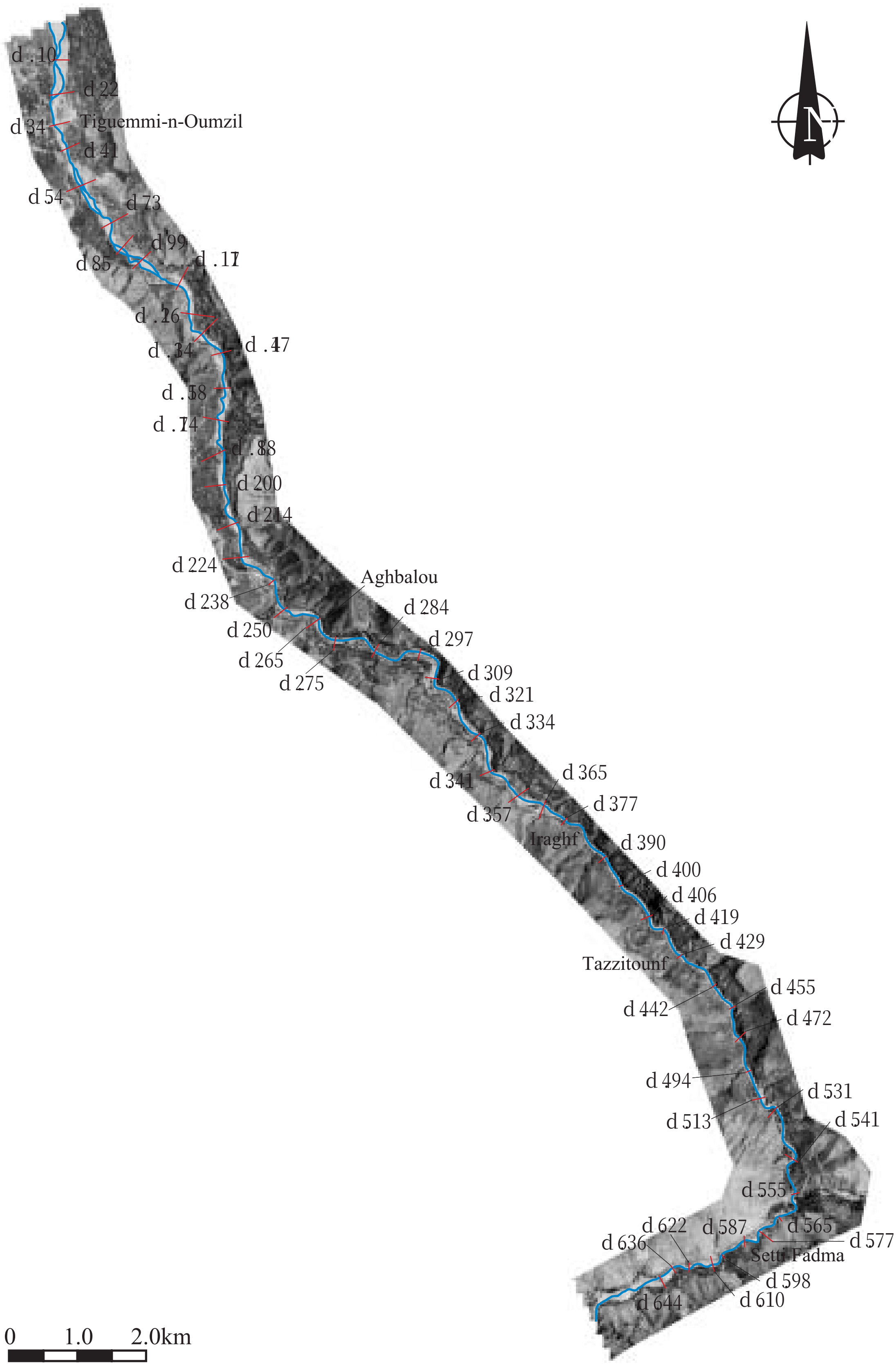
Fig. D.1.2 (2/8) LOCATION OF CROSS-SECTION SURVEY (WIRGANE RIVER)



THE MASTER PLAN STUDTY ON FLOOD FORECASTING AND WARNING SYSTEM FOR ATLAS REGION IN KINGDOM OF MOROCCO	Fig. D.1.2 (3/8) LOCATION OF CROSS-SECTION SURVEY (DOWNSTREAM OF RHERAYA)



