5 Field Work and Techniques

The field work was conducted during two field periods in Yemen in 1997 and 1998. The field period in 1997 was used as a screening and testing phase while the actual data for the study were measured in 1998.

The field work emphasises the measurement of the significant hydrologic parameters mentioned below. Beside the physical measurements, information was gained from the farmers by interviews and the rapid rural appraisal (RRA) method.

Additional information was gathered from different institutions which provided regional meteorological or hydrological data. Maps and other material could be obtained from the Ministry of Survey and Ministry of Oil and Mineral Exploration in Sana'a. The access to and the negotiation with these agencies was usually very time-consuming.

5.1 Selection of the Test Site

The test site was selected concerning the following criteria:

(1) Recent water harvesting and runon terrace irrigation is maintained and in use.

(2) Acceptance of the proposed work by the local inhabitants and their willingness to co-operate.

(3) Possibility to install and operate measuring devices without vandalism.

(4) Good working conditions for the counterpart (socio-economic criteria).

(5) Good accessibility.

(6) Possibility for housing.

(7) Scale considerations, the catchment had to be small enough to be coped with one individual.

It was not possible to meet all the given criterion equally. Compromises had to be made. The most significant criteria for the work was the existence of the water harvesting – runon terrace irrigation system (1). The other essential requirement was the acceptance and support by the local population (2). This includes the option to install measuring devices (3) and the positive working conditions for the research of the counterpart (4).

All these conditions were given in the village Mia'āmirah, the home village of the counterpart Abdul-Hadi Al-Ghory. The size of approximately 0.5 km² of the catchment was appropriate. Compromises had to be made on accessibility (5) and housing (6).[44] The distance to Ta'izz is roughly 70 km, a 4-wheel driven car was essential for access to the area. Under good weather conditions, three driving hours were needed. During rain driving was not recommended, because a significant part of the "road" runs in wadi beds. This constrained the supply of tools and food and the necessary maintenance of technical devices.

5.2 Design of the Field Work

The goal of the research was to achieve information on agricultural water availability and the effect of water harvesting and runon-irrigation on catchment scale. In contrast to EGER (1987), who worked on water harvesting runon-irrigation at field size, the new approach implies that boundary conditions cannot be specified with the same accuracy. Generalisation has to be accepted. It was not possible to measure all spatial water fluxes within the catchment. The measurements were designed to cover the principal hydrologic characteristics, fluxes and the water balance of the catchment with special respect to the runoff irrigation schemes. The following components of water balance were directly measured: precipitation, soil moisture, runoff. Additionally, the most significant meteorological parameters were collected to calculate evapotranspiration. Further geomorphological and topographical features were considered relevant.

Beyond the physical parameters indigenous knowledge and social constrains were considered. Most of the socio-economic information was provided by my counterpart Mr Al-Ghory.

5.3 Geomorphological Survey and Mapping

To achieve information on water harvesting areas and terraces, a detailed geodetic survey was carried out during the field period 1997. Special attention was paid to the terraces. The terrace walls were clearly shaped by selecting 2 measurement points next to each other, one at the foot and one at the top of the wall. The measurements were

44 The condition improved significantly in the 2nd year when a room from the school could be rented.

conducted with a theodolite, the overall survey accuracy was better than 2 cm. The survey covers an area of 41 ha[45] by 9025 survey points. The data were available in raw-data digital form (easting, northing, height, terrace code, topographic information).

Much more difficult was the determination of the terrace bottoms. Partially, rock outcrops between neighbouring terraces indicate depths. Farmers were questioned on their terrace depths and where it was possible wells or other holes were used to measure the actual terrace depth. The volume calculation could not be performed by standart tools as ArcView 3D-Analyst because the surfaces appeared to complex and lead to either unstable computing or unsatisfying results. Therefore an independent solution was programmed.

