Food and Agriculture Organization of the United Nations

Assessment of the water harvesting sector in Jordan

Final report

Cover photo
FAO/Marco Longari

Maps
Motasem Abu Khalaf

Assessment of the water harvesting sector in Jordan

Final report

Prepared by:

Maher Salman

Motasem Abu Khalaf

Brenna Moore

With contribution from:

Ahmad Al Qawabah

Ayman Al Hadid

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 2016

ISBN 978-92-5-109074-9

Table of contents

1. Introduction

1.1 WATER AND AGRICULTURE IN JORDAN

Jordan is one of the most water scarce countries in the world, with estimated renewable water resources of 148 m^3 per capita per year[1]. Water scarcity is driven primarily by the arid to semi-arid climatic regime – 80 per cent of the country receives average precipitation of less than 100 mm/year[2] – and by population increases experienced in recent decades as a result of both natural growth and immigration/refugee intake. At present, total water use exceeds renewable supply, with the balance being met mostly by groundwater over-abstraction and reclaimed wastewater, and to a lesser extent by small-scale desalination.

The agriculture sector accounted for 59 per cent of water use in Jordan in 2010[3]. The contribution of agriculture to GDP has declined from 9.7 per cent in 1978 to 2.3 per cent (as of 2008)[4]. The proportion of the economically active population working in agriculture is also declining (standing at 2 per cent in 2011[5]). While the area of land cultivated in Jordan has shown some variation over recent years, the percentage of cultivated land that is irrigated has seen an increasing trend – from 30 per cent in the early 1990s, to around 40 per cent from 2008 onwards (Figure 1). This is due to an increasing proportion of cultivated land being used for vegetables and fruit trees. This increase in irrigation is founded on increasingly unsustainable groundwater abstraction: the majority of irrigated land (around 56 per cent at the latest agricultural census) uses water sourced from wells; other important sources include dams and the King Abdallah Canal[6].

Jordan's water deficit is projected to become even more severe in the near future. Assuming that renewable supplies were to remain constant, increases in demand are projected to lead to a fall in per capita water availability to 90m^3 by 2025[7]. However, climate models for the region predict a decrease in winter rainfall and an increase in mean annual temperature[8], which will reduce the renewable water supply and further exacerbate water scarcity. The high rates of groundwater over-abstraction also cannot be sustained, as pumping costs and salinity levels will continue to increase[9].

1 FAO 2011, AquaStat: Jordan Country Fact Sheet, FAO: Rome.

2 Hadadin, N., Qaqish, M., Akawwi, E. and Bdour, A. 2010, *'Water shortage in Jordan – sustainable solutions'*, Desalination, 250, 197–202.

3 FAO 2013, National Investment Profile: The Hashemite Kingdom of Jordan, FAO: Rome.

4 FAO 2013, National Investment Profile: The Hashemite Kingdom of Jordan, FAO: Rome.

5 World Bank 2013, World Development Indicators, http://data.worldbank.org/.

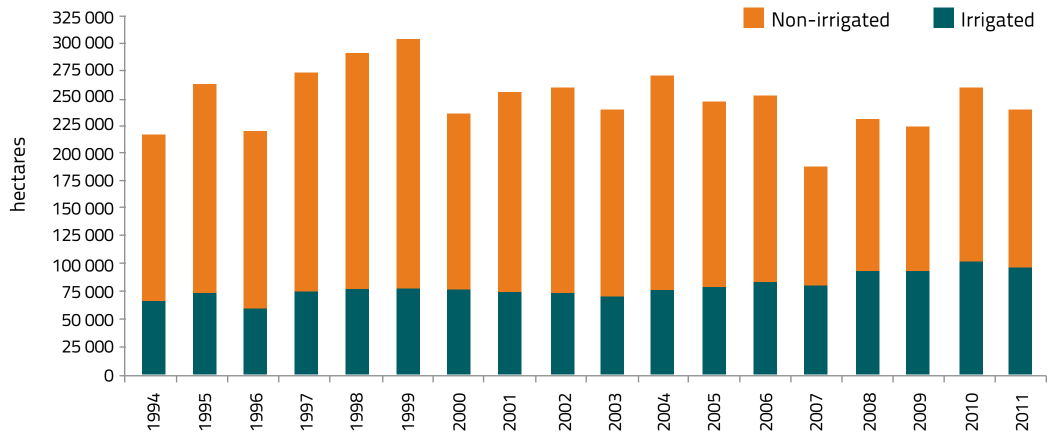
6 Government of Jordan 2007, Sixth Agricultural Census, Department of Statistics: Amman.

7 Humpal *et al.* 2012

8 Wade, A., Black, E., Brayshaw, D., El-Bastawesy, M., Holmes, P., Butterfield, D., Nuimat, S., and Jamjoum, K. 2010, *'A model-based assessment of the effects of projected climate change on the water resources of Jordan'*, Philosophical Transactions of the Royal Society A, 368, 5151–5172.

9 Humpal *et al.* 2012

Figure 1. Cultivated land in Jordan (hectares)



Source: Department of Statistics, Government of Jordan

1.2 RATIONALE FOR WATER HARVESTING

Despite the declining contribution of agriculture to GDP in Jordan, this sector nonetheless supports a large number of jobs in regions where alternative job creation would be difficult and expensive[10]. The socio-economic cost of further contraction of the agricultural sector could be substantial. Agriculture also supports export-oriented value chains, which have backward and forward linkages to the domestic economy that are not evident in the direct contribution to GDP alone. For these reasons, it is prudent to continue to support this sector in meeting its water needs.

The severe water shortages likely to be faced by Jordan require a comprehensive approach to managing both water supply and water demand. While the national government has placed a priority on meeting domestic water needs, the importance of the agricultural sector to rural employment necessitates a considered approach to improving agricultural water security. Augmenting the water supply for agriculture can make an important contribution to achieving this[11]. Large-scale seawater desalination has been promoted as the long-term solution to Jordan's water scarcity problems, but the cost involved does not make this a viable option for supporting agriculture. Alternative lower-cost approaches are needed to diversify agricultural water supply.

Water harvesting provides one such alternative[12]. 'Water harvesting' may be defined as the process of concentrating precipitation through runoff and storage for productive use[13]. Jordan is characteristic of the Near East region in that rainfall is not only low, but

[10] Humpal *et al.* 2012

[11] Water demand management can also play a role. While technical water efficiency in Jordan is high relative to the rest of the region, the Government of Jordan is also seeking to improve economic water efficiency by introducing appropriate tariffs for water use.

[12] Another alternative is the greater use of treated wastewater in agriculture, which could also form part of a package of measures to diversify agricultural water supply.

[13] Oweis, T., Prinz, D. and Hachum, A. 2001. *Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments*, ICARDA: Aleppo, Syria.

also erratic. In any given year, half of potentially cultivable land is left fallow because of fluctuating and unevenly distributed rainfall[14]. That rain which does fall is mostly lost in evaporation and unutilised runoff (which in turn often causes erosion) – leaving frequent dry periods during the growing season[15]. This creates difficulties in sustaining crops, pasture and livestock. In such a climate, rainwater harvesting is an appropriate option for augmenting the available water supply to allow for supplemental irrigation (when rainfall fails to provide sufficient moisture for normal plant growth). In this report, water harvesting structures are considered at the landscape level (e.g. dams or pools with multiple users), rather than at individual household level (e.g. cisterns).

By concentrating rainfall runoff in winter and during storms, water harvesting structures can increase the amount of supplemental irrigation available per unit of cropping area – thereby increasing and stabilizing production[16]. These structures, such as small check dams, pools and bunds, can also provide a source of drinking water for livestock, potentially throughout the year, and may also support small-scale home gardens for household income generation. Water harvesting is therefore a way to improve water security for vulnerable farmers in a high-risk climate. Water harvesting may also help to reduce the pressure currently exerted on Jordan's aquifers, and could contribute to improved groundwater recharge rates, by concentrating water in a way that allows more infiltration before the water is ultimately used or evaporates.

The importance of water harvesting has been recognized by the Government of Jordan in its Water Strategy for 2008 to 2022, *Water for Life,* which describes a number of goals and actions to address the water supply-demand imbalance. With respect to irrigation water, a specific goal is included to 'promote the use of rainfall harvesting methods in irrigation'. Water harvesting also plays an important role in the planned activities under the 2006 *National Strategy and Action Plan to Combat Desertification*.

1.3 PURPOSE OF THIS REPORT

Water harvesting has greater potential to contribute to agriculture in Jordan than what is currently being achieved. While water harvesting has been practiced in the country for centuries, modern development of water harvesting has been *ad hoc*. As noted in both Jordan's *Agricultural Strategy* and *National Environment Strategy*, there is no integrated national plan to make greater use of water harvesting for supplemental irrigation – despite the additional water that it can contribute. A sub-sector strategy for water harvesting is needed to ensure the continued development of this alternative in a way that is effective and sustainable.

The purpose of this report is to provide a first assessment of the current status of water harvesting in Jordan, using an illustrative example from the Al Mafraq region. This assessment will subsequently serve as an important input into the development of a sub-sector strategy for water harvesting. The assessment is based on the work of

[14] Government of Jordan 2009, Water for Life: Jordan's Water Strategy 2008-2022, Ministry of Water and Irrigation and others: Amman.

[15] Oweis *et al* 2001.

[16] Oweis *et al* 2001.

the FAO project *Coping with water scarcity - the role of agriculture – Phase III*, active in Jordan since 2011, which, with its in-county focussed intervention in Jordan, seeks to contribute to agricultural development through the establishment of a pilot site and training programme for water harvesting centred around beneficiary farmers (Farmers' Cooperative). The overall aim of the project is to strengthen national capacities for improving water management and dealing with the agricultural component of water scarcity.

The sub-sector strategy for water harvesting will assist the Government of Jordan to meet its stated objectives for agricultural water management. It will contribute to the achievement of a number of existing national strategies relating to water, agriculture, environmental management and desertification, and will complement in particular the new Agricultural Strategy for 2014-2020. The water harvesting strategy will be operationalized through a clear work plan so as to facilitate its implementation.

2. Methodology

2.1 MULTI-CRITERIA ASSESSMENT

A set of criteria has been developed for the assessment of water harvesting in Jordan. The proposed criteria, and the parameters for their measurement, are shown in Table 1. Each parameter was designed to answer a key question in relation to the sector. The choice of criteria and parameters was based on a review of relevant research in Jordan; consultation with key stakeholders has also contributed to the validation of these criteria. Consideration was also given to the availability of data for measurement of the parameters.

Table 1. Proposed matrix for assessment of the water harvesting (WH) sector

Criteria	Parameter to measure*	Rationale	Question to be answered
1.Water supply	Rainfall (spatial variability)	Main determinant of runoff that could be captured	Are existing and planned WH structures situated in the best areas for rainfall?
	Temperature (spatial variability)	Affects evaporation rates	Are existing and planned WH structures situated in areas with relatively lower evaporation rates?
	Design capacity of current and future WH structures	Shows the importance of this sector to water availability	What is the contribution of existing and planned WH to the national water budget?
	Actual capacity of current WH structures	Shows the importance of this sector to water availability	What is the contribution of actual volumes of stored rainwater to the national water budget?
	Available groundwater	Could provide an alternative source of water	Are WH structures located in areas with existing groundwater supplies?**
	Year of construction of WH structures	Year of construction can be used as a proxy for maintenance requirements	What are the maintenance requirements for existing WH structures?
2. Water demand	Population size	Larger populations have more need for WH to support agriculture, and provide a larger market for the resulting agricultural products	Are existing and planned WH structures situated in areas with larger populations?
	Population change	Rapidly growing populations may have greater need for WH	Are existing and planned WH structures situated in areas with more rapidly growing populations?
	Poverty levels	Areas with greater poverty are typically correlated to regions of low rainfall: WH could be an important tool to support agriculture and increase household income	Are existing and planned WH structures situated in areas of greater poverty, where need may be highest?
	Distance to market	WH structures intended to support agriculture should not be too far from markets – otherwise there is no demand for the resulting products	Are existing and planned WH structures situated so as to promote agricultural production for market sale and income generation?

3. Contribution to agriculture	Land use	Shows the local context for use of harvested water; avoid development of WH in areas designated as rangelands (where no cultivation is allowed)	What is the contribution of WH to land use?

** The parameters for each criterion are listed in order of priority, from most important to least important.*

*** In some areas groundwater availability is already considered prior to deciding on the location of WH structures (e.g. Al Rwished)*

2.2 DATA COLLECTION

Collection of data by FAO relating to the water harvesting sector in Jordan began in early 2012 in Rome, proceeding in Amman from mid-2012 onwards. It involved, as a first step, a comprehensive review of all data and publications relating to water harvesting in Jordan, produced by governmental agencies, national universities, national research institutes, and international organizations.

Based on the existing data, a database was constructed to capture the main characteristics of water harvesting structures in Jordan (name, coordinates, design capacity, current capacity, water use, construction material, height, estimated sediments, cost of construction, year of construction, and expected potential). Subsequently, FAO collaborated with the Jordanian Ministry of Agriculture (MoA), Ministry of Water and Irrigation, Natural Resources Authority, Jordan Valley Authority (JVA), and local municipalities in order to fill in any data gaps and add relevant information. Selected information from the database is shown in Annex 2. Data on the other criteria (relating to water supply, water demand, and contribution to agriculture) were collected from a wide variety of governmental sources.

2.3 DATA COMPILATION AND GIS MAPPING

The data collected for the various criteria were subsequently represented in Geographical Information System (GIS) maps. GIS techniques are useful for such a sub-sectoral assessment, due to their capabilities for storing, analyzing and displaying spatially distributed data according to user defined specifications[17]. They allow for a broad overview of the important characteristics of the existing water harvesting sub-sector.

A GIS file was created based on the database developed by FAO in cooperation with MoA and JVA. A total of 347 out of 362 existing and future water harvesting structures have defined coordinates that were able to be mapped (see Map A3.1 in Annex 3). The linking of the mapped sites to the database allows for easy editing and updating as soon as any new data becomes available.

A number of additional layers of information were developed using the data for the other

[17] Jabr, W. and El-Awar, F. 2004, GIS and Analytic Hierarchy Process for Siting Water Harvesting Reservoirs, 24th Annual Esri International User Conference, August 9–13, 2004.

criteria, and added to the main map showing distribution of water harvesting structures. The following layers were developed and geo-referenced: population, catchment areas, aquifers, rainfall, well distribution, topography, wadis, land cover, land use, roads, soil types, and geology. The resulting maps are shown in Annex 3 for the national level, although a high degree of detail is also accessible at sub-national level - for which an example is shown in Annex 4.

3. Results and analysis

The capacity of current and future water harvesting structures is discussed at national level, with relevant maps provided in Annex 3. The subsequent discussion uses an example from Al-Mafraq governorate to illustrate the type of more detailed analysis that may be undertaken using the data from the GIS maps. Al-Mafraq maps are provided in Annex 4.

The area selected from Al-Mafraq governorate was chosen based on its characteristics in relation to water harvesting. The area includes the full range of water harvesting structure types – existing, ongoing construction, and planned. Data was available to measure the distance from the water harvesting structures to wadis and to roads, and to assess land use and population. The area is also located close to an international border, which is an additional constraining factor in developing water harvesting structures (as a minimum distance from the border has to be observed). Al-Mafraq example is used to illustrate this first assessment of the water harvesting sub-sector, but a similar approach could be used to assess other areas – ultimately building up a picture of Jordan's water harvesting sector at the national level.

3.1 CRITERION 1: WATER SUPPLY

Capacity of current and future WH structures

The research undertaken indicates that there are 250 existing water harvesting structures in Jordan as of October 2013, with a further 112 structures under construction or planned for construction (Table 2). The design capacity of these structures is shown in Table 3, while the map with their distribution is shown in Annex 3 (Map A3.1). Most water harvesting capacity is found in small dams, with small contributions from ponds and pools[18]. The use of these structures varies, with dams typically being used for irrigation while ponds and pools are used for both irrigation and livestock. The largest proportion of the existing capacity in water harvesting is found in the north-eastern governorate of Al-Mafraq (67 per cent), as well as in Karak and Ma'an (10 per cent each). Further detail taken from the water harvesting database can be found in Annex 2.

