Chapter 18

Anti-Lebanon

INVENTORY OF

SHARED WATER RESOURCES IN WESTERN ASIA (ONLINE VERSION)

How to cite

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Anti-Lebanon

EXECUTIVE SUMMARY

The Anti-Lebanon Mountain range is located at the Lebanese-Syrian border between the Bekaa Plain in the west and the Damascus Plain in the east. The mountain range stretches from the Homs Plain in the north to beyond its highest peak, Mount Hermon, in the south. The Anti-Lebanon receives significant precipitation, especially along its western flank, and is an important source of water, both locally and in the wider regional context, as it forms the source of a number of rivers in the Mashrek.

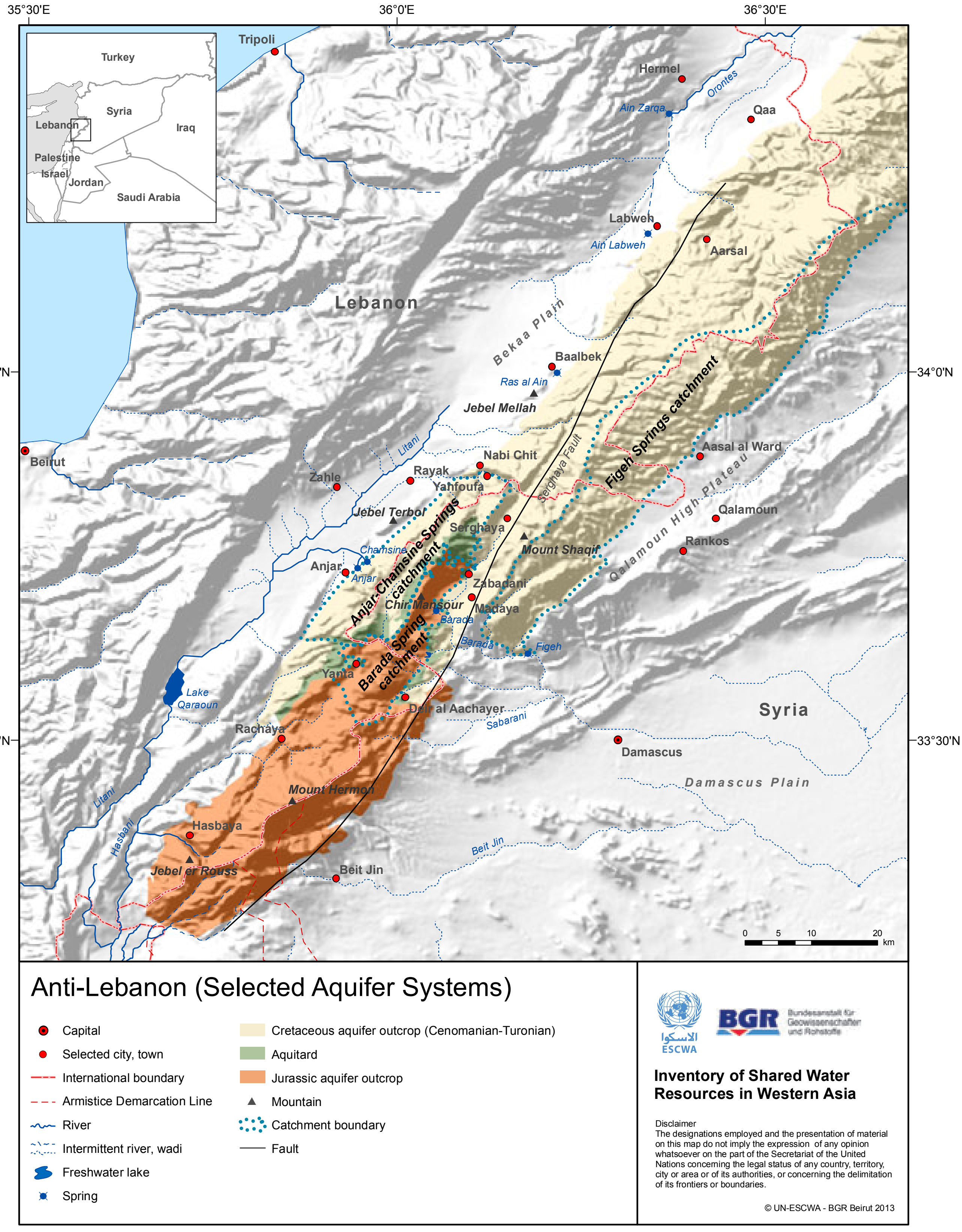
The hydrology and hydrogeology of this deeply faulted mountain range is highly complex and poorly understood to date, also in terms of the transboundary nature of surface and groundwater basins. Groundwater in the Anti-Lebanon is mainly stored in highly fractured and karstified Jurassic and Cretaceous (Cenomanian-Turonian) carbonate rocks, which often extend across political borders. Several large springs emanate from these aquifers and contribute to the Awaj, Barada, Litani, Orontes and (Upper) Jordan Rivers.