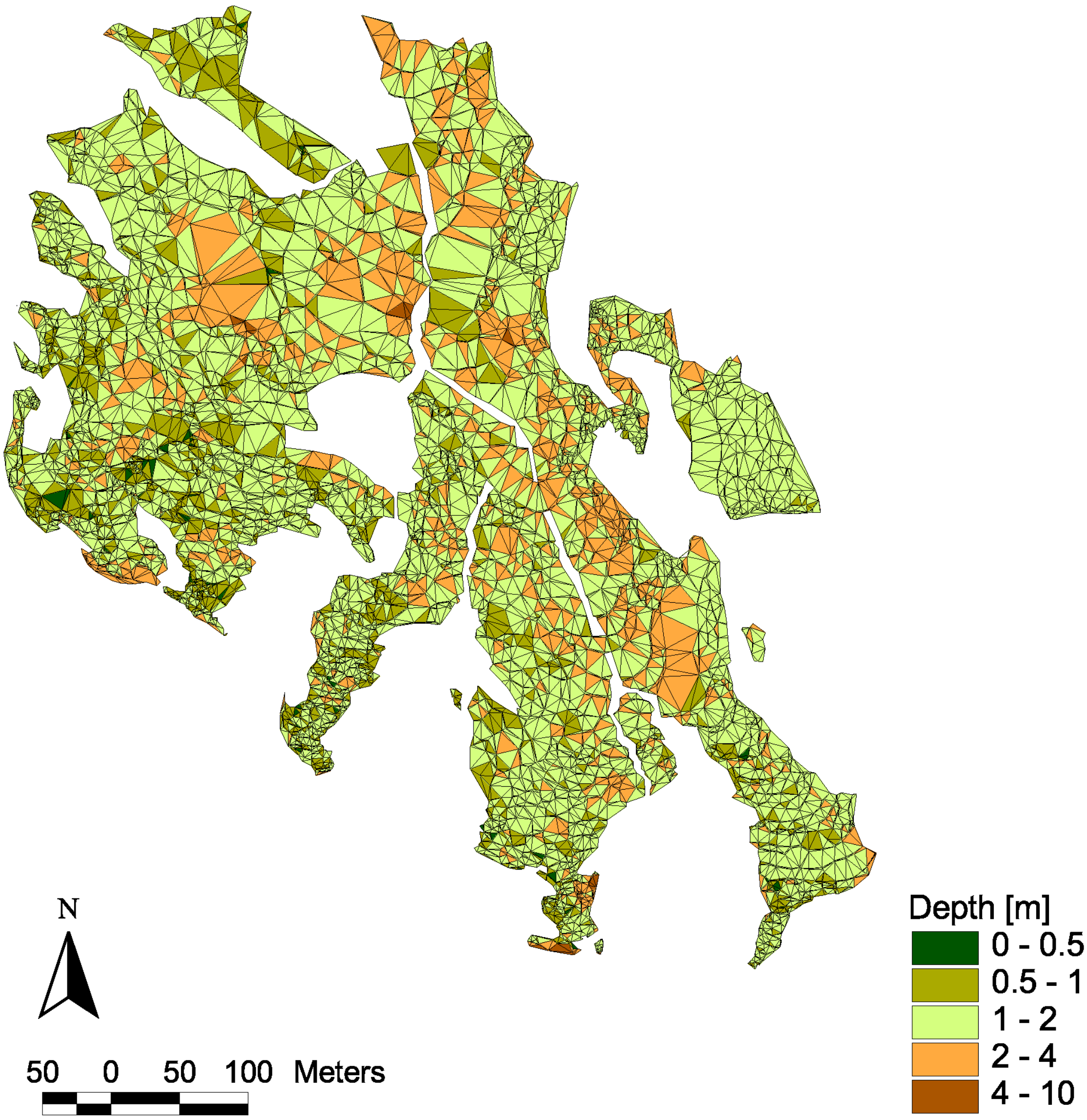

Figure 5.1 Calculated soil depth of triangle irregular network (TIN)

45 The survey covers an area a little larger than the catchment (37.9 ha).

The level of the interpolated bottom surface was assigned as an additional feature to the survey points in the terraced area. Errors, such as bottom surface above top surface were eliminated. From the measuring points a TIN (triangle irregular network) was derived (figure 5.1) and the volume of every TIN-tetraeder of the upper and lower surface was calculated. The terrace volume was calculated by subtracting the corresponding tetraeders from each other. In the final step, the volume was converted into average terrace depth for every terrace zone as shown in figure 5.1. The terrace depth corresponded with the expected rooting depth of the major crops (sorghum).

The water harvesting factor is a major figure in runoff-runon irrigation systems. The water collection and distribution scheme in Mia'amirah was mapped and analysed commensurate with the concept described in chapter 3.1.1. The results are shown in figure 5.3.

The potential water storage capacity is the geomorphological comparative to the *TAW* mentioned in chapter 3.3.3. It is the maximum amount of water that can be stored in a soil column of terrace body. This amount defines the maximum periods that plants survive without new rain or irrigation. Therefore it is a key figure in agricultural water and drought management. It depends on the considered terrace volume (or depth, figure 5.4), soil texture and stone content (figure 5.6). If only the plant available water between field capacity and wilting point is considered, the equation is analogous to equation (3.24) for the *TAW*:

$$PM = 1000(\Theta_{FC} - \Theta_{WP}) \cdot (T_{vol} - SC) \tag{5.1}$$

where	PM	potentially available moisture [mm]
	Θ_{FC}	water content at field capacity [1]
	Θ_{WP}	water content at wilting point [1]
	T_{vol}	terrace volume [m^3]
	SC	stone content [m^3]

The result for the Mia'amirah catchment is shown in figure 5.7. The map shows a range from less than 50 mm, mostly in the up-slope terraces, to more than 350 mm. Due to the quite homogeneous soil texture, the strongest influence on the potential storage capacity comes from the terrace volume and the stone content in the soil body (figure 5.6). Especially in the up-slope areas the potential storage capacity is limited by the high stone content of the terraces. The maximum storage capacities can be found at the mid-slope where loamy texture is combined with large terrace depths and low stone content.