Table 2. Number of water harvesting structures in Jordan, October 2013

	Existing	On-going	Future projects	Total	% of total
Dams	56	6	29	91	25.1%
Ponds	129	31	46	206	56.9%
Pools	65	-	-	65	18%
Total	250	37	75	362	

Source: Database developed by FAO in cooperation with MoA and JVA

Note: the number of dams excludes existing large dams situated on rivers

[18] The Government of Jordan customarily defines these structures by their capacity: pools hold less than 50,000 m^3; ponds hold 50,000–200,000 m^3; and dams hold more than 200,000 m^3.

Table 3. Construction capacity of water harvesting structures in Jordan, October 2013 (1000 m^3)

	Existing	On-going	Future projects	Total	% of total
Dams	95,297	9,060	10,755	115,112	84%
Ponds	15,190	2,625	3,880	21,695	15.8%
Pools	268	0	0	268	0.2%
Total	110,755	11,685	14,635	137,075	

Source: Database developed by FAO in cooperation with MoA and JVA

Note: the capacity of dams excludes existing large dams situated on rivers

The capacity of water harvesting structures can be compared to the total amount of water resources available in Jordan, to show the potential contribution of water harvesting to national water supply. The annual renewable water supply is shown in Table 4 below. Due to the difficulties in obtaining information on the actual volume of water in existing water harvesting structures, this can for now only be compared to the total construction capacity (110,755 m^3 for existing water harvesting structures).

Table 4. Annual renewable water resources in Jordan, 2011 (1000 m^3)

	Natural	Actual
Renewable surface water	1,155,000	650,000
Renewable groundwater	720,000	540,000
Total renewable water resources	**1,622,000**	**937,000**

Source: FAO Aquastat

Note: Natural resources refer to water resources expected under natural conditions, i.e. without human influence. Actual resources refer to the water resources observed in reality, accounting for human influence.

Groundwater, rainfall and temperature variability[19]

Taking the case of the selected area in Al-Mafraq, it appears that most water harvesting structures are situated some distance from wells (Map A4.1, Annex 4). Further examination of rainfall variability (Map A4.2) shows that the wells are situated in the area of lowest rainfall (<50 mm per annum), while most water harvesting structures are in areas with relatively higher rainfall (50-150mm per annum).

The location of existing and planned water harvesting structures can also be compared to the distribution of wadis (Map A4.3). Three dams are planned in the selected area: two of these are located at the confluence of two wadis. The planned future pond is also located

[19] At present, data on temperature variability is not available.

at the confluence of two wadis, whereas the existing ponds and pool do not appear to be located on any wadis.

3.2 CRITERION 2: WATER DEMAND

The demand for harvested water is a function of various factors. The first relates to population size in the area in question (Map A4.4). The population figures indicated in the map refer to the entire population of the indicated sub-districts – showing that population density in the selected area is low.

Demand for water harvesting is also related to market access. Assuming that most water harvesting would preferably be used for crop irrigation, the demand for these crops in the nearby markets is a determinant of how much harvested water is needed. The distance between water harvesting structures and urban centers is an indicator for market access. At present, this data is available but has not yet been translated into a GIS map.

Finally, there may be a higher demand for water harvesting in areas that are relatively poor, where alternative water sources (e.g. wells) or income sources (non-agricultural) are limited. The data is available to compare the poverty levels in Jordan to the location of water harvesting structures, but has not yet been translated into a GIS map.

3.3 CRITERION 3: CONTRIBUTION TO AGRICULTURE

By examining the land use and land cover in the area surrounding water harvesting structures (Maps A4.5 and A4.6), it is possible to identify what type of activities these structures may be contributing towards. In the selected area, there is some indication of cultivation relatively close to ongoing and planned water harvesting structures. The land use around the existing structures is largely undefined, but is most likely used for livestock grazing.

4. Conclusions

4.1 CONCLUSIONS DRAWN FROM AL MAFRAQ EXAMPLE

Considering the selected example from the Al-Mafraq governorate, a number of initial conclusions can be drawn based on the data available. The distribution of water harvesting structures relative to rainfall variability suggests that in areas where precipitation makes water harvesting feasible, such structures are preferred to groundwater wells. Alternatively, it may be that the official abstraction limit for groundwater has been reached for this area, and that no new wells can be built – meaning that water harvesting provides an essential alternative water source. A comparison of the existing and planned water harvesting structures relative to the distribution of wadis suggests that perhaps the planning of water harvesting structures has improved in recent years, as the future planned structures are located in places that are more efficient for capturing scarce rainfall and/or preventing erosion (compared to those constructed in the past).

Population density in the selected area is low, suggesting a primarily nomadic population reliant on water harvesting to support livestock production. With respect to land use, the data shows that there is potential to expand cultivation in the areas surround water harvesting structures in the sample area. Given that the structures will mostly be empty during the warmest months when irrigation is most needed, they could instead provide supplemental irrigation for winter crops – as has been tested in the pilot for the 'Coping with Water Scarcity" project. Water harvesting could be particularly useful for supporting the cultivation of fodder crops, given the existing importance of livestock in the area.

4.2 GENERAL CONCLUSIONS

This report has described the rationale for further investment in the water harvesting sub-sector in Jordan, in particular through the development of a sub-sectoral strategy. It has provided an overview of the data available for assessing the water harvesting sub-sector, and an example of how this might be done at the sub-national level. The assessment has been undertaken based on a set of criteria relating to supply and demand for harvested water.

The report is intended to provide the basis for the development of a sub-sector strategy on water harvesting. However, it has not covered several factors that are nonetheless important in developing such a strategy. These are:

(a) The impact of the allocation of **land rights** on the location and use of water harvesting structures. The land tenure system can influence the success of water harvesting in various ways. If land rights are unclear, farmers may be unwilling to invest in water harvesting structures on land that they do not formally own;

the same may also be true for communal or state-owned land[20]. The land tenure system in Jordan is complex. There are three main types of land tenure: private ownership (land that is registered and documented), tribal ownership (historically distributed by the sheikhs), and state land (free access to resources)[21]. There is often overlap and a lack of clarity between state land and customary tribal systems, frequently leading to unsustainable land use practices[22]; there is also substantial fragmentation of land rights over subsequent generations. Land rights cannot be measured using a simple indicator such as those shown in the proposed matrix. Nonetheless, the land tenure regime, both formal and informal, must be taken into consideration when designing a national sub-sector water harvesting strategy for Jordan.

(a) **Equity issues** – as with any development strategy, the national sub-sector strategy on water harvesting should ensure that the promotion of this approach is not particularly advantageous to one group of people while excluding others[23]. To some extent, the indicator on poverty levels allows for an assessment of those areas where the need for water harvesting is the greatest (see Section 3.2 for further discussion). Due consideration should be given to equity issues, particularly given that while state law in Jordan does not differentiate between men and women in terms of rights to natural resources, customary law typically does not allow for women to have ownership or use rights over land or water[24].

(b) **Other physical features** – the assessment has not considered all physical features that may be relevant to the future direction of the water harvesting strategy: partly because the assessment does not seek to determine site selection for water harvesting structures, but also due to a lack of data. Other features that could be considered in future analysis are temporal rainfall variability (rather than only spatial), slope gradients, and the soil profile.

(c) The question of **water tariffs** – Jordan's National Water Strategy envisages the introduction of appropriate water tariffs in order to promote water efficiency in irrigation. The more rigorous application of tariffs to irrigation water, particularly that sourced from groundwater, may create incentives to invest more in water harvesting.

These factors must be taken into consideration in the drafting of the strategy itself. The next step for development of the sub-sector strategy is to form a steering committee to lead the drafting process, and an agreed workplan. The drafting of the strategy will be led by the Government of Jordan with inputs from FAO and other stakeholders as appropriate.

[20] Critchley, W., Siegert, K., Chapman, C. and Finkel, M. 1991, *A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production*, FAO: Rome.

[21] Al-Oun, S. 2005, *Land Tenure and Tribal Identity in the Badia of Jordan: Reality and Projections,* cited in National Center for Research and Development 2011, Securing rights and Restoring Range Lands for Improved Livelihoods in the Badia of the Zarqa River Basin – Jordan, NCRD: Amman.

[22] National Centre for Research and Development 2011, Securing rights and Restoring Range Lands for Improved Livelihoods in the Badia of the Zarqa River Basin – Jordan, NCRD: Amman.

[23] Critchley et al. 1991

[24] National Centre for Research and Development 2011

Annex 1.
References

Al-Adamat, R. 2008. GIS as a decision support system for siting water harvesting ponds in Jordan, *Journal of Environmental Assessment Policy and Management*, 10 (2), 189-206.

Al-Oun, S. 2005, *Land Tenure and Tribal Identity in the Badia of Jordan: Reality and Projections,* cited in National Centre for Research and Development 2011, *Securing rights and Restoring Range Lands for Improved Livelihoods in the Badia of the Zarqa River Basin – Jordan*, NCRD: Amman.

Critchley, W., Siegert, K., Chapman, C. and Finkel, M. 1991, *A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production*, FAO: Rome.

FAO 2011, AquaStat: Jordan Country Fact Sheet, available from http://www.fao.org/nr/water/aquastat/data/cf/readPdf.html?f=CF_JOR_en.pdf

FAO 2013, *National Investment Profile : The Hashemite Kingdom of Jordan*, FAO: Rome.

Government of Jordan 2007, *Sixth Agricultural Census*, Department of Statistics: Amman.

Government of Jordan 2009, *Water for Life: Jordan's Water Strategy 2008-2022*, Ministry of Water and Irrigation and others: Amman.

Hadadin, N., Qaqish, M., Akawwi, E. and Bdour, A. 2010, 'Water shortage in Jordan – sustainable solutions', *Desalination*, 250, 197–202.

Humpal, D., El-Naser, H., Irani, K., Sitton, J., Renshaw, K., and Gleitsmann, B. 2012, *A Review of Water Policies in Jordan and Recommendations for Strategic Priorities*, USAID: Amman, Jordan.

Jabr, W. and El-Awar, F. 2004, *GIS and Analytic Hierarchy Process for Siting Water Harvesting Reservoirs*, 24th Annual Esri International User Conference, August 9–13, 2004.

Oweis, T., Prinz, D. and Hachum, A. 2001. *Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments*, ICARDA: Aleppo, Syria.

Wade, A., Black, E., Brayshaw, D., El-Bastawesy, M., Holmes, P., Butterfield, D., Nuimat, S., and Jamjoum, K. 2010, 'A model-based assessment of the effects of projected climate change on the water resources of Jordan', *Philosophical Transactions of the Royal Society A*, 368, 5151–5172.

World Bank 2013, World Development Indicators, http://data.worldbank.org/.

Annex 2.
Selected data from the water harvesting database

The database developed by FAO in cooperation with MoA and JVA contains all the available data found by the review of information, and other up-to-date data which provided by the local authorities. In some instances, the desired information was not available (for example the current volume stored in most water harvesting structures). The database covers three types of water harvesting structures: dams, Ponds (*hafeirs*) and pools. These structures may be existing, on-going (i.e. under construction), or proposed. The following tables provide an overview of the information contained in the database.

Table A1. Number of water harvesting structures in Jordan by governorate, October 2013

Governorate	Dams			Ponds			Pools
	Existing	On-going	Future projects	Existing	On-going	Future projects	Existing
Al-Mafraq	12	-	12	42	9	25	43
Irbid	1	-	-	-	-	-	4
Ajloun	-	1	-	1	-	-	3
Jarash	-	-	-	-	-	-	1
Zarqa	5	-	1	12	-	1	-
Amman	4	-	4	21	-	1	2
Balqa	-	-	2	-	-	-	2
Madaba	-	-	3	-	-	-	2
Karak	15	2	3	15	3	-	6
Tafiela	11	2	3	2	-	-	-
Ma'an	8	1	1	36	17	17	2
Aqaba	-	-	-	-	2	2	-
	56	6	29	129	31	46	65
		91			206		65
				362			

Table A2. Capacity of water harvesting structures in Jordan by governorate, October 2013 (1000m^3)

Governorate	Dams			Ponds			Pools
	Existing	On-going	Future projects	Existing	On-going	Future projects	Existing
Al-Mafraq	71,605	-	1,319	2,644	800	1,980	126.6
Irbid	700	-	-	-	-	-	11.5
Ajloun	-	6,700	-	30	-	-	3.8
Jarash	-	-	-	-	-	-	10
Zarqa	5,515	-	500	1,550	-	100	-
Amman	2,900	-	950	2,500	-	100	81.6
Balqa	-	-	300	-	-	-	3.5
Madaba	-	-	2,300	-	-	-	3.3
Karak	5,452	2,170	5,050	5,781	175	100	18.8
Tafiela	925	120	136	75	-	-	-
Ma'an	8,200	70	200	2,610	1,450	1,500	9.2
Aqaba	-	-	-	-	200	200	-
	95,297	9,060	10,755	15,190	2,625	3,880	268
		115,112			21,695		268
				137,075			

Figure A1. Capacity of existing water harvesting structures in Jordan by governorate, October 2013 (1000m^3)

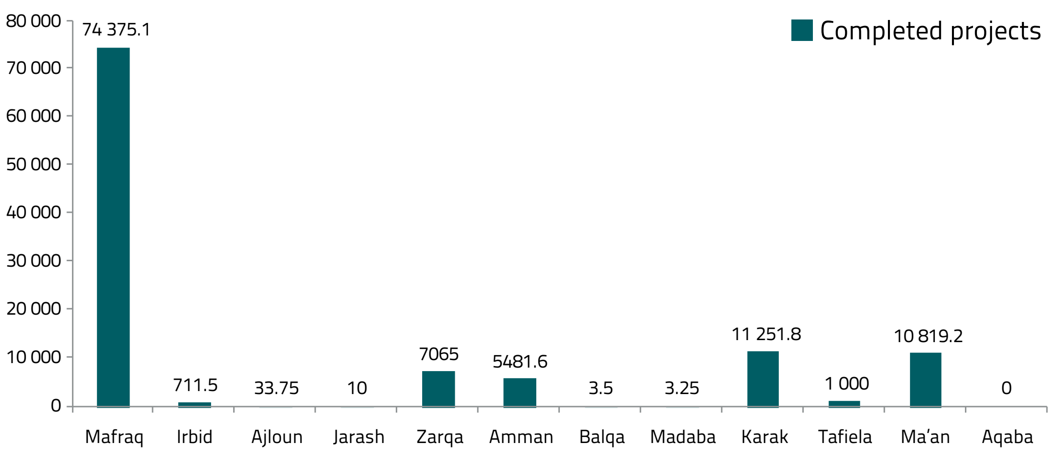
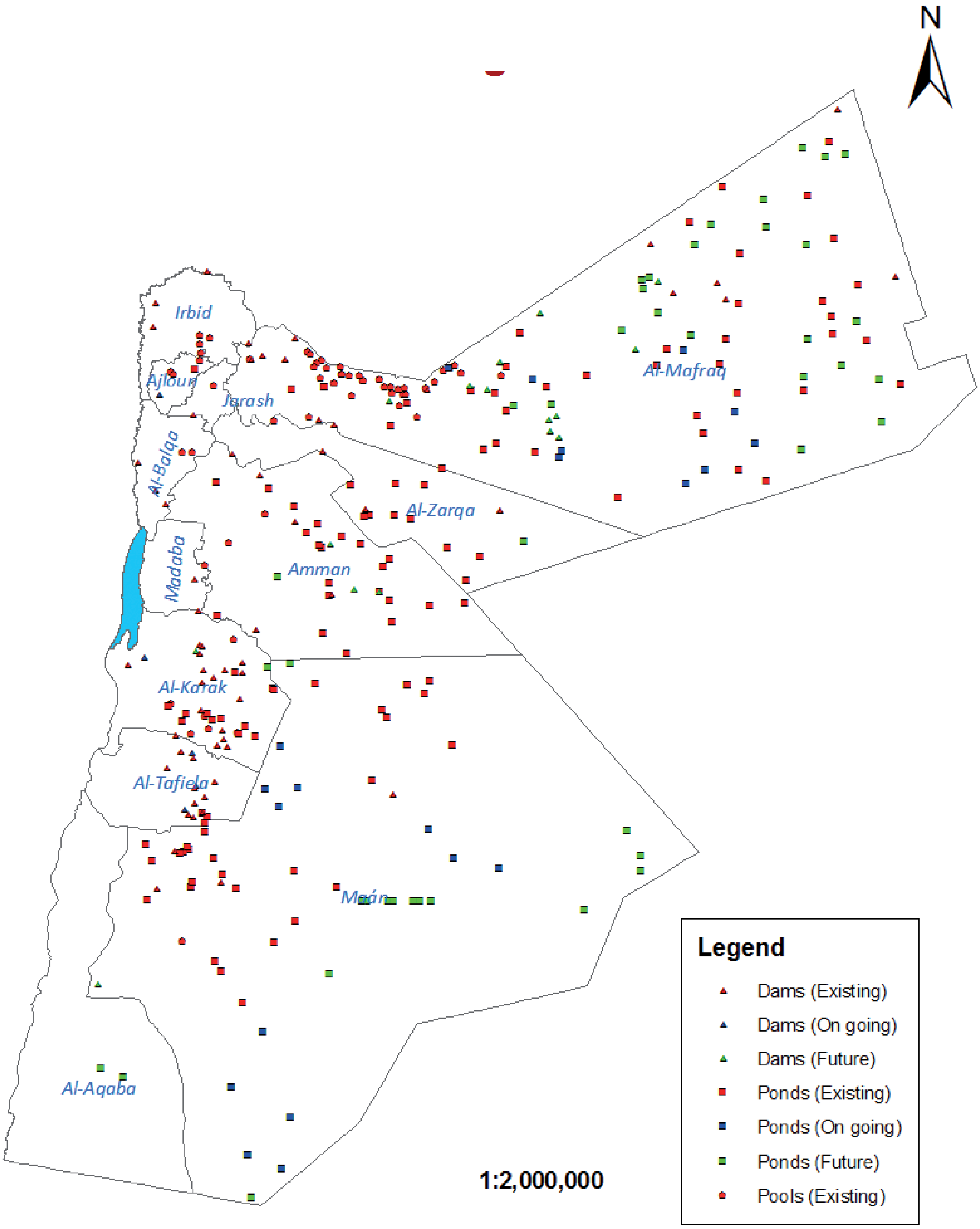