This chapter describes the Anti-Lebanon Mountain range in general terms, introduces the main aquifer systems and provides more detailed information on the catchments of the Anjar-Chamsine, Barada and Figeh Springs as examples of shared groundwater resources in the mountain range (see table opposite). Despite the potential benefits of joint investigations, management and protection schemes, there is limited cooperation between Lebanon and Syria on shared water resources in the Anti-Lebanon. The springs and catchments that originate in the southern part of the Anti-Lebanon and contribute to the headwaters of the Jordan River are covered in more detail in Chapter 6.

BASIN FACTS

RIPARIAN COUNTRIES	Lebanon, Syria
MAIN AQUIFERS	Cretaceous (Cenomanian-Turonian), Jurassic
ALTERNATIVE NAMES	-
SHARED BASINS	Anjar-Chamsine, Barada, Figeh
RENEWABILITY	Medium to high (20 - >100 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Strong
ROCK TYPE	Carbonate, karstic
AQUIFER TYPE	Anjar-Chamsine: unconfined-confined Barada: .. Figeh: unconfined, semi-confined, confined
EXTENT OF CATCHMENT	Anjar-Chamsine: 248 km^2 Barada: 149 km^2 Figeh: 658 km^2
AGE	Mesozoic (Upper Cretaceous, Jurassic)
LITHOLOGY	Limestone, dolomites, marls
THICKNESS	Anjar-Chamsine: 900 m (AVG) Barada: 2,000-2,200 m Figeh: 480-680 m
AVERAGE ANNUAL ABSTRACTION	-
STORAGE	-
WATER QUALITY	Anjar-Chamsine: .. Barada: <500 mg/L TDS Figeh: 200-600 mg/L TDS
WATER USE	Agricultural, domestic and industrial
AGREEMENTS	-
SUSTAINABILITY	Local abstractions and contamination in catchments may impact quantity and quality of discharge from springs

OVERVIEW MAP



CONTENTS

FIGURES

TABLES

Introduction

LOCATION

The Anti-Lebanon Mountain range is oriented in a north/north-east to south/south-west direction, parallel to the Lebanon Mountain range in the west. It stretches into the Israeli-occupied Syrian Golan Heights in the south (see Overview Map), with Mount Hermon (2,814 m asl) forming the highest peak in the Anti-Lebanon Mountain range.

The political border between Lebanon and Syria runs through the Anti-Lebanon Mountain range, but has never been clearly defined. This Inventory uses the border delineations applied by the United Nations Cartographic Section.[1] However, future revisions to the Lebanese-Syrian border may impact the identification and description of shared aquifer systems as presented in this Inventory.

AREA

The Anti-Lebanon Mountain range extends from the area south of Mount Hermon to the Homs Plain in the north over a length of 120 km. With a width of about 20 km, it is laterally bounded by the Bekaa Plain in the west and the Damascus Plain (680 m asl) and the Qalamoun High Plateau in the east. The central part of the mountain range comprises a western and an eastern section, which are separated by the Madaya-Serghaya Corridor.

The western section extends from the Mount Hermon foothills at Yanta to Baalbek, with a width of 10 km in the south and 3 km in the north. It is composed of three parallel orographical units:

- A line of hills reaching 1,300 m asl and lining the Bekaa Plain, including Jebel Fawar Terbol and Jebel Mellah.
- A mountain range with peaks at 1,400-1,700 m asl, including Jebel ash Sharqi east of Anjar and Jebel er Rouss.
- The main range, with Jebel Chir Mansour (1,885 m asl) and Dahr el Ghorbane (1,750 m asl), which slopes down towards Baalbek.

The units are separated by narrow corridors with the same orientation through which seasonal wadis flow. They slope westward, and are steep toward the Madaya-Zabadani Plain (1,100 m asl, 4 km wide) and the Sahl er Ramli-Serghaya Plain (1,400 m asl, 1 km wide).