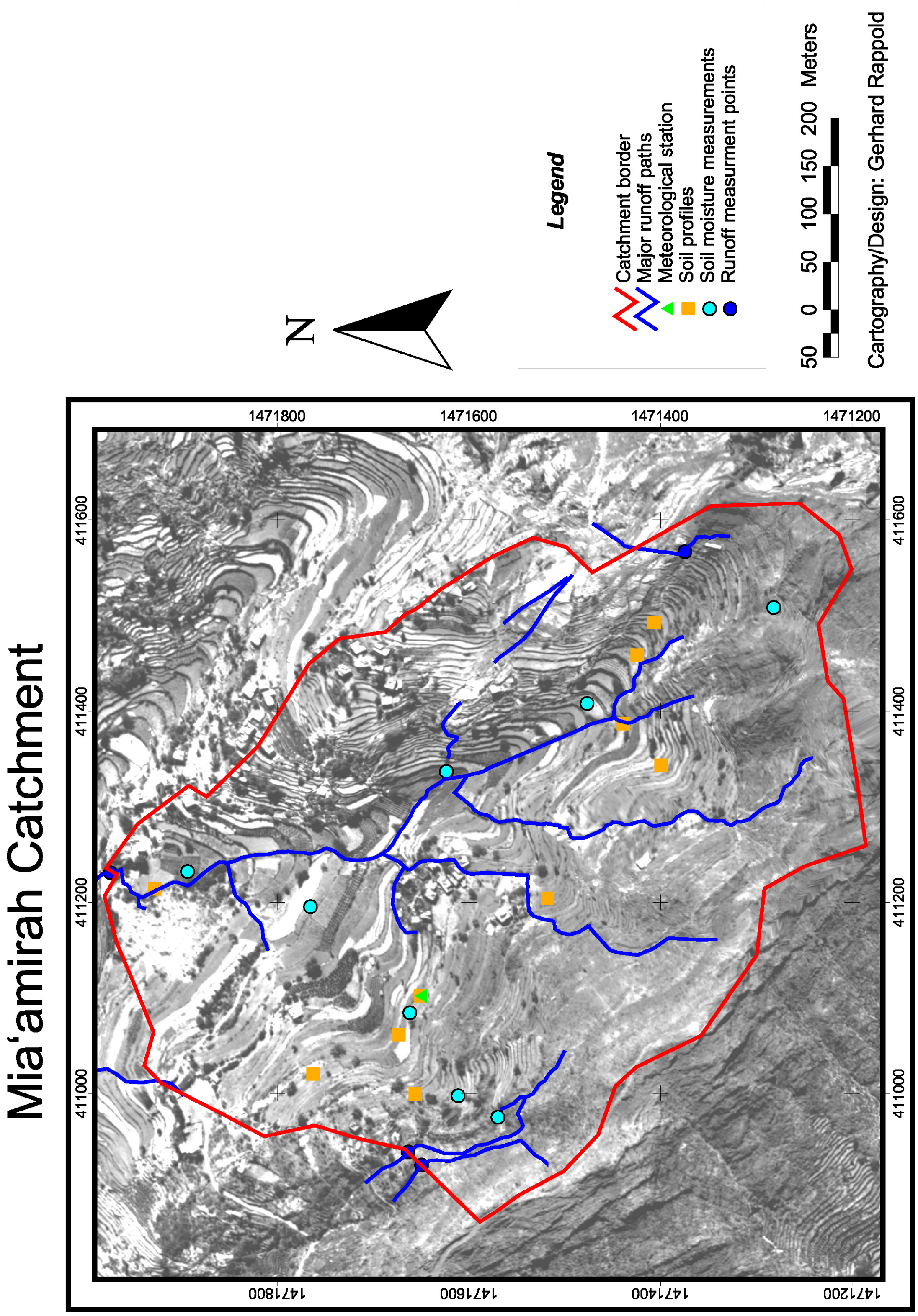

Figure 5.2 Overview on the Miamirah catchment

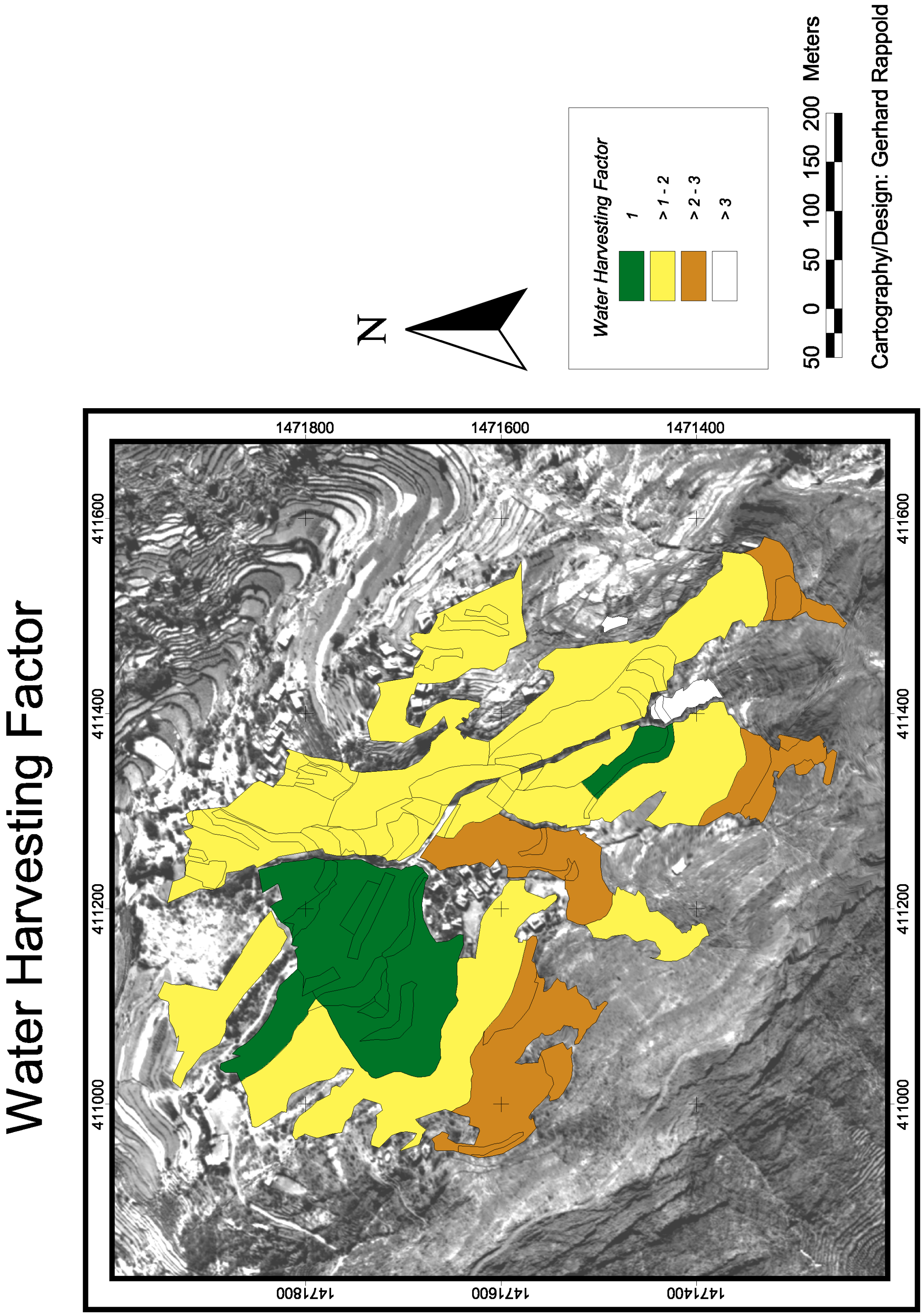

Figure 5.3 Water harvesting factor of the different water harvesting zones