Table A3. Year of construction/last maintenance – existing water harvesting structures, October 2013

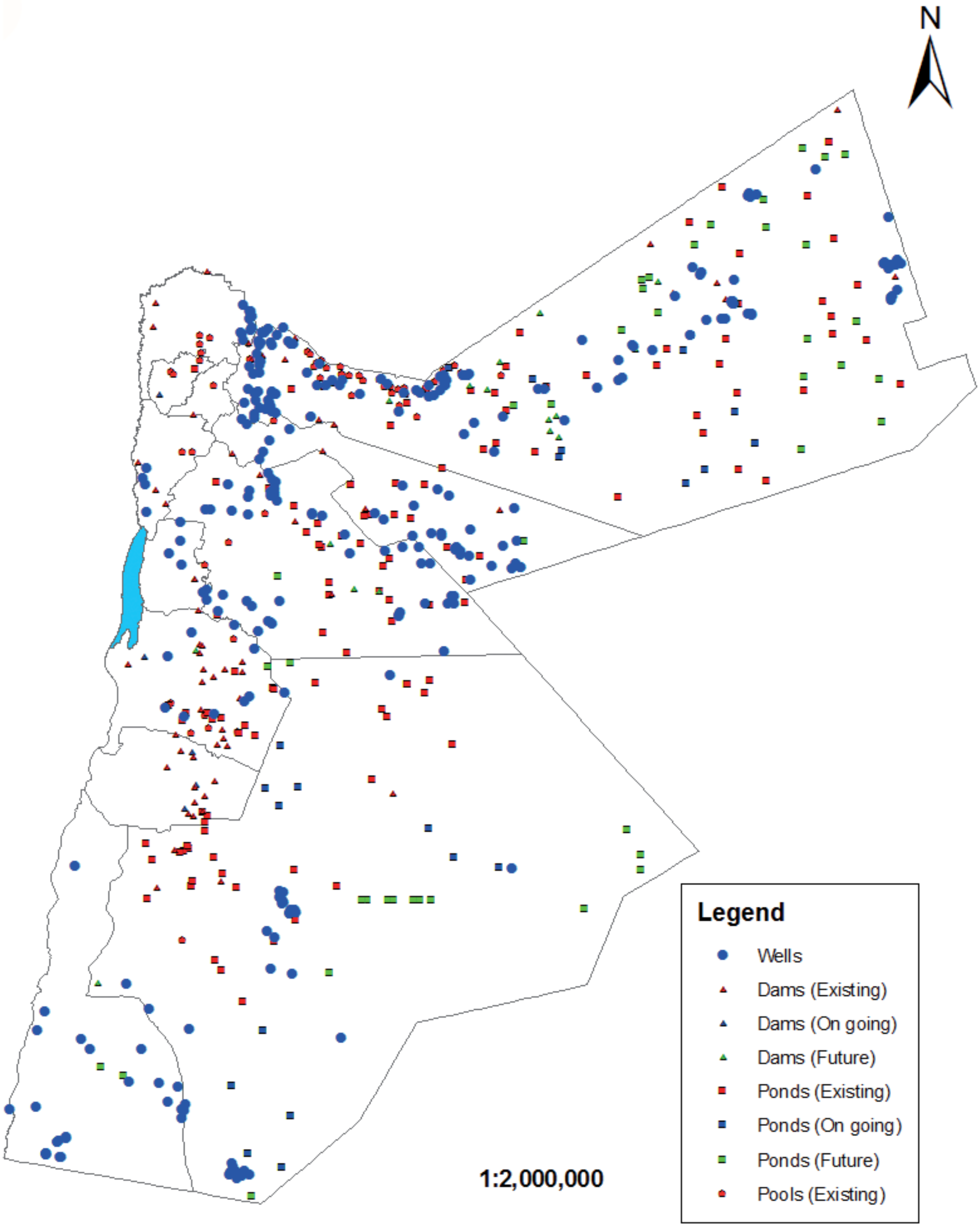
Year of construction / last maintenance	Number of structures	% of total number	Capacity of structures (1000m^3)	% of total capacity
Pre-1990	19	8.8%	34,172	30,9%
1990-1999	101	39.6%	12,210	11,0%
2000-2013	121	48.1%	62,674	56,6%
Unknown	9	3.5%	1,700	1,5%
Total	250		110,755	

Annex 3.
GIS mapping of criteria (national level)

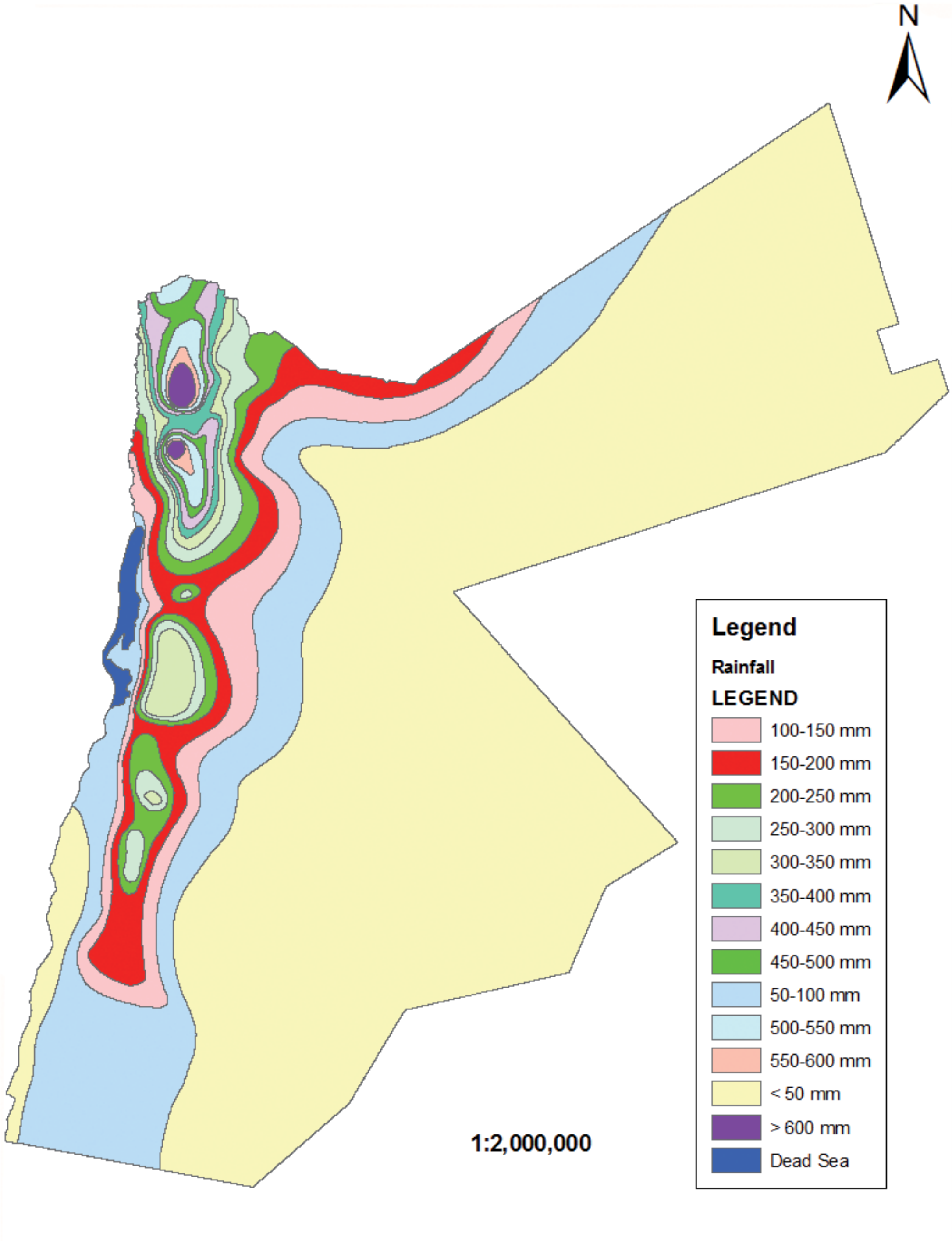
Map A3.1. Water harvesting sites in Jordan, October 2013



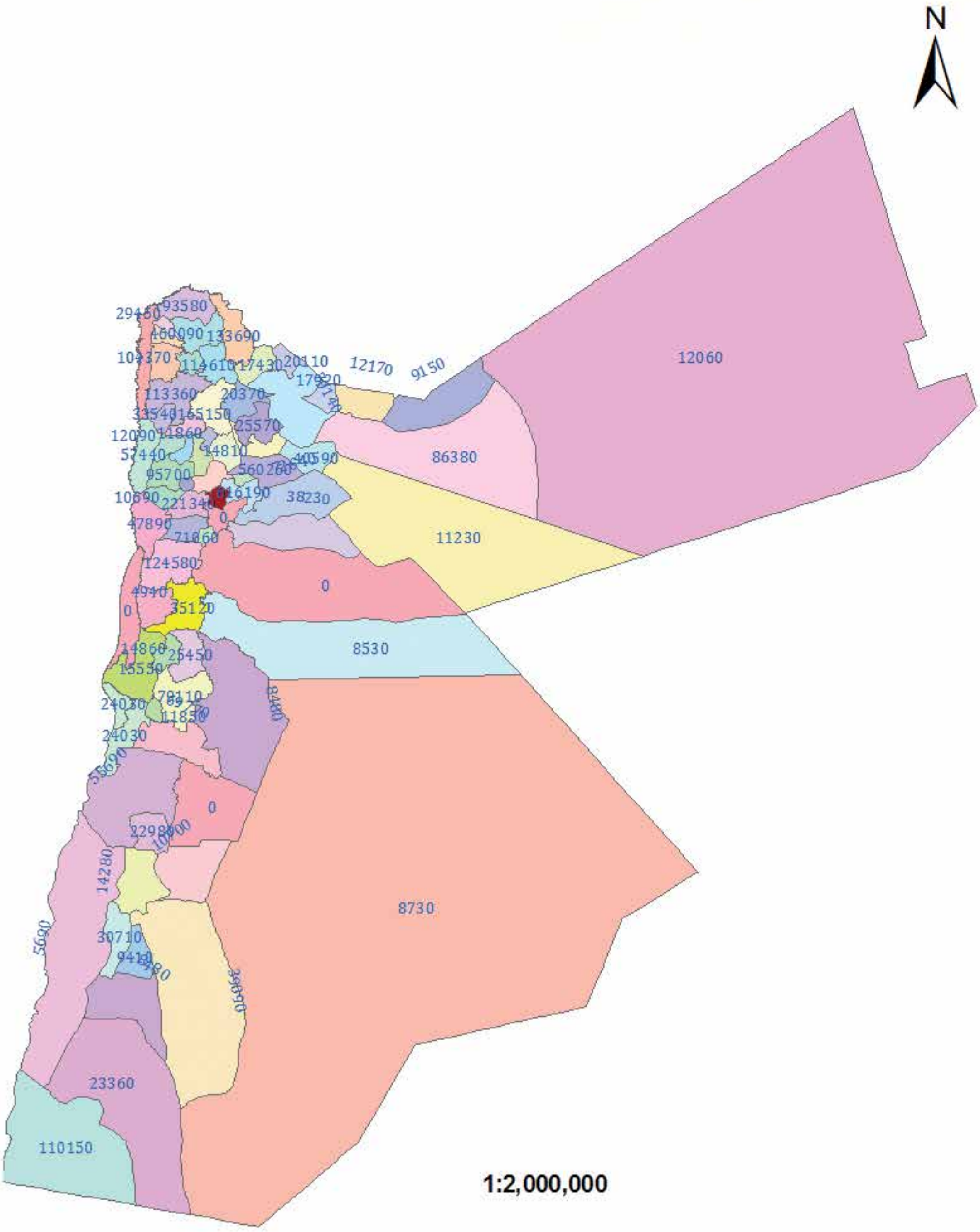
Map A3.2. Distribution of wells in Jordan, October 2013