The eastern section begins to the north of Jebel Mazar (1,634 m asl). A crest line extends from Jebel Habil (1,320 m asl), south of the Barada River to Jebel Khorm (1,700 m asl), Jebel Shaqif (2,420 m asl) and Jebel Ayoun al Berdi (2,462 m asl). The elevation remains around 2,200 m asl and drops to 1,150 m asl at Jebel Hessia. In the north, the Anti-Lebanon Mountain range progressively sinks underneath the Neogene age formations and Quaternary alluvium of the Homs Plain (600 m asl on average). The high mountain domain is a rough and bare limestone massif, gently sloping towards the northern Bekaa and the Hessia Plain with a 9%-10% slope.

The Anti-Lebanon Mountain range is regularly intersected by dry valleys, which are transformed into detrital fans encroaching on alluvial plain sediments. Wadi Yahfoufa near Nabi Chit is the only deeply entrenched valley on the western Anti-Lebanon flank. On the eastern side, the relief is more rugged, featuring the large intra-mountainous Zabadani and Serghaya Basins.

The Anti-Lebanon Mountain range is the primary source of water for several of the region's rivers. In the north/north-western part of the Anti-Lebanon, groundwater contributes to the Orontes River (see Chap. 7), which flows north from Lebanon through Syria and Turkey, and discharges into the Mediterranean Sea at Antakya. Groundwater in the western and south-western parts of the Anti-Lebanon Mountain range flows to the Litani River in Lebanon, which flows south through the Bekaa Valley and then veers west to discharge into the Mediterranean Sea. In the eastern and central part of the Anti-Lebanon Mountain range groundwater feeds the Barada River, which flows eastward into the endorheic Damascus Basin. Groundwater in the southern part of the Anti-Lebanon Mountain range discharges on the western slopes of Mount Hermon and contributes to springs that feed the Jordan River in Israel, Lebanon and Syria (see Chap. 6). The eastern slope of Mount Hermon feeds the springs of the Awaj River, which flows eastward into the Damascus Basin.

CLIMATE

The climate in the Anti-Lebanon Mountain range is continental and semi-arid, with cold, humid winters and hot, dry summers. The mean annual air temperature west of the Anti-Lebanon Mountains at Rayak (930 m asl) in the central Bekaa Plain was 14°C for the period 1965-1972, while average precipitation for the period 1931-1960 was 600 mm in Rayak and 510 mm at Anjar.[2] Average annual precipitation on the ridge reaches 1,200 mm, in winter mainly in the form of snow, while the eastern flank is drier, with an average annual precipitation of 450 mm in Madaya and 200 mm in the Damascus Basin.

POPULATION

Exact population figures are not available for the Anti-Lebanon Mountain range. The main towns along the western flank of the mountain range in Lebanon are Aarsal and Baalbek in the north; Anjar, Chamsine, Majdal Anjar and Rayak in the central part; and Deir al Aachayer in the south. Most towns are small, with 5,000-10,000 inhabitants.[3]

The main towns in the Syrian part of the Anti-Lebanon Mountain range are Bloudan, Madaya, Serghaya and Zabadani and smaller villages in the Zabadani Plain, which has an estimated total population of 105,340 inhabitants.[4] Towards the east, the area in the immediate vicinity of the Figeh Spring is sparsely populated. Towns such as Rankos and Aasal al Ward have between 8,000 and 12,000 inhabitants.[5]

The ruins of Anjar, Lebanon, 2011. Source: Khalid Albaih.

Overview of Aquifer Systems

MAIN SPRINGS AND AQUIFER SYSTEMS

Four main aquifers provide groundwater in the Anti-Lebanon Mountain range:

- **Jurassic limestone and dolomite formation**
  The formation constitutes the core of the Anti-Lebanon Anticline with large outcrops, especially in the southern and central parts. Groundwater discharges to the east in Syria at Beit Jin into the Sabarani and Genani Rivers and the Barada Spring. The catchments of these springs and the aquifers are shared between Lebanon and Syria.

- **Upper Cretaceous (Cenomanian-Turonian) limestone formations**
  Groundwater from these formations discharges mainly at the Ain Zarqa, Anjar and Chamsine, Labweh and Ras al Ain Springs in Lebanon, and at the Bisan, Boukein and Figeh Springs in Syria. Since it is the largest outcropping aquifer formation, it is certainly the main aquifer in the Anti-Lebanon Mountain range, with the largest resources and storage capacity. The outcrops cover more than 3,000 km^2.[6] The aquifer is shared between Lebanon and Syria.

- **Eocene limestone**
  The formation forms a discontinuous line of hills on both flanks of the Anti-Lebanon Mountain range. Groundwater discharges from a number of local springs, such as the springs at Mount Terbol in Lebanon (Ain al Bayda, Ain al Khadra and Ain al Saheb) and the Mneen Springs in Syria. The respective aquifers are mostly of local nature and not necessarily connected to each other. There is also no evidence that these aquifers extend across the Lebanese-Syrian border. As such, the Eocene limestone is not considered a shared aquifer.