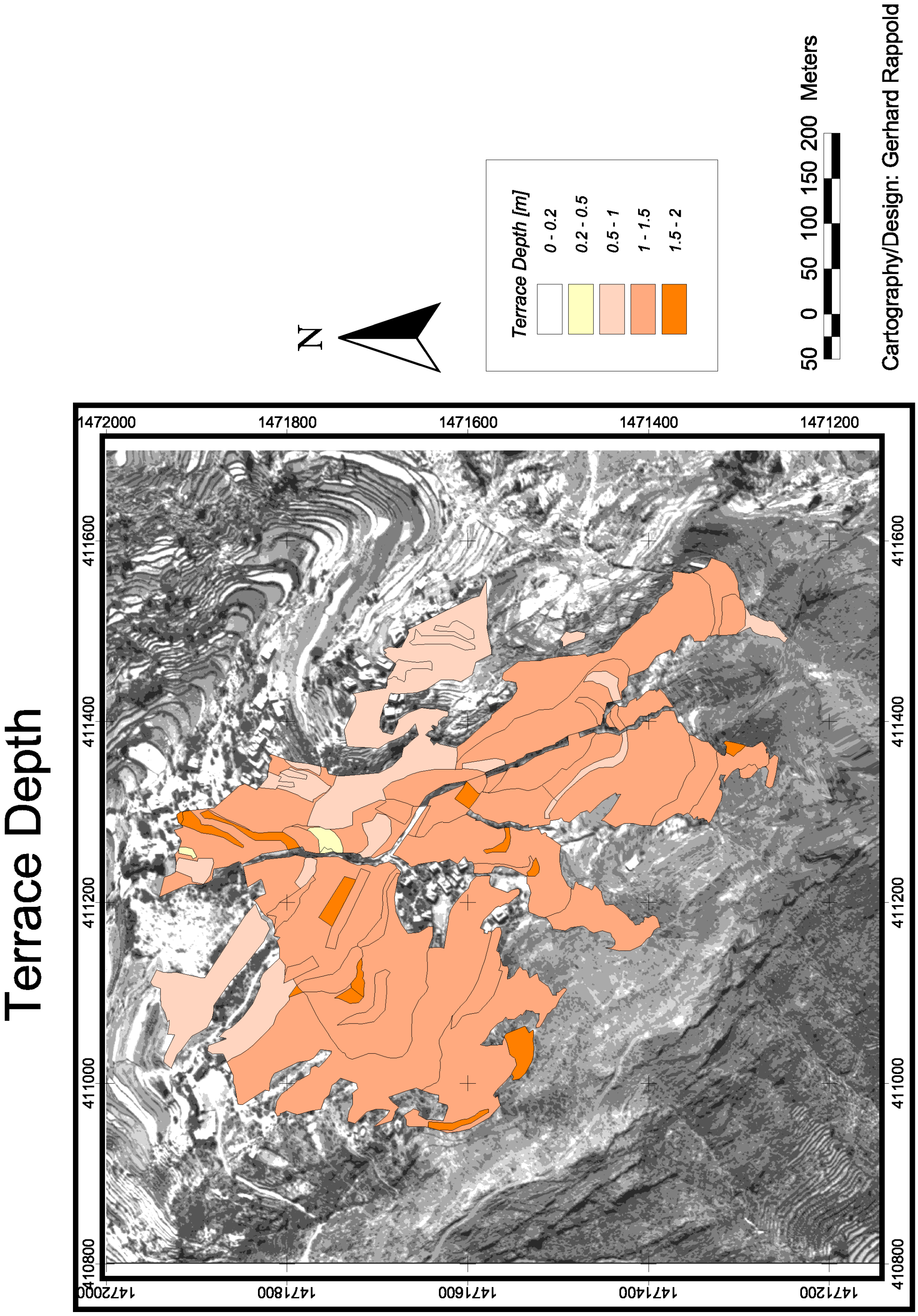

Figure 5.4 Terrace depth

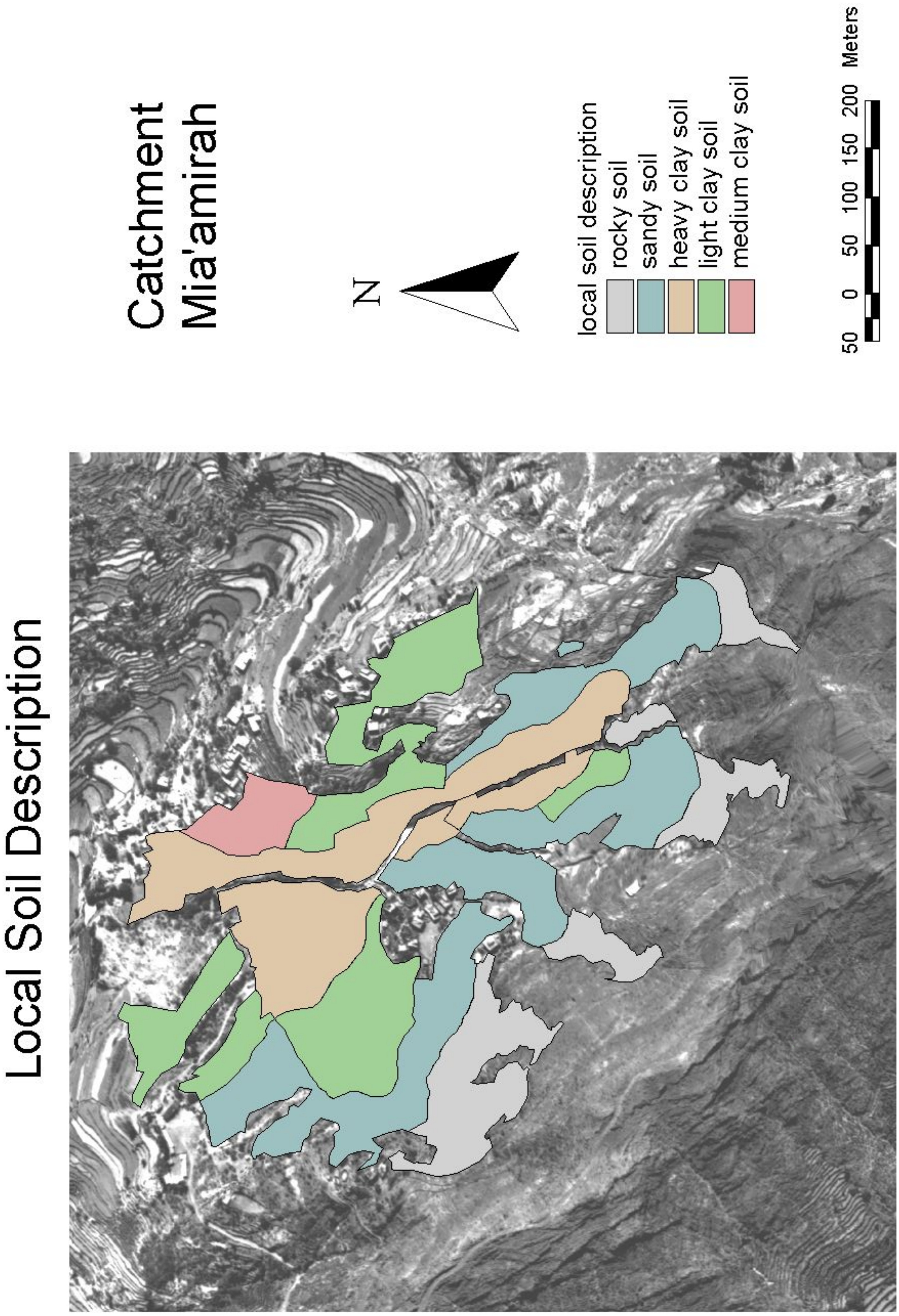

Figure 5.5 Local soil description

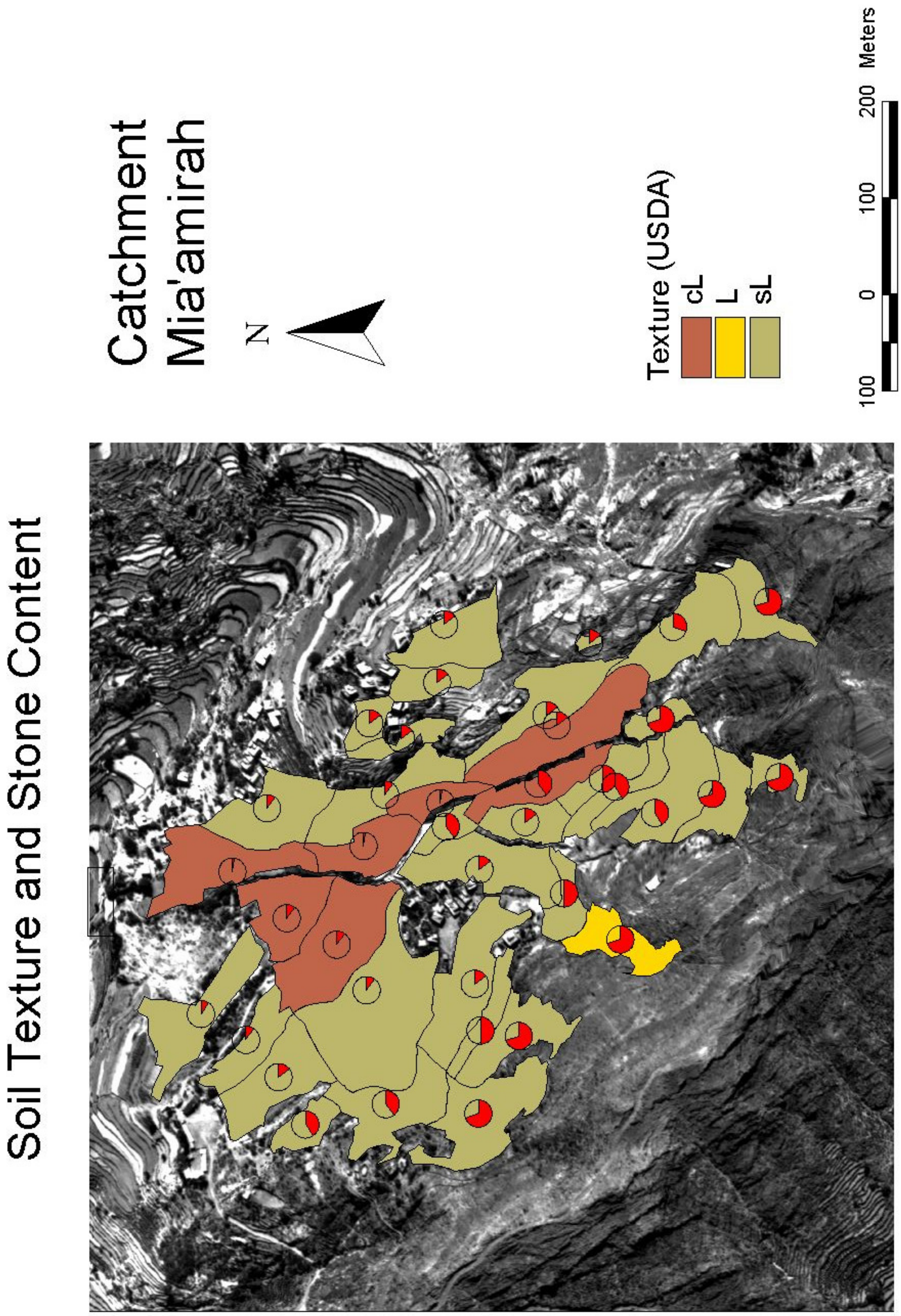

Figure 5.6 Soil texture and stone content