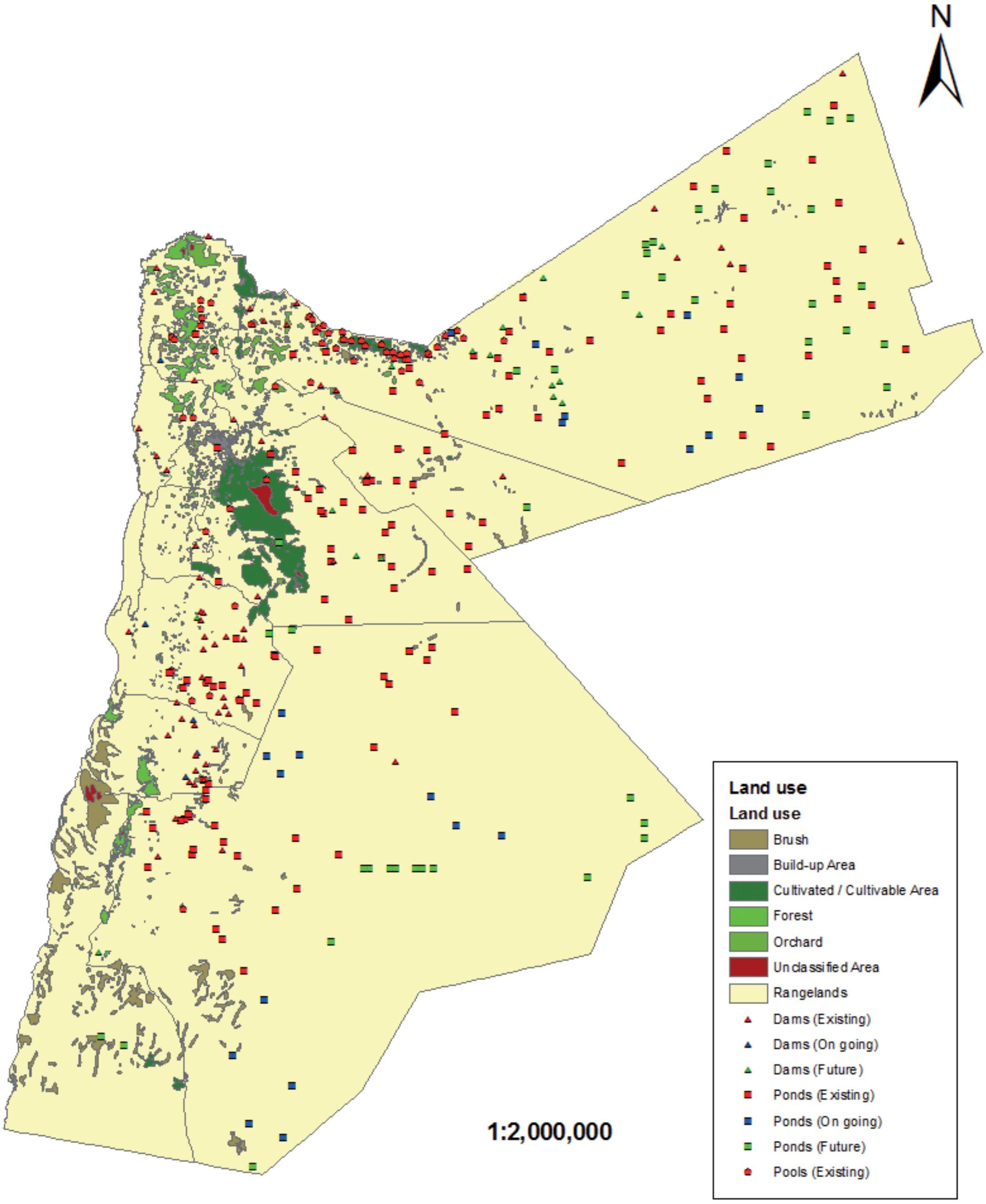
Map A3.3. Spatial rainfall variability in Jordan, October 2013



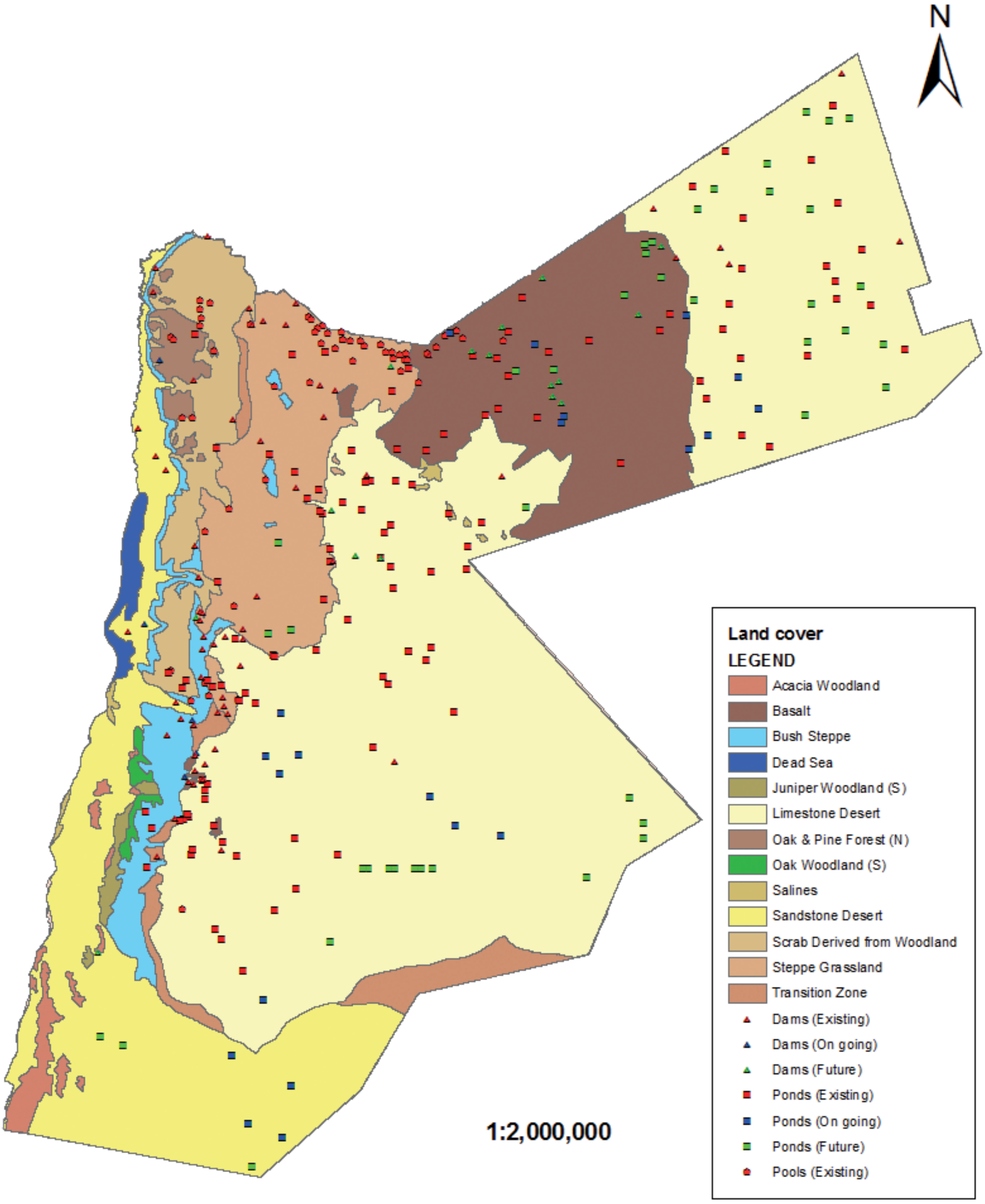
Map A3.4. Population distribution in Jordan, October 2013



Map A3.5. Land use in Jordan, October 2013

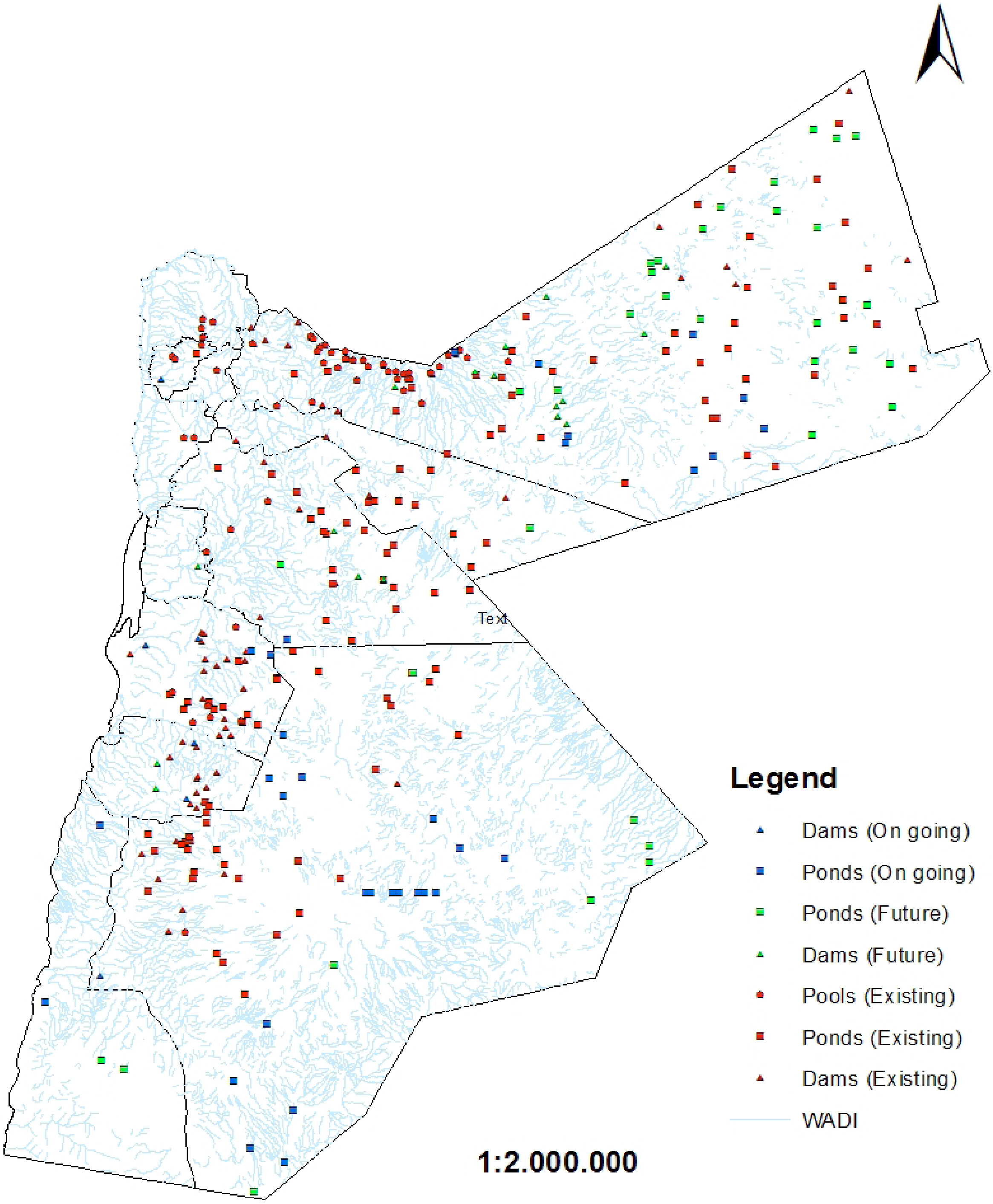


Map A3.6. Land cover in Jordan, October 2013

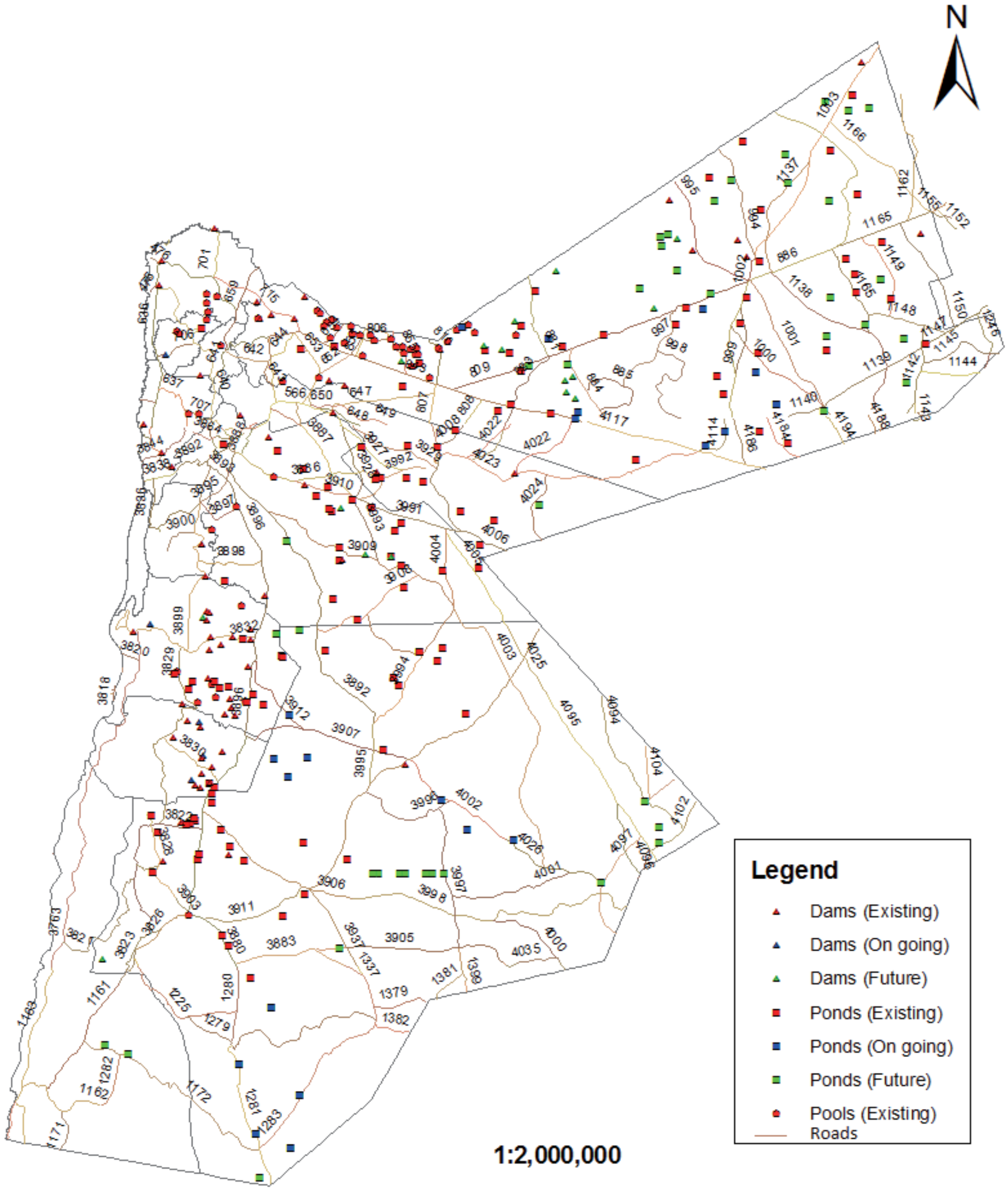


Map A3.7. Additional map: topography of Jordan

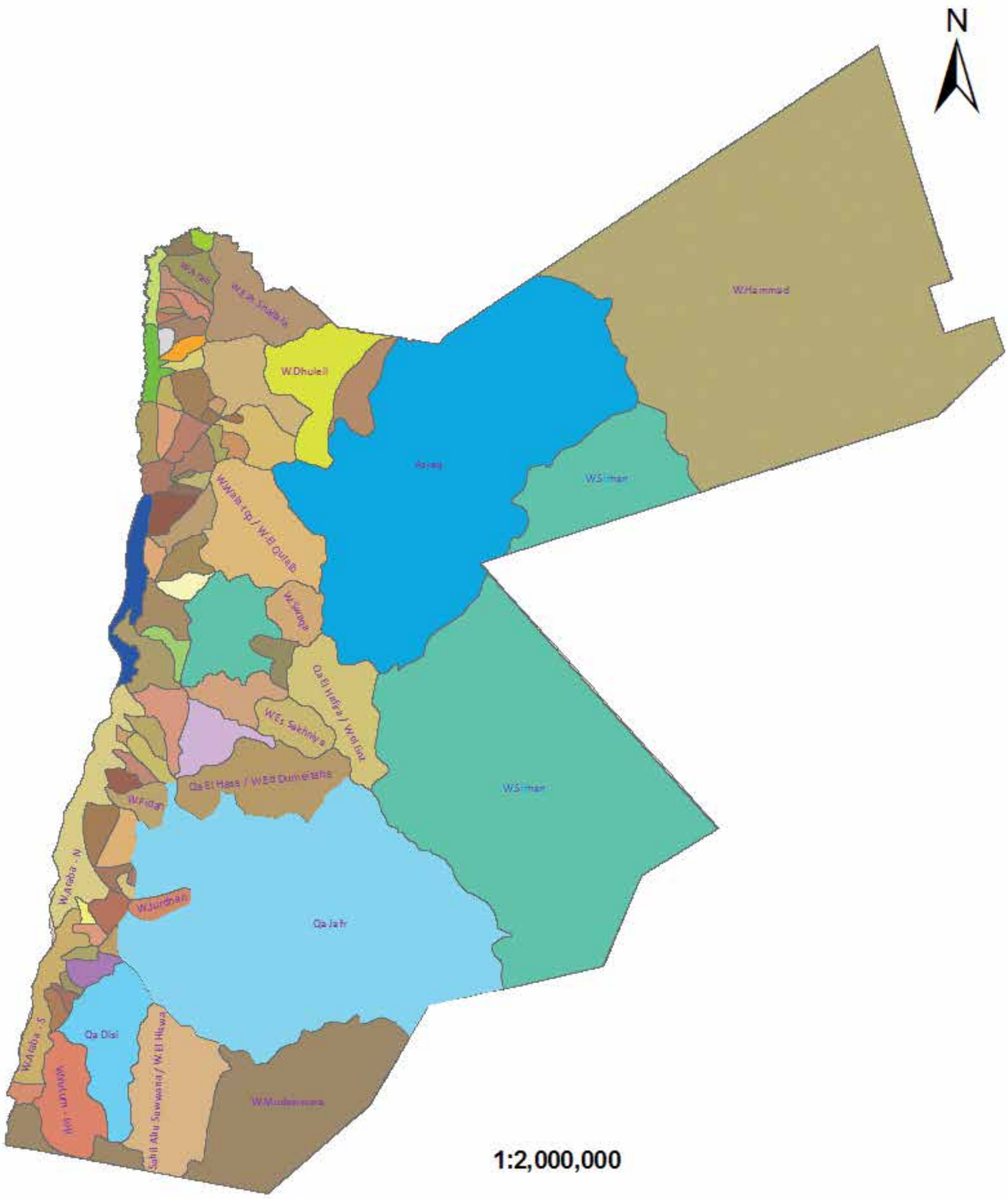
Map A3.8. Additional map: wadis in Jordan