- **Quaternary alluvial aquifers**
  The alluvial aquifer in the Bekaa Plain in Lebanon is multilayered and – in its shallow part – connected to the Orontes River in the north and to the Litani River and its tributaries in the south. The Bekaa Valley sediments are not considered part of the formation in the Anti-Lebanon Mountain range. Local alluvial aquifers are also present in some valley fills. As these alluvial fills are of a local nature and do not reach substantially across the Lebanese-Syrian border, they are not considered in this Inventory.

The main Jurassic and Upper Cretaceous aquifers are generally separated by thick aquiclude formations. However, the faulting and erosion that have occurred since the formation of the Bekaa Plain and the uplift of the ridges may have created some interconnection between the aquifers at depth.

Geographically, the importance of the respective transboundary aquifers varies.

In the northern part of the Anti-Lebanon, the main springs are Ain Zarqa and Ain Labweh located in Lebanon which feed the Orontes River (see Chap. 7). In the central part of the Anti-Lebanon, the main spring in Lebanon is Ain Anjar, while in Syria the Barada and Figeh Springs contribute to the Barada River.

Further south, in the area of Mount Hermon the aquifer is mainly of Jurassic age and feeds springs on both flanks of the Anti-Lebanon Mountain range. This includes the Barada Spring, the springs issuing from the slopes of Mount Hermon in Syria, the Hasbani and Wazzani Springs in Lebanon, the Banias Spring in the Israeli-occupied Syrian Golan Heights and the Dan Spring[7] in Israel. The springs in the south-western part of the Anti-Lebanon Mountain range contribute to the Upper Jordan River (see Chap. 6).

This chapter focuses on the catchments of the three main springs in the central part of the Anti-Lebanon Mountain range: the Anjar-Chamsine, Barada and Figeh Springs. They discharge into the Barada and Litani Rivers.

STRATIGRAPHY

Table 1 shows the general hydrostratigraphy of the Anti-Lebanon Mountain range in Lebanon and Syria.

The regional basement is formed by Jurassic age formations. These crop out on the flanks of Mount Hermon in Lebanon and Syria and on the western and southern hills in the Zabadani Plain. The formations are made up of a 1,500 m thick series of limestones and dolomites, overlain by 200 m thick interbedded marls and limestones.

The Lower Cretaceous is characterized primarily by terrigenous, silty sediments, including a thin limestone layer. At the lower end it starts with a 50-250 m thick formation (C1) made of coastal sandstone. Many small springs discharge from this aquifer at an average rate of $3.2x10^{-2}$-$4.7x10^{-2}$ MCM/yr, with a nearly constant year-round flow. They form an important local source of irrigation water. This pre-upper Aptian Formation is followed by 150-250 m thick Aptian ferruginous sandstone and pelitomorphic limestone (C2). The following Albian 150 m thick yellow limestone (C3) is difficult to separate from the Cenomanian-Turonian age formations (C4-C5).

The Cenomanian-Turonian age formations comprise the main aquifers of the Anti-Lebanon Mountain range. The 900 m-thick limestone covers about 2,200 km^2 in Lebanon and 2,500 km^2 in Syria. It is made of metric beds that include thin interbedded marl with ammonites at the C4-C5 transition. The top of Cenomanian and Turonian-age formations are frequently dolomitized.[8]

It follows the Upper Cretaceous with a 500 m thick series of Senonian white marls (C6), characterizing the series of depressions between the Anti-Lebanon flank and the foothills lining the Bekaa Plain.

The Middle and Upper Eocene is made of 200 m thick reefal limestone, which ends with the general uplift and emersion.

The source of the Barada Spring in the Anti-Lebanon Mountains in Syria, 2009. Source: Adel Samara.