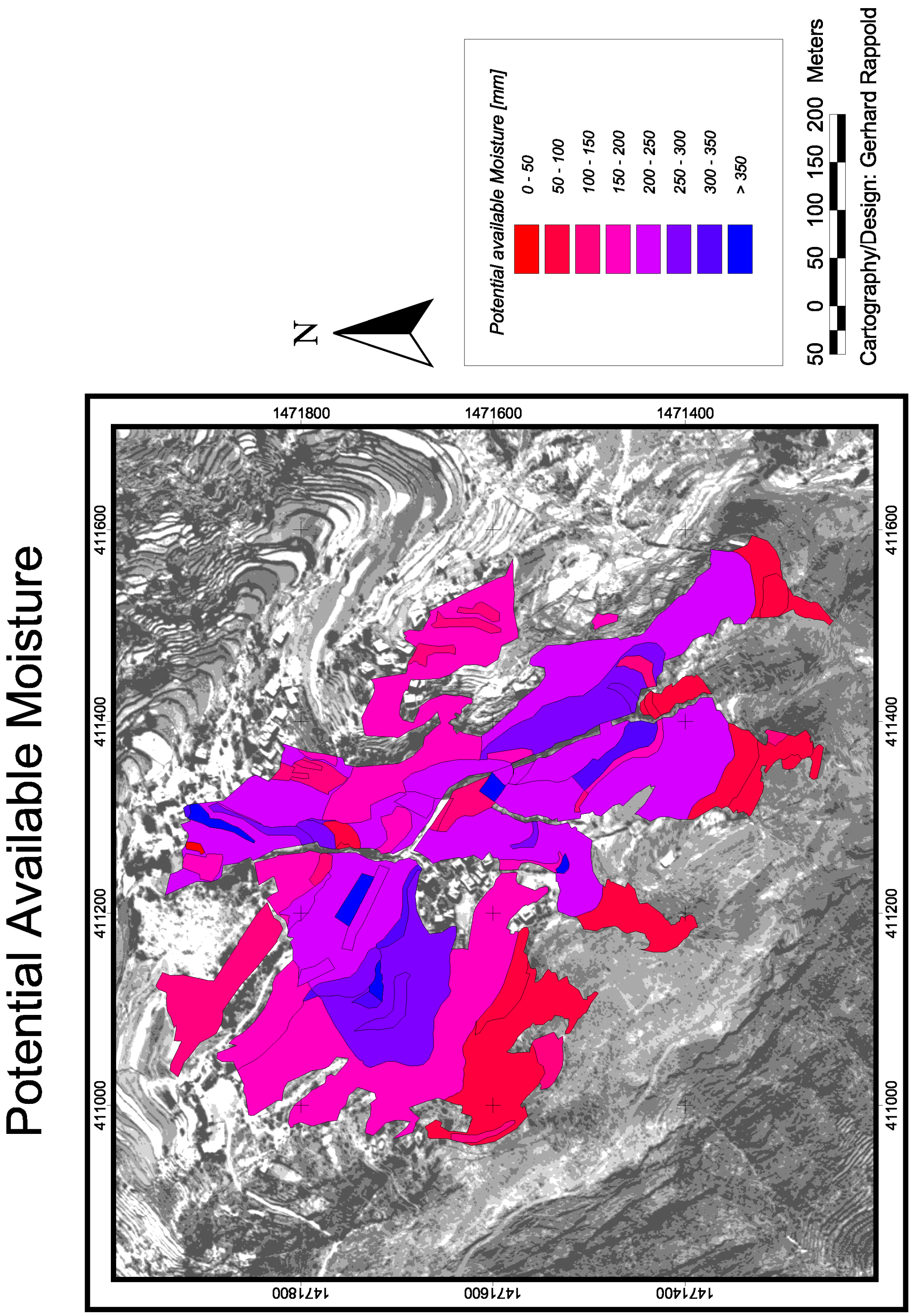

Figure 5.7 Potential available moisture

5.3.1 Soil Mapping and Soil Profiles

For the soil survey two different methods were combined. On the one hand, soil profiles according the FAO-UNESCO classification of soils were made, on the other hand rapid rural appraisal (RRA) techniques were used to reveal indigenous knowledge of the local farmers and get information about the spatial pattern of soil types.