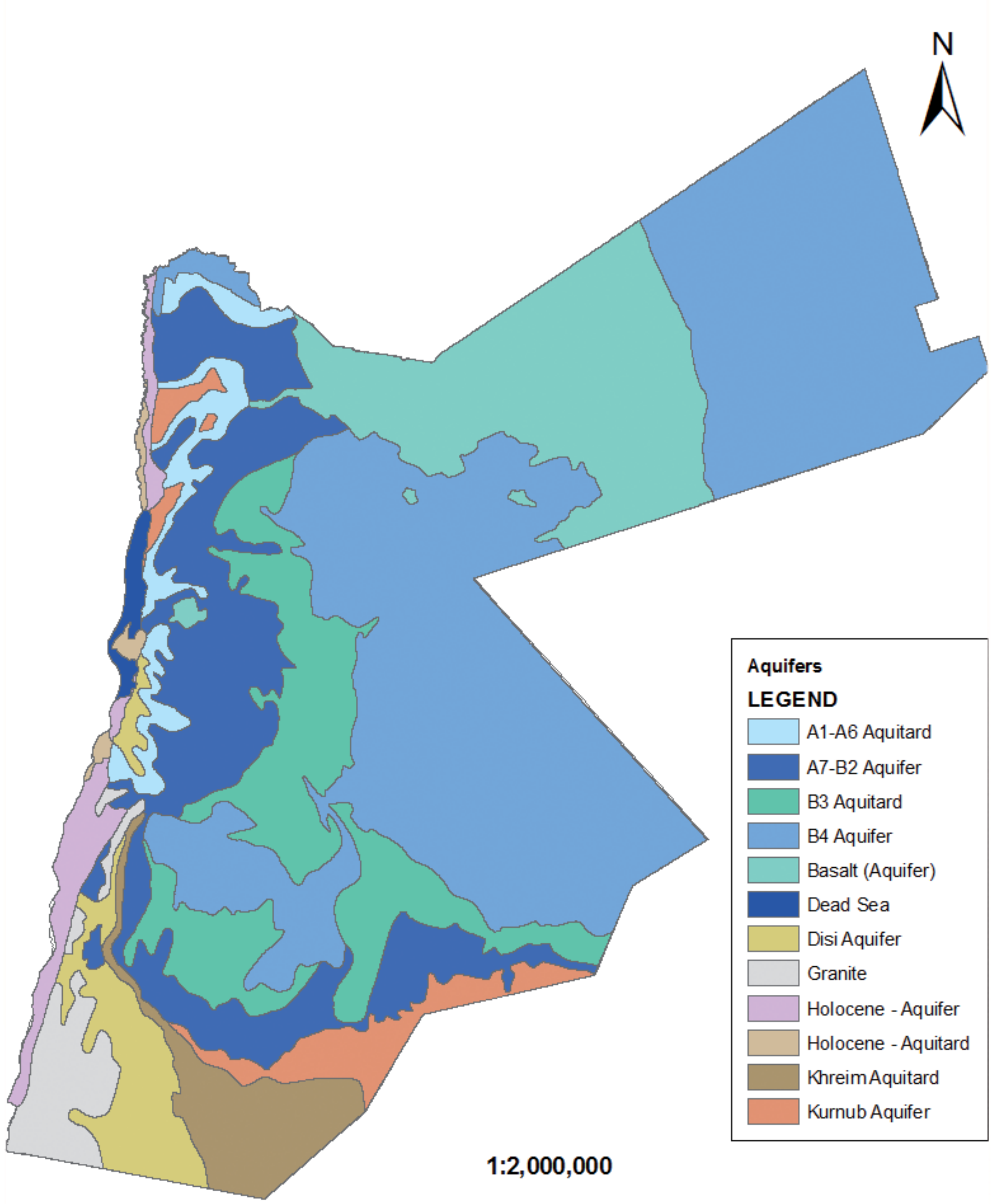
Map A3.9. Additional map: road network in Jordan, October 2013



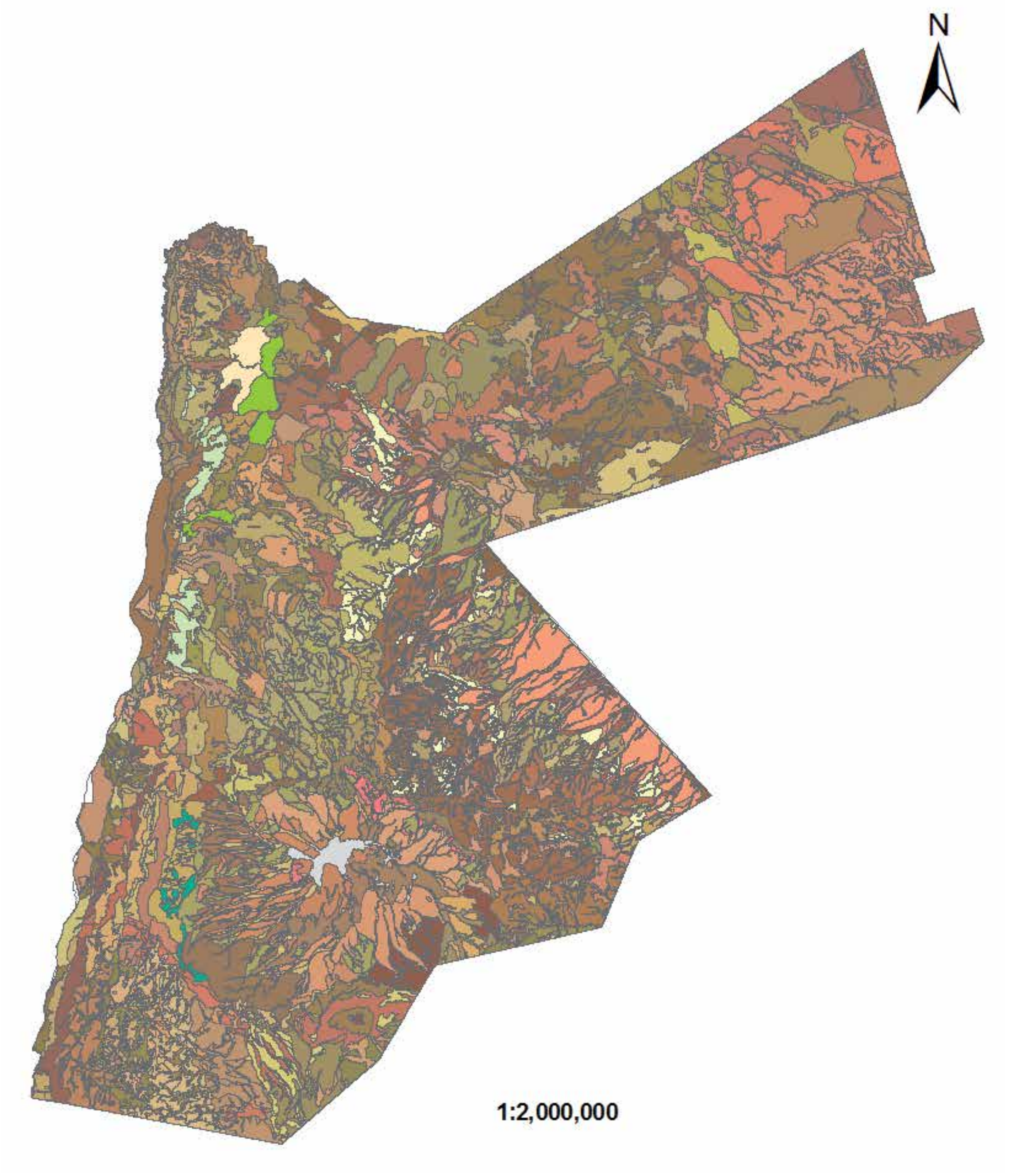
Map A3.10. Additional map: catchment areas in Jordan



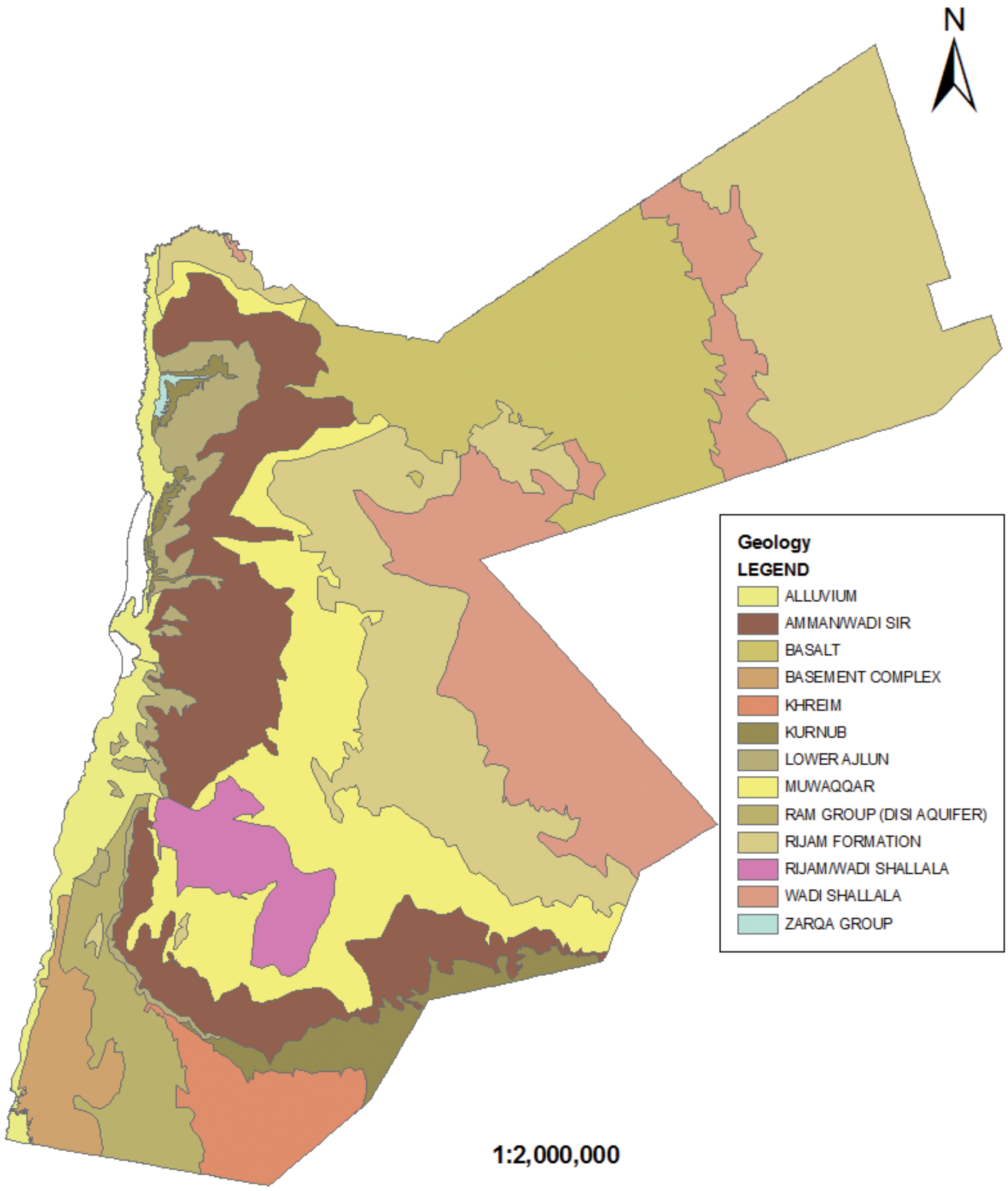
Map A3.11. Additional map: aquifers in Jordan