Table 1. Lithostratigraphy of Lebanon and Syria

ERA	PERIOD	EPOCH	STAGE	INDEX	HYDROGEOLOGICAL UNIT	LITHOLOGY
Cenozoic	Quaternary	Holocene	-	Q	Aquiclude to aquitard.	Volcanic, alluvial, lacustrine and proluvial deposits.
		Pleistocene	Upper		Semi-aquifer, local water-bearing formations can be found in the alluvial and proluvial deposits.	Unconsolidated lacustrine, alluvial, volcanogenic, proluvial and effusive deposits.
			Middle			
			Lower			
	Tertiary Neogene	Pliocene	Upper	P	Aquitard/aquifer Neogene System.	Limestone, reefal limestone, lacustrine and alluvial deposits.
			Lower			
		Miocene	Middle	M		
			Lower			
	Paleogene	Oligocene	-	Missing	-	-
		Eocene	Upper	E	Aquitard of Eocene series, locally water bearing.	White and cream marbly limestone. At the bottom, limestones with intercalations of marl and clay.
			Middle			White and light grey chalk-like limestone.
			Lower			-
		Paleocene	-	Missing	-	-
Mesozoic	Cretaceous	Upper	Senonian/ Conacian/ Santonian/ Campanian/ Maastrichtian/ Danian	C6	Aquiclude	Marls
						Chalky, argillaceous limestone.
						Chalky limestone.
			Turonian	C5	Cenomanian-Turonian aquifer.	Massive karstified limestone with occasional intercalation of dolomitic limestones.
			Upper Cenomanian	C4b		Alternation of organogenous, pelitomorphic, argillaceous and dolomitic limestone and compact marls.
			Lower Cenomanian	C4a		Alternation of organogenous, pelitomorphic, argillaceous and dolomitic limestone and compact marls.
		Lower	Albian	C3	Aquitard/aquifer of the Albian series.	Massive pelitomorphic limestone alternating with argillaceous limestones.
			Upper Aptian	C2	Aquitard/aquifer of the Aptian series.	Ferruginous quartz sandstones.
						Pelitomorphic limestone (Muraille Blanche).
			Pre-Upper Aptian	C1		Brown hematite, clayey, and clay-sandy with limonite and marcasite concretion.
						Ferruginous clays with intercalations of argillaceous sandstone.
			Aptian basalt	Bc	Aquiclude	Basalt
	Jurassic	Upper	Titonian	J	Jurassic Aquifer.	Karstified limestone, dolomite.
			Kimmeridgian			..
			Oxfordian			
		Middle	Callovian			
			Bathonian			

Source: Compiled by ESCWA-BGR based on Khawlie and Shaban, 2003; Selkhozpromexport, 1986.