The plowing of the fields in Mia‘amirah is the job of professional farmers who own oxen.[46] Only two farmers in Mia‘amirah provide this service. Therefore one of them, Abdul Hak, plows on all sites of the catchment and knows the soil properties in detail. With field visits and the interpretation of the aerial photo it was possible to produce a a detailed local soil map (figure 5.6). Furthermore, a “sand model” of the catchment was built with the local villagers. In contrast to conventional maps and aerial photographs, which were unfamiliar to the villagers, the model was produced by themselves and everything could be explained. This RRA-modelling technique[47] was very effective and accurate. A discussion about water harvesting areas, terraces and runoff paths were initiated with interested villagers. The information was documented by sketches, photos and notes, and compared with own observations.[48]

Soil profile descriptions of man made terraced slopes are a delicate issue. The terraces are an ancient system that has been permanently maintained, changed, rebuild and restored. Tillage practice created a permanent impact. Manuring to enhance fertility or measures of weed control and other schemes permanently interrupted the soil development. At terraces with runon irrigation, new material accumulates on the top soil and has been worked in the soil by tillage year by year. The genesis of the soil was never undisturbed. The development of soil horizons is faint. Human influence is more than obvious. Nine soil profiles were made. The plots were selected where terrace walls were destroyed by sayl. The farmers did not permit to dig new profiles. This was a major constrain and plots were

46 Much of the male labour is done by professional workers due to the migration of male family members to the cities or abroad.

47 Schönhuth, Kievelitz (1993)

48 In contrast to the map and the aerial photo it was difficult for the author to document the extensive and detailed information. The photo documentation appeared illustrative but was not very informative. Therefore the full potential of this method could not be exausted. For better documentation the author would use video (if possible) to record the discussion.

selected "by chance" if a part of a terrace broke down after intensive rainfalls. In all cases the profile could be cleared. Nevertheless the soil profiles could be made in all parts of the catchment. For description, the FAO-Unesco soil classification was applied. The description of the soil profiles are in appendix 9.1.

5.4 Acquisition of Hydrological Data

5.4.1 Meteorological Parameters

The meteorological parameters shown in table 5.1 were collected using an automatic weather station. The location of the station was selected according to the following criteria:

1. Representative location for the conditions in the catchment.
2. Levelled ground with short grass cover and no major obstacles in the direct neighbourhood (close to international standards for weather stations).
3. Permission by the local inhabitants.
4. No unsupervised access by children (request by the inhabitants).

Table 5.1 Parameters of the Meteorological Station

Parameter	***Unit***	***Temporal Resolution***
Air humidity	[%]	30 min
Air temperature	[° C]	30 min
Air pressure	[mbar]	30 min
Solar radiation	[W/m²]	30 min
Wind speed	[m/s]	30 min
Wind direction	[°]	30 min
Soil temperature	[° C]	30 min
Volumetric Water Content	[%]	30 min
Precipitation	[mm]	10 min

All parameters except precipitation were measured and stored in 30 min intervals. Precipitation was measured in 10 min intervals, but only if it exceeded 2 mm within one interval.[49]

The 1st criterion is hard to meet in such a diverse environment. A location on the NNE exposed mid-slope was selected to avoid extraordinary exposition at the ridge or the valley bottom. The mountain covers the W to S directions and this influenced the wind direction. However, an ideal position does not exist and topographic influences cannot be avoided in

49 The rain gauge measured the rainfall by a tilt-balance. That type of device can also be triggered by shock caused by goats who bump into the device.

mountainous terrain. The 2nd criterion could be met by selecting an idle edge of a terrace which was almost flat and had a grass cover. The criteria 3 and 4 were also met because the location was close to the house of Mr Al-Ghory and the station was protected by a fence. Only the rain gauge had to be installed outside, otherwise the measurement would have been influenced too much by the construction of the weather station. Beside the meteorological parameters, the soil temperature and soil moisture were measured in three depths (40 cm-60 cm-80 cm) in the adjacent terrace.

5.4.2 Runoff Measurements

The catchment had one natural outlet and three man-made runoff canals which formed extra outlets. The runoff was measured at all outlets.[50]

Location 1 – Outlet –

The 1st measuring point was located in a channel. One side was a natural stone wall, the other a terrace wall. The flow path was straight for 12 m, the slope of the bed approximately 3°. A venturi-flume with an float gauge was installed. The design of the flume was adapted from RÖSSERT (1994). The volumetric discharge was computed by

$$Q = 0.985\, b_2 \sqrt{g}\, b_2 / b_1\, h^{3/2} \tag{5.2}$$

where:	Q	runoff [m³/s]
	g	gravitational acceleration 9.81 m/s²
	b_1	min channel width
	b_2	max channel width
	h	water level [m]

The gauges recorded on 24-h paper, the recording cylinder was replaced after every runoff event. The temporal resolution was approximately 5 minutes.

Location 2 – Askeri – and location 3 – Double V –

The 2nd discharge measuring point “Askeri[51]” was located at the end of one of the bypass channels in the east of the catchment. It collected the discharge of an area of approximately 3000 m².