Map A3.12. Additional map: soil type in Jordan

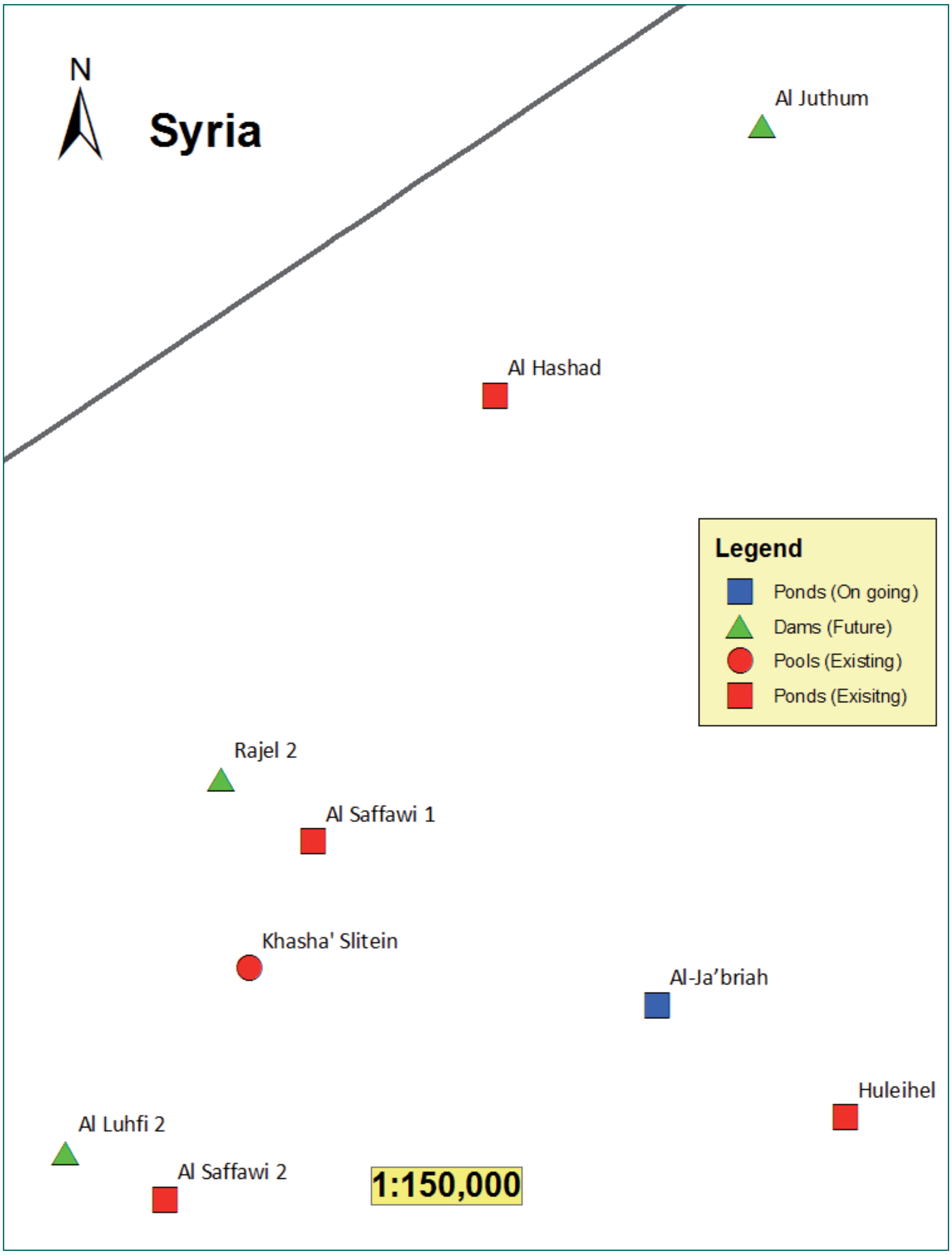


Map A3.13. Additional map: geology in Jordan

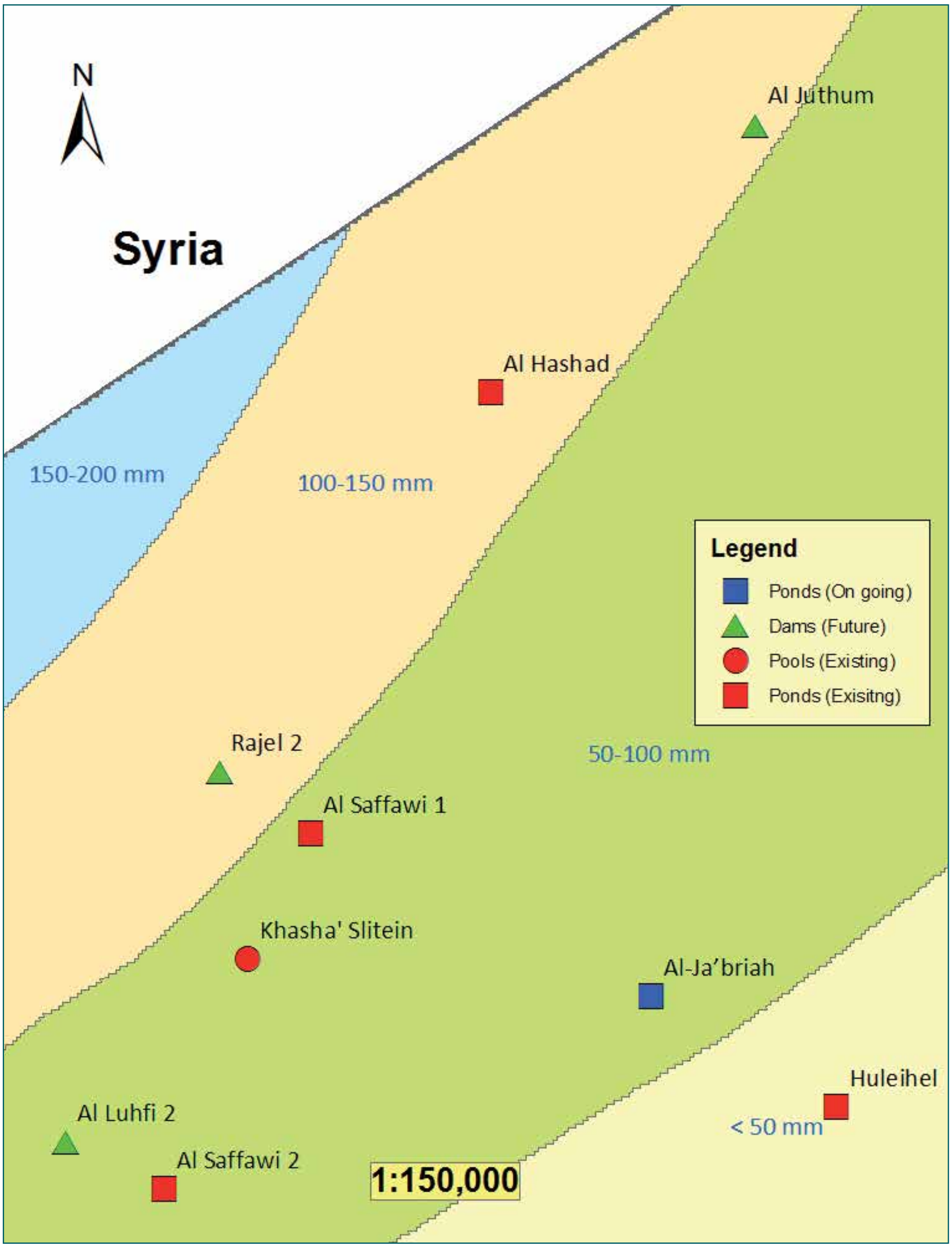


Annex 4.
GIS mapping of criteria (sub-national example)

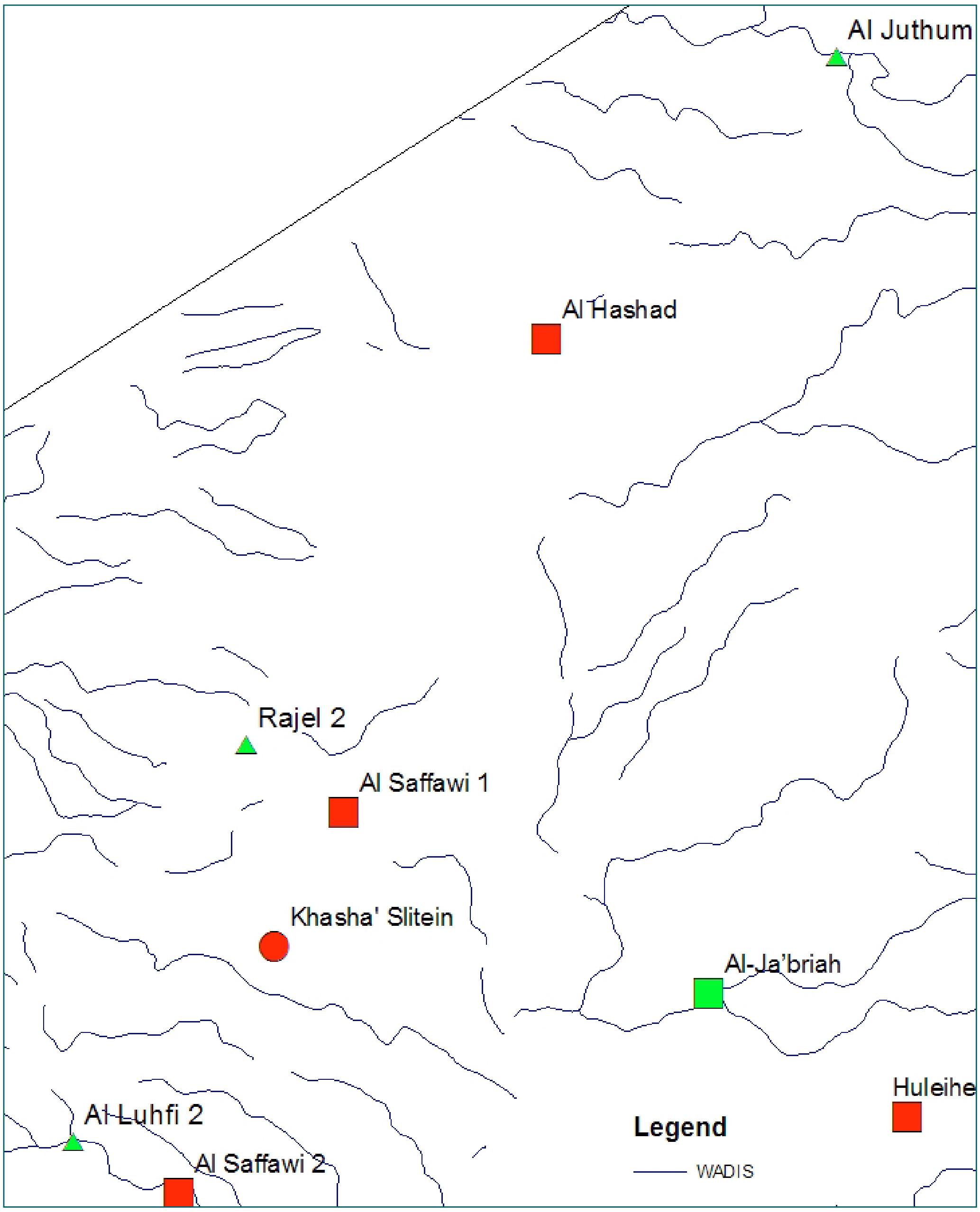
Map A4.1 Location of water harvesting structures in selected part of Al Mafraq governorate, October 2013



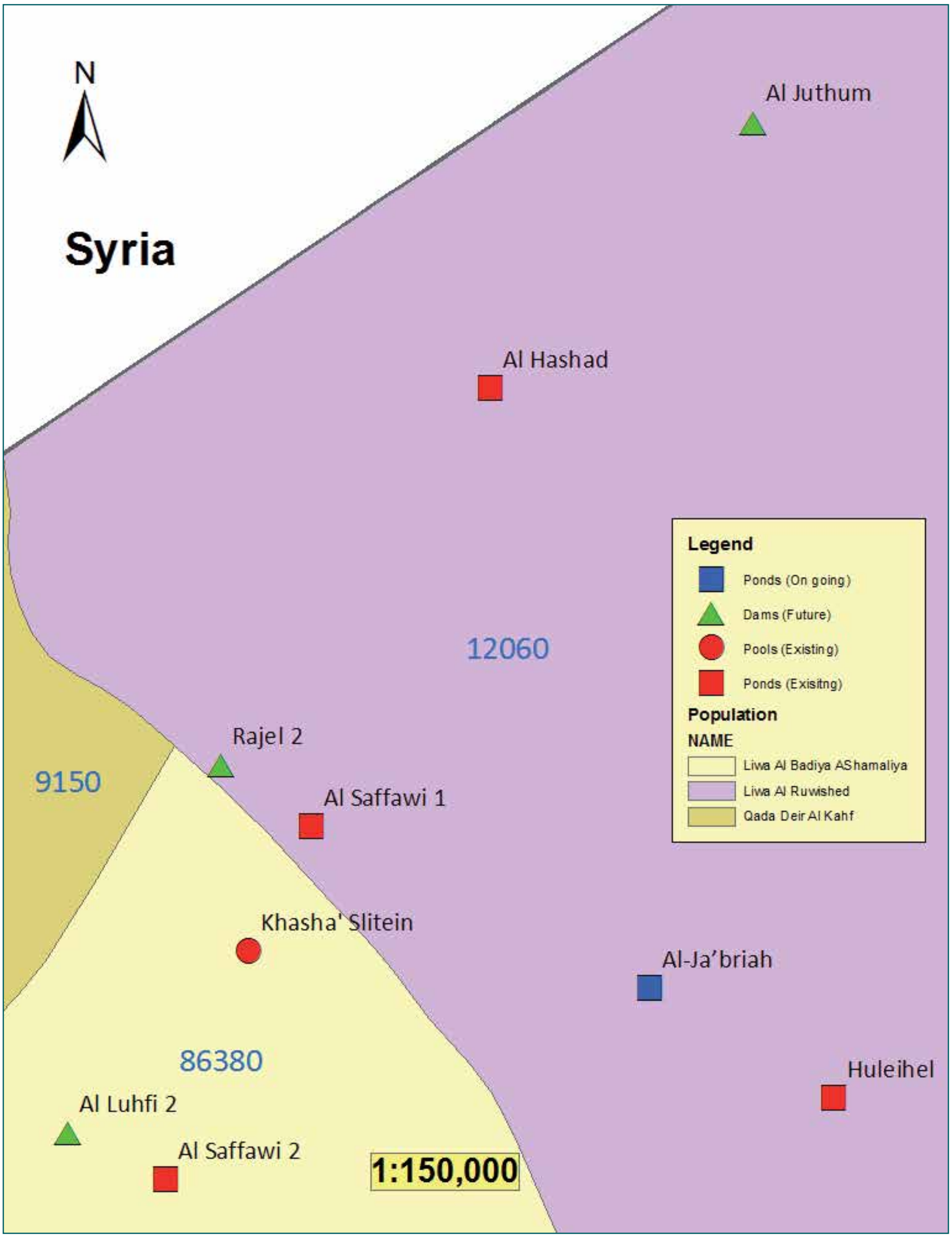
Map A4.2 Annual rainfall distribution in selected part of Al Mafraq governorate



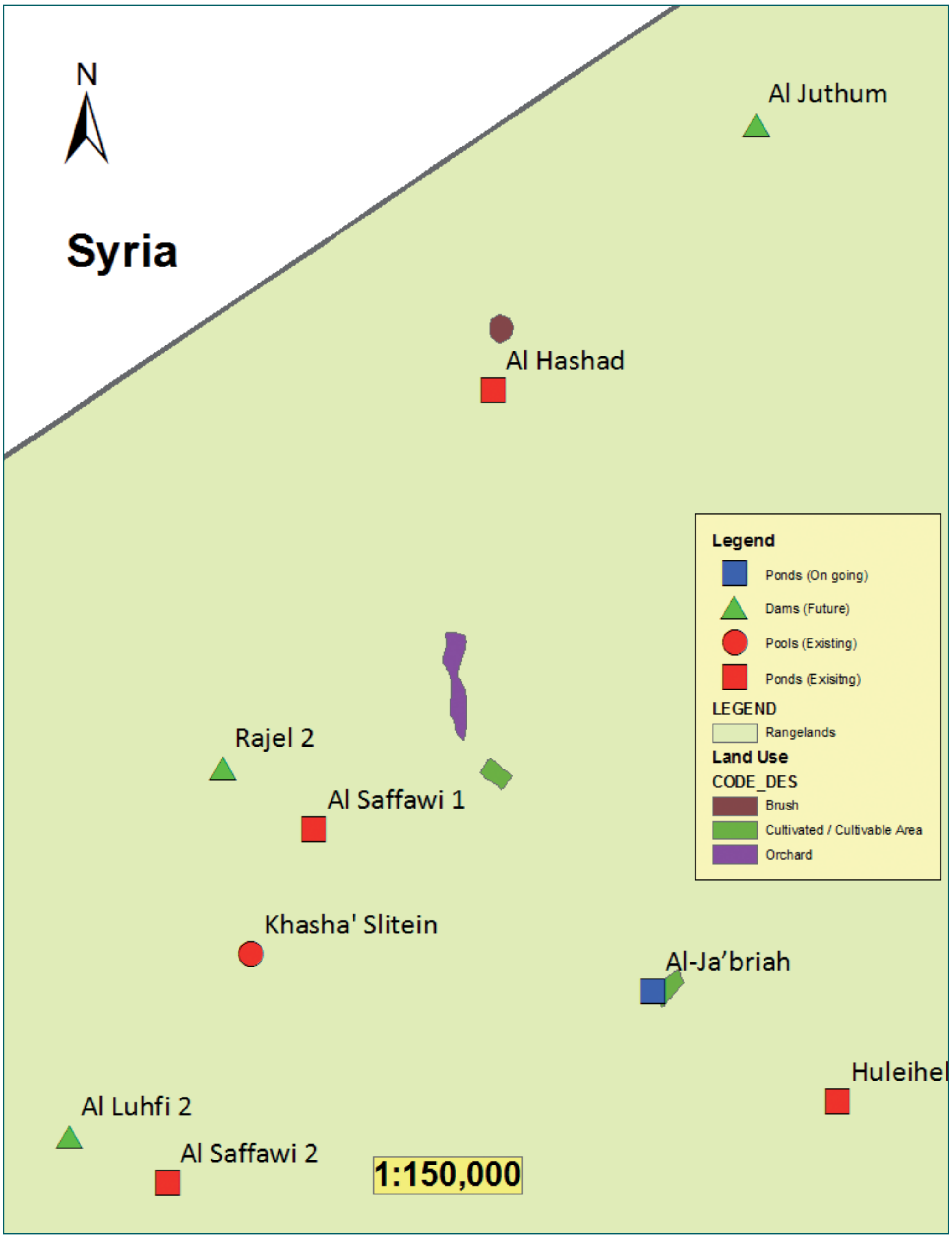
Map A4.3 Wadi distribution in selected part of Al Mafraq governorate