The Anjar-Chamsine Springs

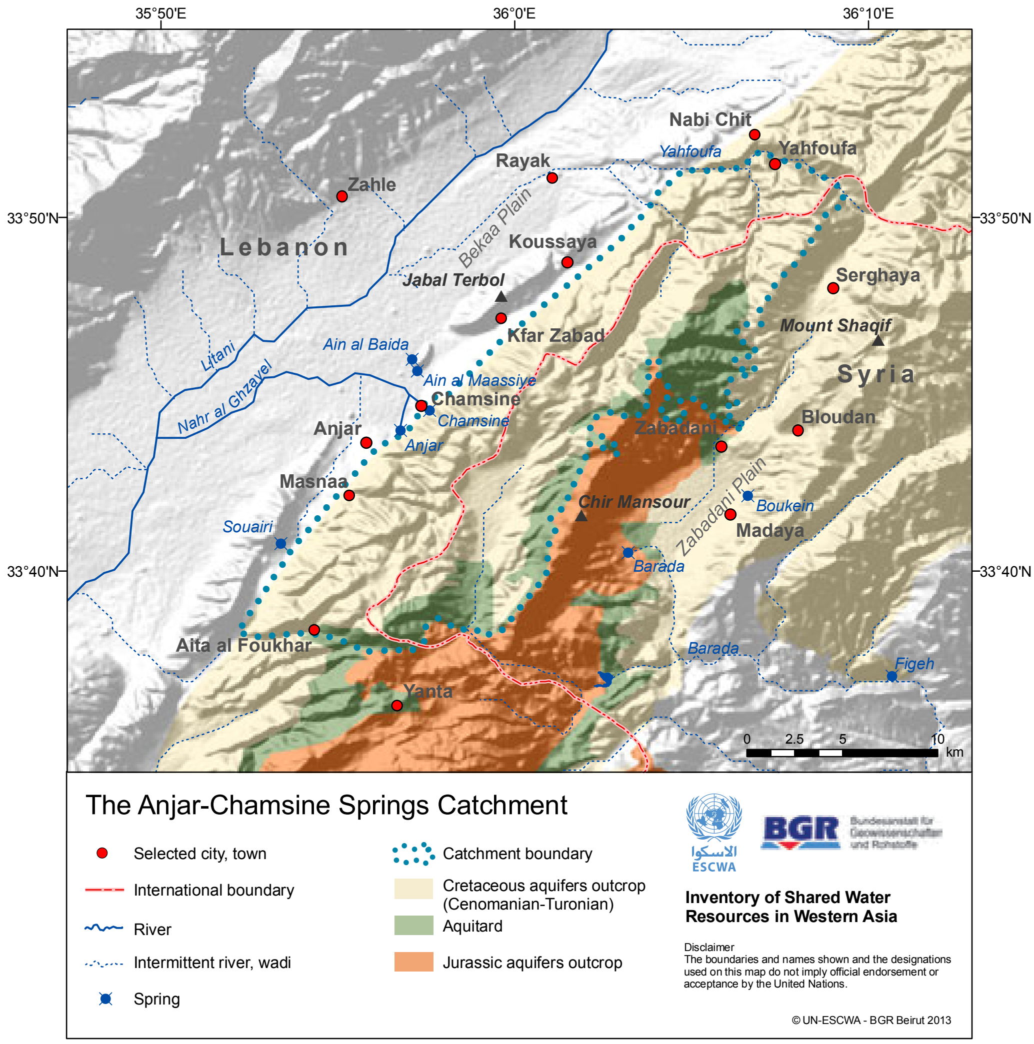
INTRODUCTION

The Anjar-Chamsine Springs[9] are located at the foot of the Anti-Lebanon Mountains in the east of the Bekaa Plain in Lebanon, north of the village of Anjar. The spring outlets are located at an altitude of 870 m asl, discharging from the Cretaceous (Cenomanian-Turonian) Aquifer in the Anti-Lebanon Mountain range. The springs at Anjar-Chamsine include the Anjar Spring, the Chamsine Spring and the smaller Souairi Spring to the south (Figure 1). The Anjar-Chamsine Springs contribute to the Litani River, which flows south through the Bekaa Valley and then veers west to discharge into the Mediterranean Sea. Water from the Anjar-Chamsine Springs is used locally for irrigation and in fish farms, while water from the Litani River is used for irrigation purposes and hydropower at Lake Qaraoun.[10]

Area

The lateral boundaries of the overall catchment area of the Anjar-Chamsine Springs are assumed to be mainly the outcrop area of the Cenomanian-Turonian age formations (C4-C5), and possibly some of the aquitard/aquiclude outcrop areas in the east.[11]

Figure 1. Overview Map of the Anjar-Chamsine Springs catchment area



Source: Compiled by ESCWA-BGR based on Dubertret et al., 1955; Khawlie and Shaban, 2003.

The catchment is further limited by the Yahfoufa River valley in the north and Aita al Foukhar Valley at Masnaa in the south (Figure 1). Within the boundaries, the extent of the Anjar-Chamsine Springs catchment is approximately 248 km^2, of which 49% is located in Lebanon and 51% in Syria.[12]

HYDROGEOLOGY

Aquifer configuration

The northern and eastern limits of the Anjar-Chamsine Springs catchment area include impermeable layers. The layers allow for concentrated recharge, which is likely to be at the origin of conduit development, particularly in the Yahfoufa River valley along the northern limit of the catchment. The western limit is only related to recharge and point discharge locally at the Anjar and Chamsine Springs. However, the aquifer develops at depth below the Upper Cretaceous, Tertiary and Quaternary sediments where it may discharge towards or be recharged from other systems.

The lateral boundaries of the catchment can be described as follows:

- The western limit is formed by the contact between the Cenomanian-Turonian (C4-C5) limestone and the impermeable Senonian (C6) marls. The aquifer develops at depth in the west below a confining sediment cover from Senonian marls to Miocene and Quaternary continental sediments.
- In the north, the water of the Yahfoufa River is partly swallowed, recharging the aquifer when crossing the karstified C4-C5 limestone.
- In the north-east, the limit is imposed by the anticline axis, which is close to the surface watershed.
- The eastern limit of the spring catchment reaches at least to the eastern extent of the C4-C5 outcrop. The surface runoff on the underlying aquitard to the east frequently flows westwards, towards the C4-C5 outcrop. The eastern limit of the catchment thus extends beyond the eastern limit of the C4-C5 outcrop to include the westward draining surface catchment of the underlying impermeable Lower Cretaceous formations. Surface runoff infiltrates, recharging the C4-C5 aquifers in concentrated or diffuse form over their outcrop area.
- The south-eastern limit is formed by what is probably an impermeable fault between the C4-C5 limestone and the Jurassic formations.
- In the south, the limit follows the Aita al Foukhar Valley.

Aquifer thickness

The Cenomanian-Turonian limestone (C4-C5) has an average thickness of 900 m. The upper section (Turonian, C5) is made up of up to 200 m of white stylolithic reef limestone with typical reef fossils.