THE MASTER PLAN STUDTY ON FLOOD FORECASTING AND WARNING SYSTEM FOR ATLAS REGION IN KINGDOM OF MOROCCO	Fig. D.1.2 (4/8) LOCATION OF CROSS-SECTION SURVEY (UPSTREAM OF RHERAYA)



THE MASTER PLAN STUDTY ON FLOOD FORECASTING AND WARNING SYSTEM FOR ATLAS REGION IN KINGDOM OF MOROCCO	Fig. D.1.2 (5/8) LOCATION OF CROSS-SECTION SURVEY(OURIKA RIVER)

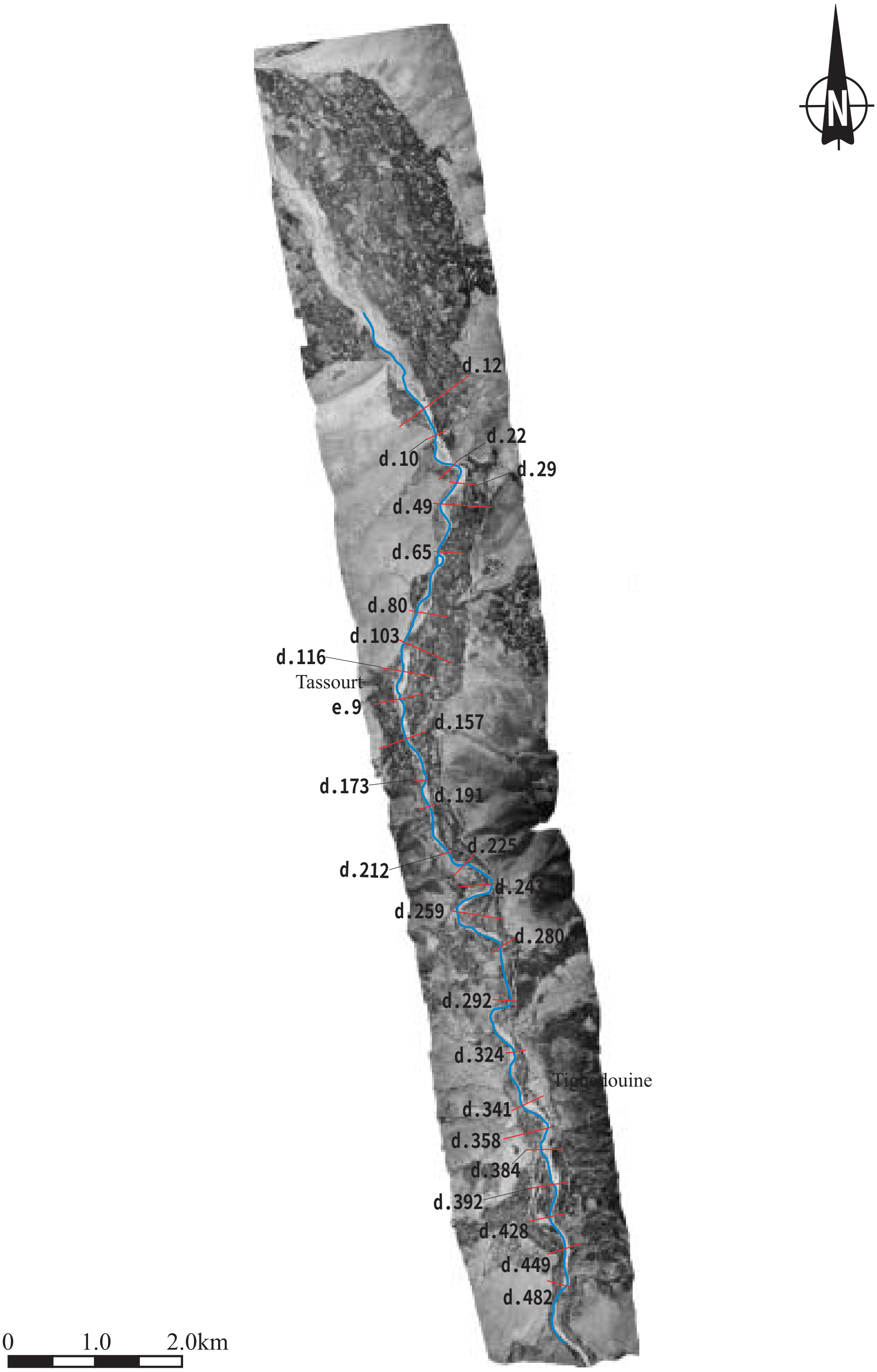


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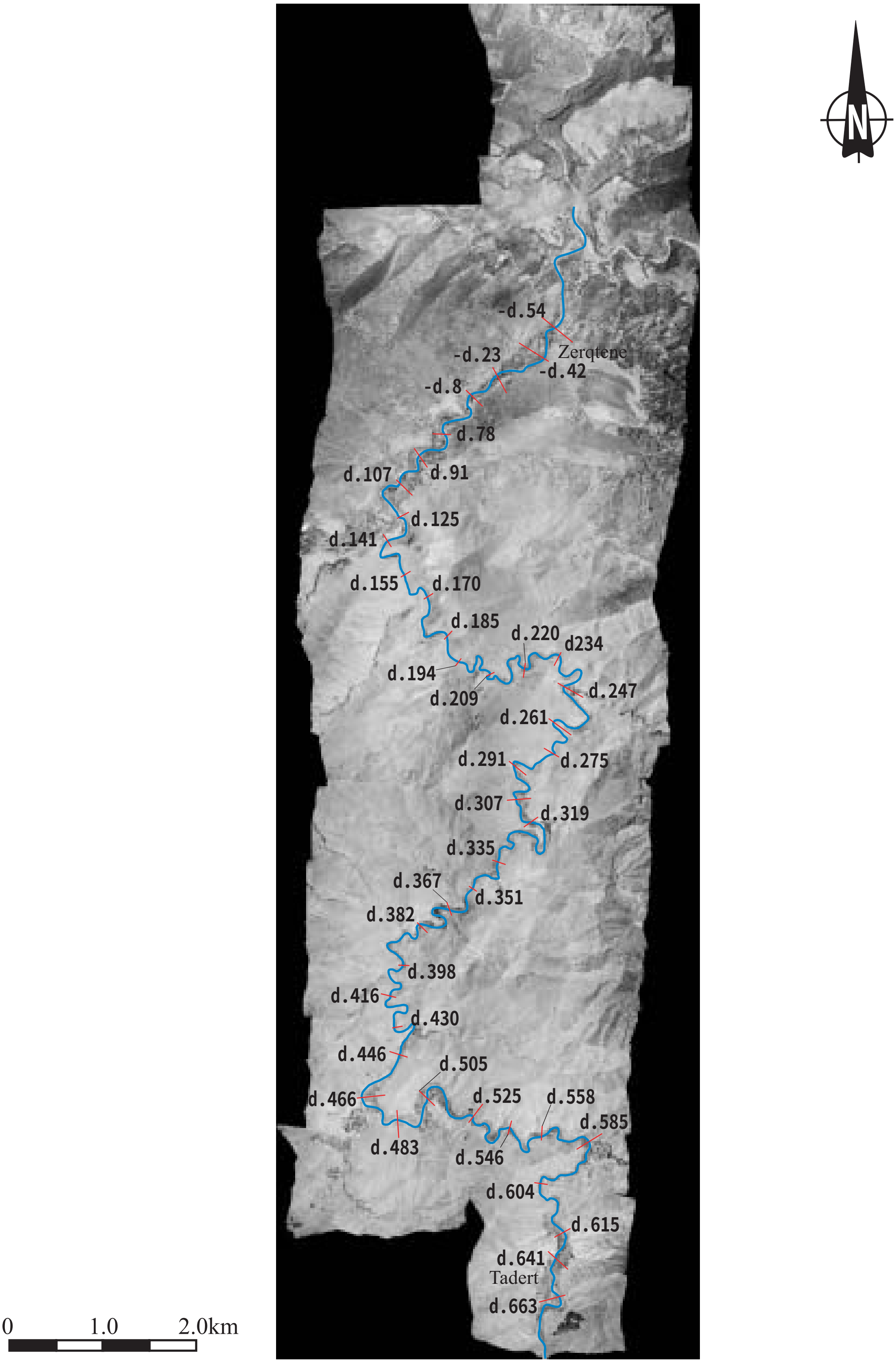
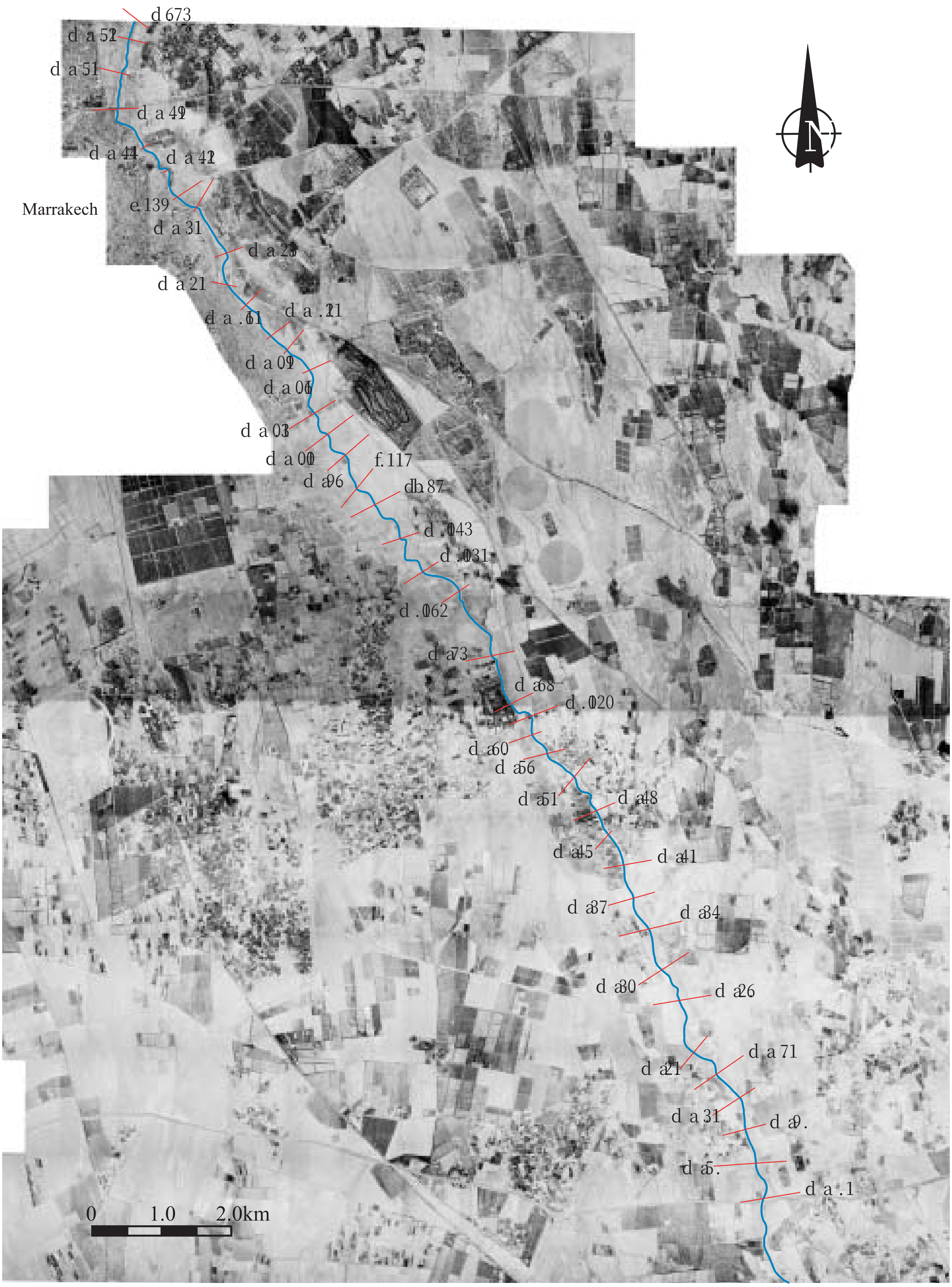
Fig. D.1.2 (6/8) LOCATION OF CROSS-SECTION MEASURE WORKS (ZAT)



THE MASTER PLAN STUDTY ON FLOOD FORECASTING AND WARNING SYSTEM FOR ATLAS REGION IN KINGDOM OF MOROCCO	Fig. D.1.2 (7/8) LOCATION OF CROSS-SECTION SURVEY (R'DAT RIVER)



THE MASTER PLAN STUDTY ON
FLOOD FORECASTING AND WARNING SYSTEM
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Fig. D.1.2 (8/8) LOCATION OF CROSS-SECTION SURVEY (ISSYL RIVER)