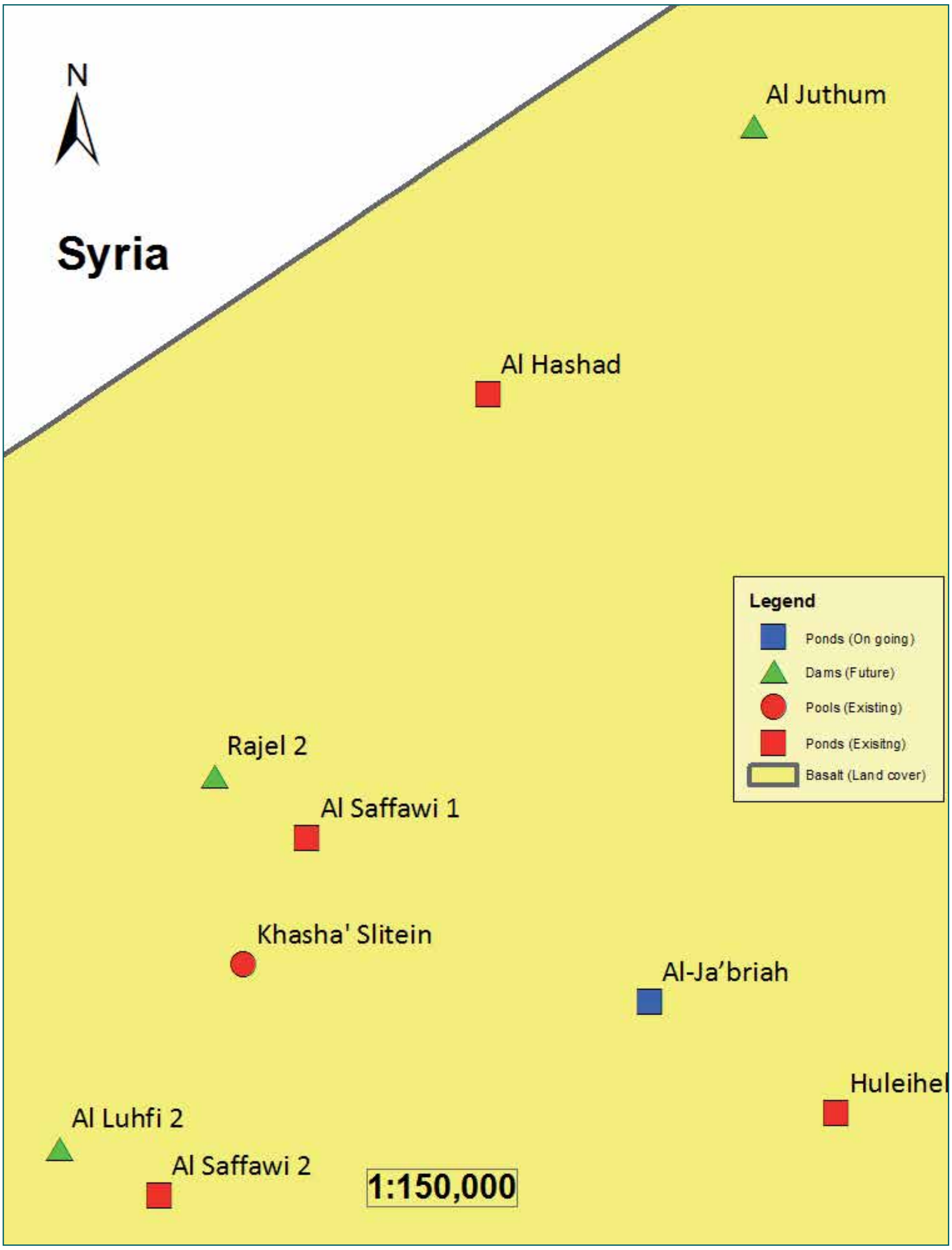
Map A4.4. Population distribution in selected part of Al Mafraq governorate, October 2013



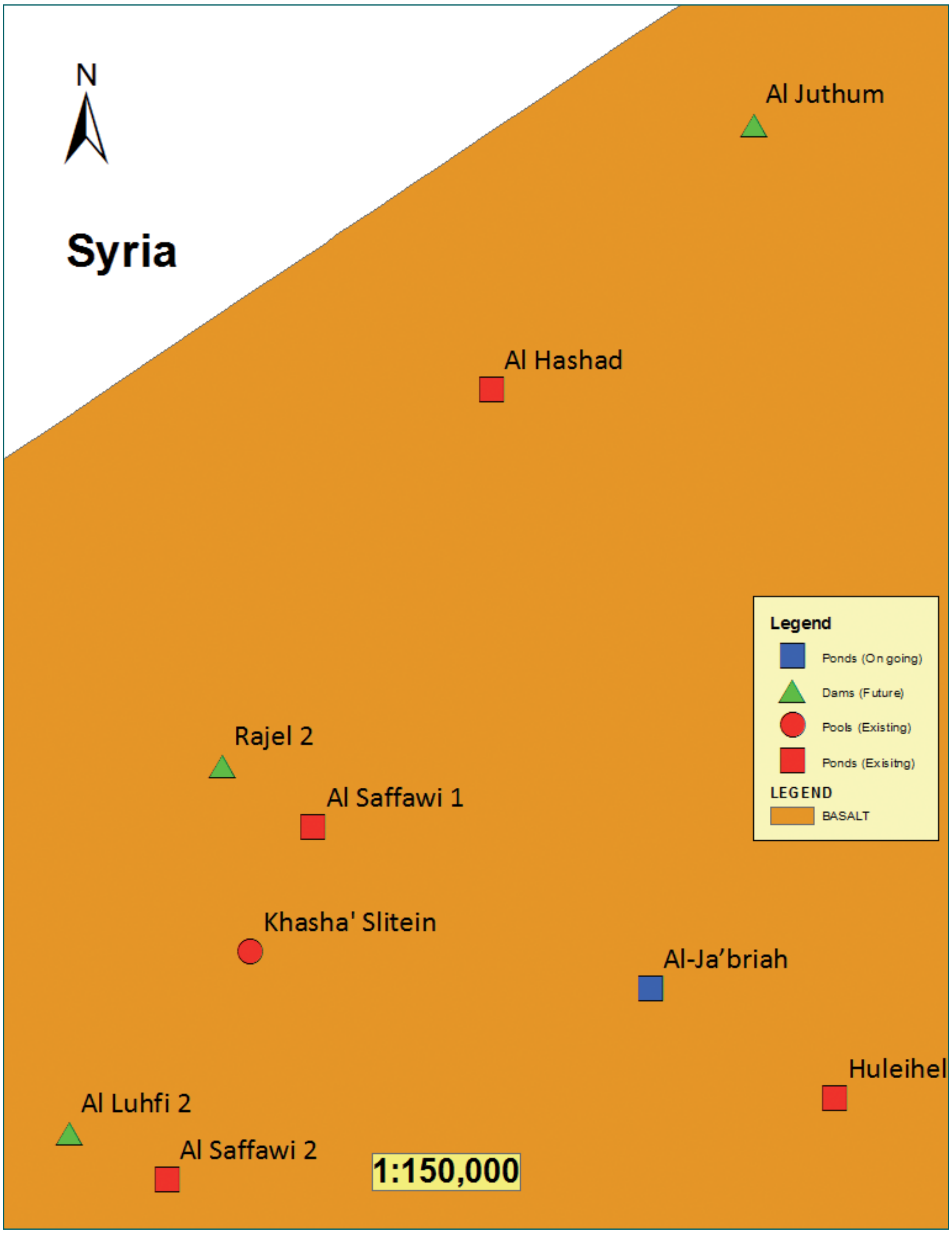
Map A4.5. Land use in selected part of Al Mafraq governorate, October 2013



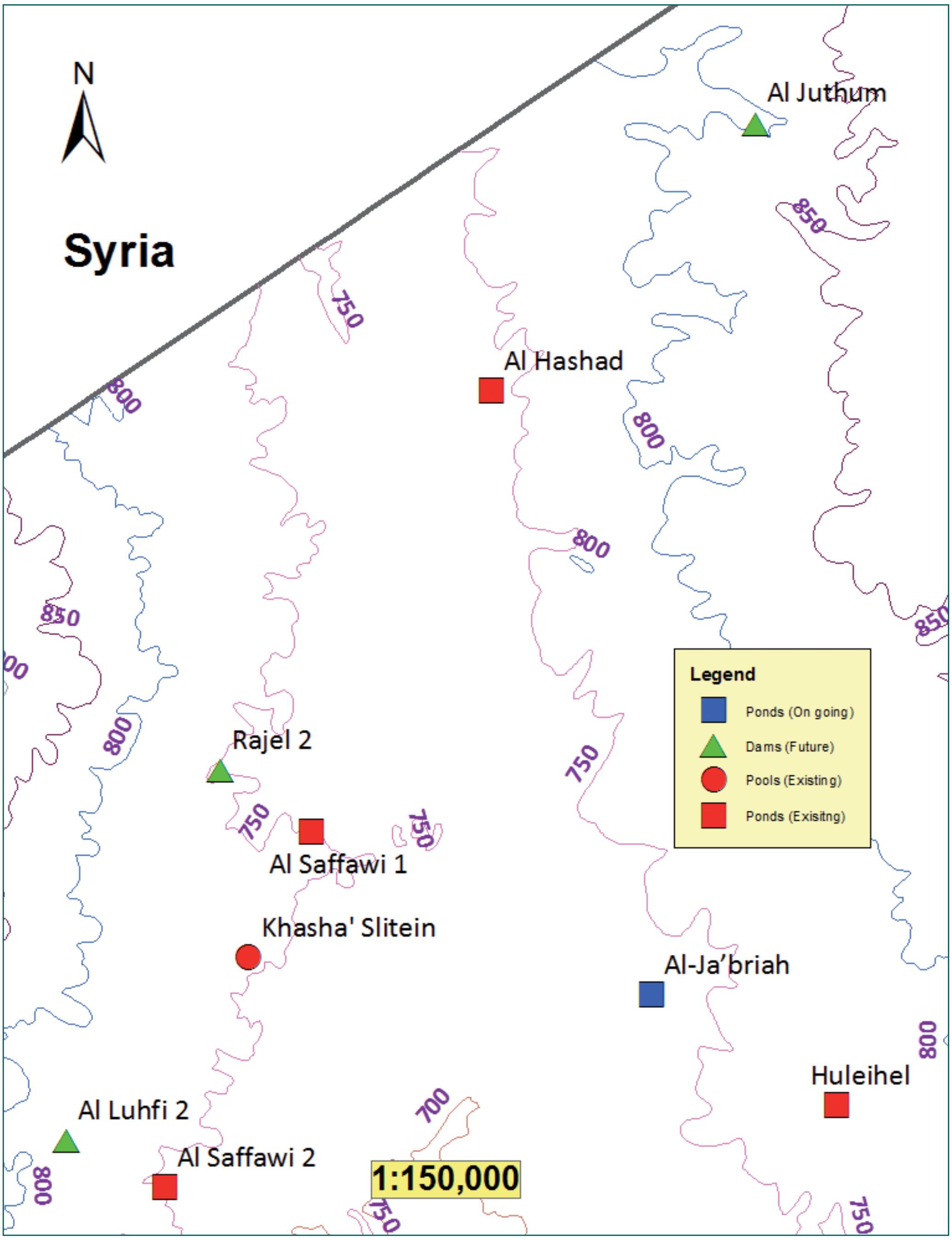
Map A4.6. Land cover in selected part of Al Mafraq governorate, October 2013



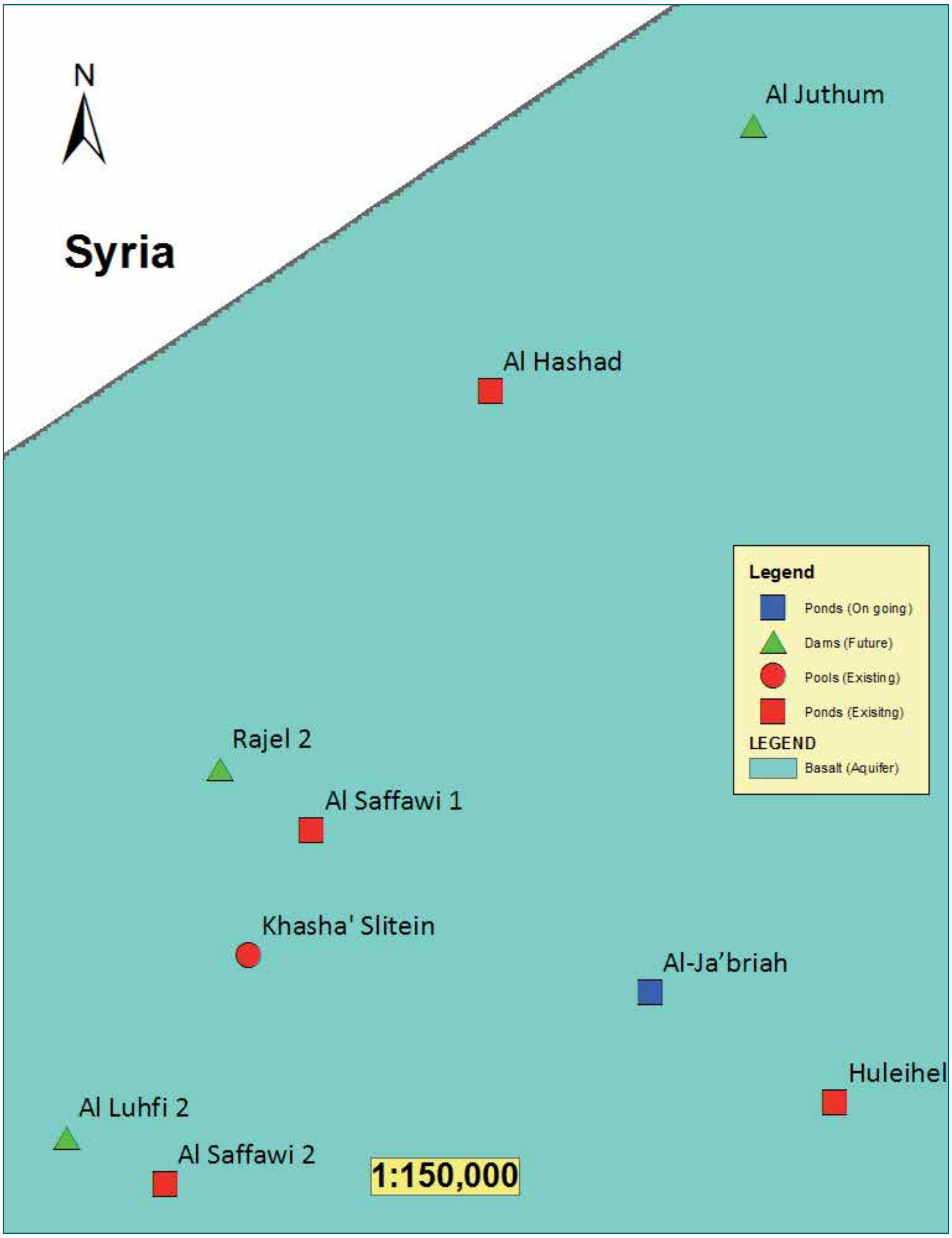
Map A4.7. Geological map of the selected part of Al Mafraq governorate, October 2013