Aquifer type

The aquifer is unconfined in the eastern part and confined in the west where it slopes at depth below a sediment cover, from Senonian marls (C6) to Miocene and Quaternary continental sediment. As a strongly karstified aquifer system, it comprises two different flow components: a conduit-controlled and a matrix-controlled flow system.

Aquifer parameters

Little is known about the hydraulic characteristics of the aquifer around the Anjar-Chamsine Springs. Two sets of pumping tests resulted in different transmissivity values and storage coefficients.[13] Pumping tests conducted in the 1970s at the Anjar Spring found a transmissivity value of $1.1x10^{-2}$ m^2/s at the source and $1.5x10^{-2}$ m^2/s at a test well. The storage coefficient was estimated at 0.032. A more recent study from 2005 included the results of pumping tests in bore-hole adjacent to the spring and demonstrated that there is no correlation between transmissivity and distance to the spring. The aquifer transmissivities in six bore-holes were estimated between $1.5x10^{-2}$ and $6.9x10^{-1}$ m^2/s with an average transmissivity of $3.3x10^{-1}$ m^2/s and an average storage coefficient of 0.032.[14]

Recharge

The mean annual precipitation in the catchment area of the Anjar-Chamsine Springs was estimated at 750 mm, which is equivalent to 165 MCM over an assumed catchment area of 220 km^2.[15] The actual evapotranspiration rate was estimated at 518 mm, which is equivalent to a total annual evapotranspiration of 114 MCM.[16] Thus the annual recharge was estimated at 232 mm or 51 MCM for the whole catchment area. It is also assumed that point recharge takes place from swallow holes along the Yahfoufa River, at a rate of up to 150 L/s or 4.75 MCM/yr. Water budget calculations indicated that further recharge may take place from the Jurassic age aquifers or from the C4-C5 aquifers at the bottom of the Bekaa Plain.

Flow regime

The principal flow direction in the Anjar-Chamsine Springs catchment is from east to west. As recharge occurs over the whole outcrop area and point recharge occurs in the Yahfoufa River valley, flow is also directed from the northern and southern boundaries towards the spring outlets. Little is known about water levels, heads and gradients.

Storage

The system has considerable storage: dynamic storage is estimated at around 100 MCM, varying from one year to another between 70 and 165 MCM, depending on the annual precipitation, making total storage even higher.[17] The residence time in the phreatic zone is estimated at around two years, which is relatively long for a karstic aquifer.[18]

Discharge

The total annual discharge of the Anjar-Chamsine Springs is estimated at 89.42 MCM, which is calculated as the sum of the total mean annual discharge of the Anjar Spring (74.16 MCM), the Chamsine Spring (13.68 MCM) and the Souairi Spring (1.58 MCM).

GROUNDWATER USE AND SUSTAINABILITY ISSUES

The Anjar-Chamsine Springs have been in use for centuries and were probably already developed in the 8th century CE, with large stone blocks raising the spring outlet and distributing water throughout the valley via channels.

Until the late 1990s, the C4-C5 aquifers were mainly exploited by pumping water from the springs. Around 2.52 MCM/yr is abstracted from the Chamsine Spring, while seasonal withdrawal for irrigation purposes from the Anjar Spring may be up to 18.9 MCM/yr. Additional water is used locally in a fish farm, which discharges its water back to the river.

More recently, several wells with depths up to 200 m were drilled in the plain near the limestone outcrops. Abstraction has been estimated at a few tens of litres per second, with seasonal withdrawal from the most productive wells. The situation is likely to impact spring discharge during the low-flow period and threatens the public water supply.[19]

Groundwater quality issues

There is limited information on water quality. However, the Bekaa Water Establishment regularly monitors bacteria levels and major dissolved solids at the Chamsine Spring, which is used for domestic purposes. Unconfirmed reports suggest that the spring water is polluted with faecal bacteria, which would explain why it is chlorinated before use.

All springs display seasonal variations in their chemical content, which is typical of karstic springs. However, the range of variation is low. Chloride (Cl^-) (approx. 9 mg/L) and nitrate (NO_3^-) (approx. 12 mg/L) content is low compared to potable water standards, but significantly higher than in non-contaminated groundwater in the same region (Cl^-: 2 mg/L; NO_3^-: about 3 mg/L).

Contamination probably originates from the villages located on the Cenomanian (C4) limestone and Senonian (C6) marls (Chamsine, Deir al Ghazal, Kfar Zabad, Koussaya and Yahfoufa), none of which are equipped with individual septic tanks or wastewater treatment plants. All the villages are located in the area where the main karst conduit develops from the Yahfoufa River swallow holes to the Anjar Spring, where the aquifer is particularly vulnerable to pollution.