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50 The graphs of the hydrographs are given in appendix 8.3.

51 The name was derived from the neighbours nick name; he did not come from the area but belonged to the sheiks guard in the 60ties, "askeri" means "guard or police man".

The 3rd discharge measuring point "double-V" was located below the water harvesting areas of the western slope of the catchment. It consisted of two v-notches side by side which measured the runoff of two channels which drained the upper slope. The runoff was measured separately, but as they drained the same slope the data were processed together.

The discharge at these two locations was measured by Thomson v-notches. They were manually operated by local staff who read the water level in 5 minutes intervals. Although the reliability of the staff was high, problems occurred because the reading watches were often not precisely synchronised, time checks between the watches often showed 5 – 10 min differences. The conversion from water level into discharge volume for the Thomson v-notches (angle 90°) is given by the following equation provided by the DVWK (1991)

$$Q = 1.367 \cdot h^{5/2} \qquad (5.3)$$

where Q: discharge [l/s]

h: water height [cm]

5.4.3 Soil Moisture Measurements

The soil moisture was measured twice a week at 10 terraces to obtain information on the soil moisture conditions of the terraces. The gravimetric method was applied. This method was preferred to TDR[52] measurements and tensiometers. On principle the TDR-method is more precise than the gravimetric method, but the following restrictions could not be overcome:

- With the available device only surface measurements were possible.
- In dry conditions the soil turned very hard and it was not possible to prove if the device was inserted into the soil in an appropriate way.
- In soils with high stone content – as found in several places – the use of this instrument was not advisable.

Tensiometers present other problems. Because of the high altitude above sealevel the measuring range is limited. If the soil turned slightly too dry, the ceramic cell drew air and no further measurement was possible. However, the use of the gravimetric method had some difficulties, too. With the gravimetric method the samples were taken out and the

52 TDR = Time Domain Reflecting Method

sample plot had to change. Due to the inaccessibility of the working area it was not possible to ship the samples to the laboratory in Ta‘izz and the onsite drying procedure was susceptible to errors.

The sampling locations were chosen along two profiles between the wadi and the top of the terraces. The first on an E-exposed slope and the second one an N-exposed slope (see 5.2). The samples were collected by an auger in the depths of 0-30-60-90 cm. In shallow terraces sampling depths of 60 cm and 90 cm were not possible. The samples were stored in pre-labelled and weighed plastic bags. All samples were weighed immediately after finishing the sampling tour with a mechanical balance (precision 0.02 g). They were dried in 2 steps. First in the open bag until the probe was “air” dry. Afterwards, the soil was carefully poured into aluminium bowels and dried in an simple stove in the field for 6 to 8 h. Due to this procedure, the interpretation of the results is limited.

5.4.4 Infiltration Experiments

Infiltration experiments were conducted in 1997 and 1998 with double ring infiltrometers with a diameter of 40 cm and 110 cm. The devices used in 1997 and 1998 differ in their gauging type.

In 1997 a 2 l glas bottle was used as a water reservoir. It was placed upside down above the inner ring and a pipe refilled the water in the inner ring. By this method the water level remained constant during the experiment. The infiltration rate was gauged at a scale at the bottle. The disadvantage of this type of experimental design was that the infiltration rates are considerably high and the depletion of the 2 l reservoir was often too fast for smooth measurements.

In 1998 a simple ruler with a range was attached to the inner ring. The decrease of the water level could be easily observed. Refilling of the ring was easy. The disadvantage of this gauging method was that they result a) in high congestion of water in the ring (> 4 cm) and b) in changes of the water level which affect the infiltration rates.

The locations of the infiltration experiments were selected to match the different soil types. A major constrain was the water supply. Constant infiltration rates are reached approximately after 4 h of infiltration. More than 500 l of water was required and had to be carried in 20 l canisters on foot to the infiltration plots. Water could be taken only from public wells because the farmers would not "waste" water from their privat wells by infiltration into the ground. Because of the limited number of canisters some of the experiments in remote plots were always not fully conducted. But due to the short duration of rainfalls (usually less than 45 min) the infiltration rate at the beginning is of the highest interest.

5.4.5 Data from other Institutions

The Natural Water Resource Authority (NWRA) provided the monthly precipitation data for Ta'izz from 1944 until 1995 (missing years 1954-1960, 1973, 1975). These data have been compiled from several sources and represent several locations (old airport, Osiferah and others) in Ta'izz. A clear documentation was not available. Therefore the interpretation of these data is rather limited.

The current meteorological station in Ta'izz is operated by the Agricultural Research and Extension Authority (AREA) and located on their experimental farm on foot of the town in the quarter Osiferah. The coordinates are: latitude: 13°36', longitude 44°01', altitude 1400 m a.s.l. At the station the following parameters are measured: windway (km/d), maximum temperature, minimum temperature, dry and wet temperature and daily rainfall. The data collection is usually done daily during the late morning. The overall impression of the station was medium to poor, but nevertheless it was still in function.

The precipitation data available from this station are for the period from 1st January 1980 until 31st December 1991 and from 1st January 1995 until 31st December 1998. The data were obtained as photocopies of the handwritten observation protocols. They were digitised manually.

The topographical maps 1:250.000 and 1:50.000 and aerial photographs were made available to the IDAS-Project by the Survey Authority, the Ministry of Oil and Mineral Exploration and the National Water Resource Authority (NWRA). A black and white aerial photograph of the study area is available in a scale of approximately 1:5000. It was taken in April 1980. The aerial photograph was orthorectified to the base map of the survey.