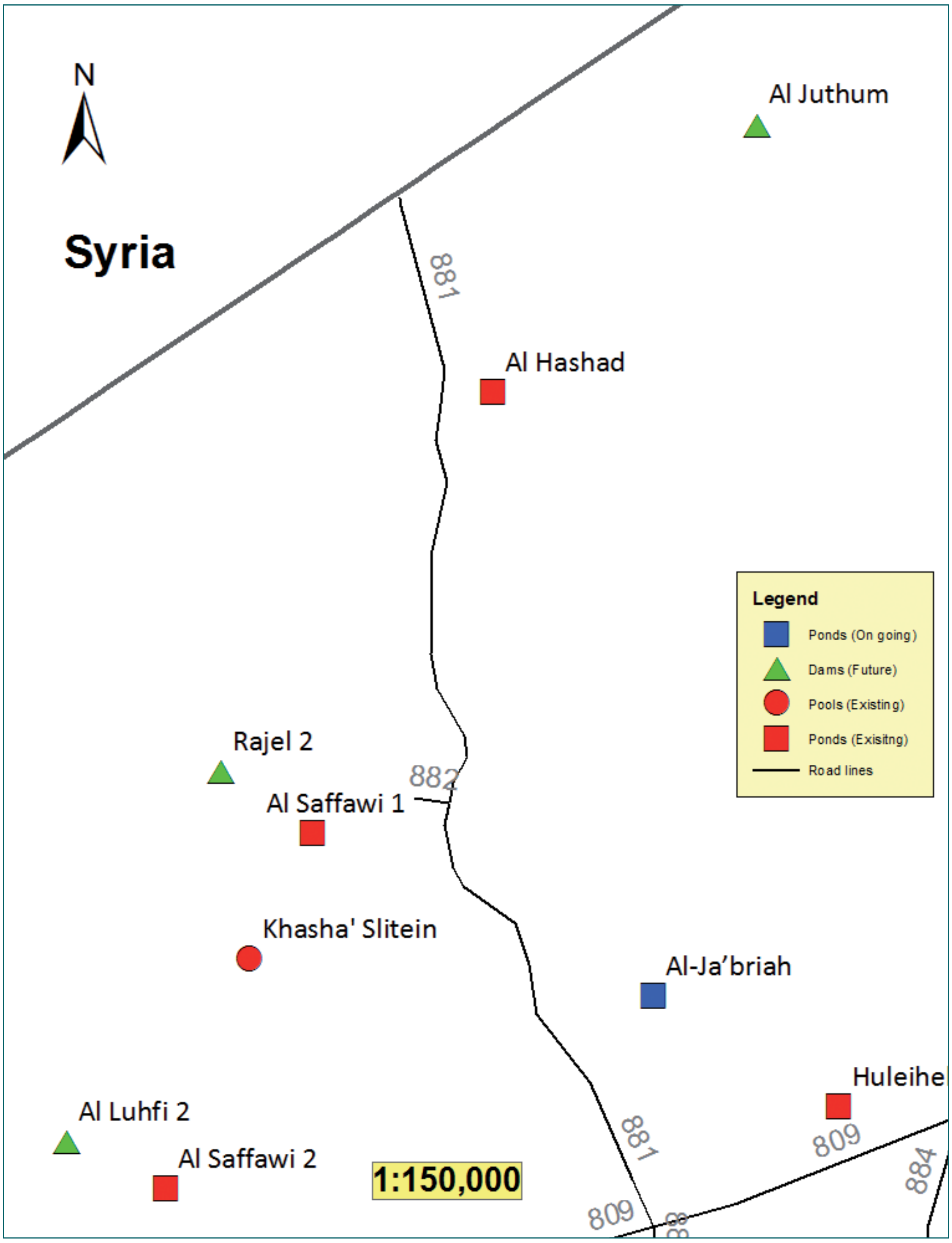
Map A4.8. Contour map of the selected part of Al Mafraq governorate, October 2013



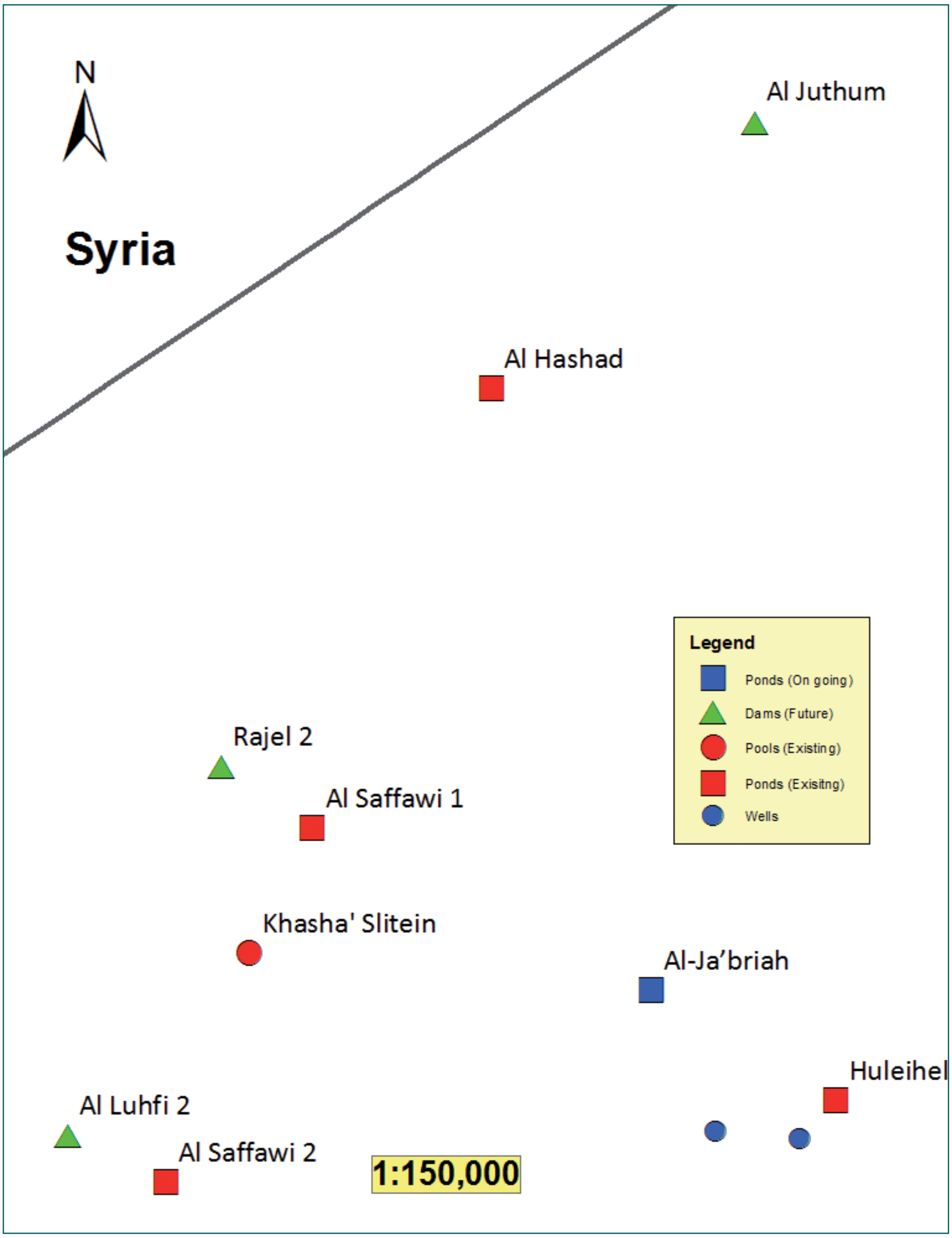
Map A4.9. Aquifer map of the selected part of Al Mafraq governorate, October 2013



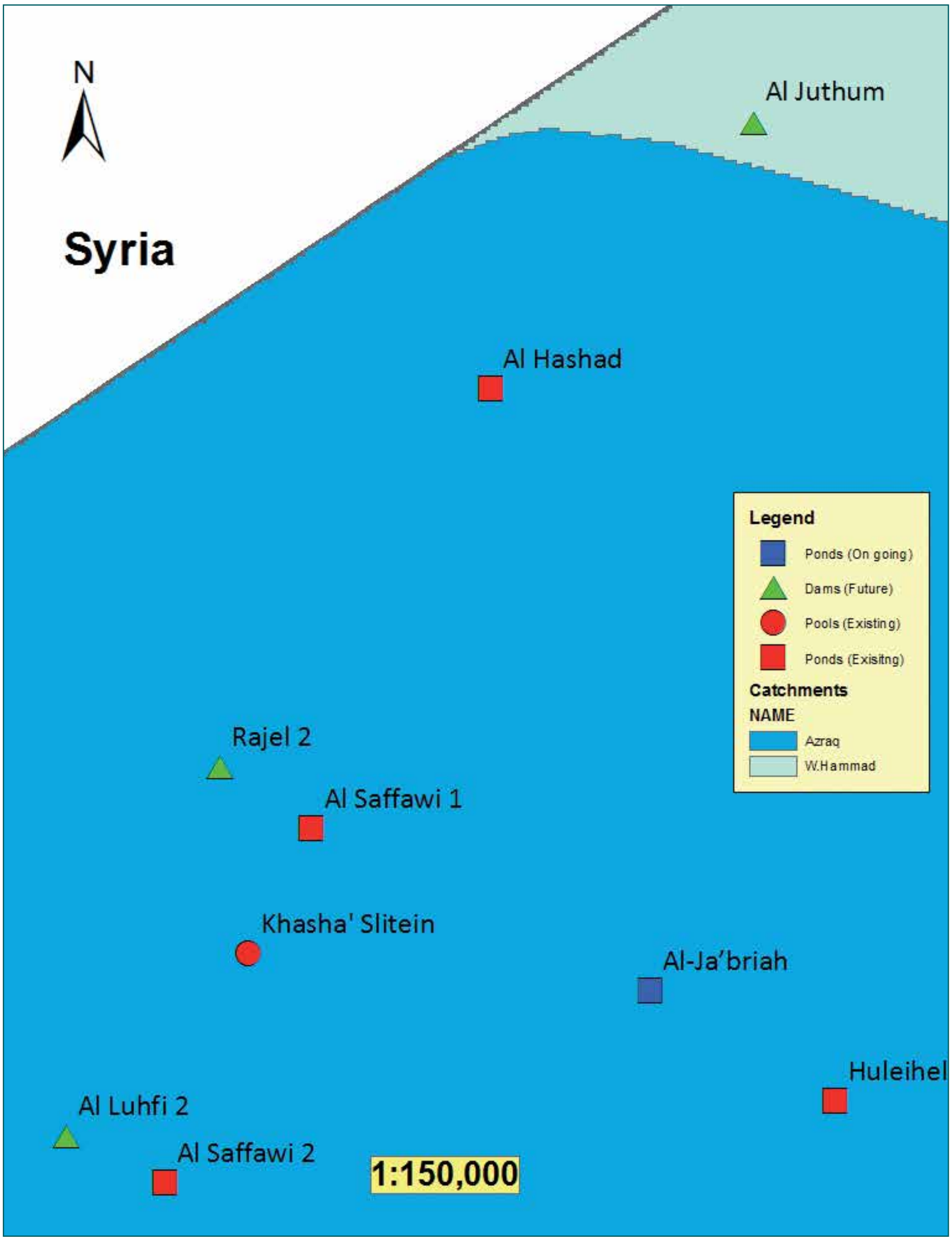
Map A4.10. Road map of the selected part of Al Mafraq governorate, October 2013



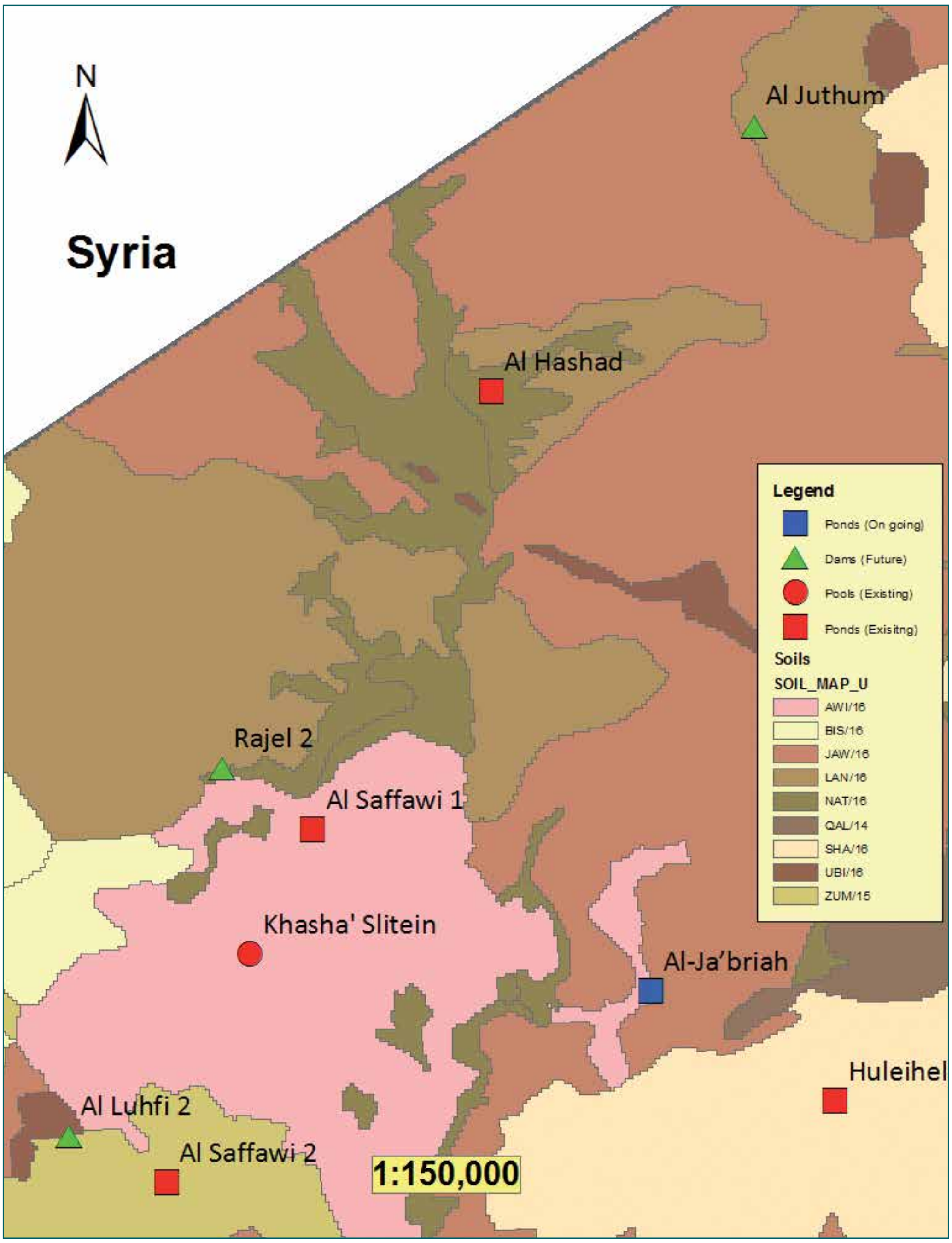
Map A4.11. Wells map of the selected part of Al Mafraq governorate, October 2013



Map A4.12. Catchments map of the selected part of Al Mafraq governorate, October 2013



Map A4.13. Soil map of the selected part of Al Mafraq governorate, October 2013



Contact

Maher Salman, Technical Adviser
Maher.Salman@fao.org
Land and Water Division (AGL)
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

FAO Jordan
Nasredin Hag Elamin, FAO Representative
Nasredin.HagElamin@fao.org

Financial support provided by
Italian Development Cooperation (IDC)

ISBN 978-92-5-109074-9

I5390E/1/02.16