Sustainability issues

The water level in wells used for domestic purposes and irrigation water supply has reportedly decreased over the past decade, forcing farmers in the area to abandon or deepen their wells. That suggests over-exploitation of the aquifer system. As spring discharge is not accurately measured, it is not clear whether pumping from private irrigation wells already affects flow. Moreover, actual spring discharge cannot be measured as several users withdraw water directly from the spring pool or from wells around the spring pool during low-flow periods. The absence of initiatives to improve environmental management – specifically groundwater protection – means that groundwater in the catchment remains at risk from domestic and agricultural pollution.

The Barada Spring

INTRODUCTION

The Barada Spring[20] is located around 30 km north-west of the Syrian capital Damascus. The spring outlet is located in the Zabadani Basin at an altitude of 1,095 m asl. The Barada Spring is the largest spring discharging from the Jurassic Aquifer in the Anti-Lebanon Mountain range. In spring time, the Barada Spring outlets fill Lake Barada and form the source of the Barada River, which flows through Damascus. Barada spring water is used for domestic water supply in Damascus and for irrigation purposes.

Area

Figure 2 shows the estimated boundaries of the Barada Spring catchment area. Further studies are required to delineate the boundaries more precisely, especially in the area of the Lebanese-Syrian border and towards Mount Hermon. The preliminary delineation covers an area of approximately 149 km^2 of which 54% is located in Lebanon and 46% in Syria.

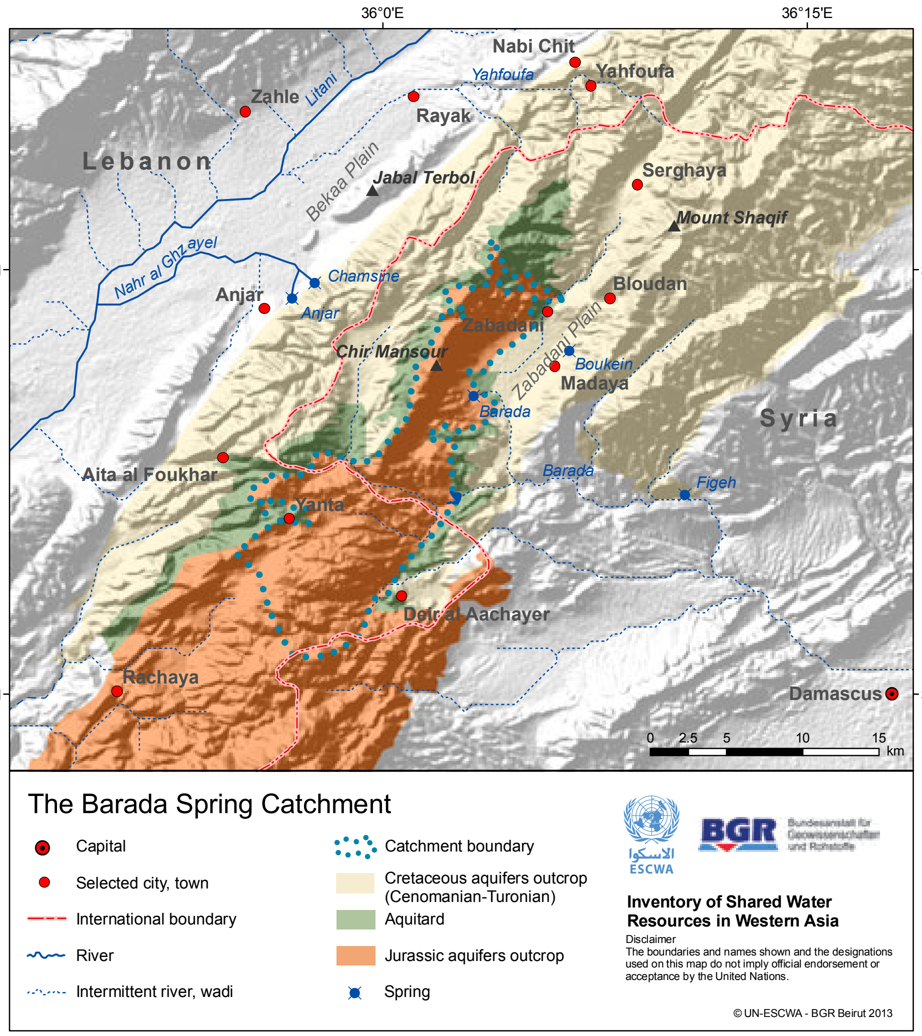
HYDROGEOLOGY

Aquifer configuration

Three major aquifers exist in the catchment area of the Barada Spring:

- The karstified limestones of the Jurassic Aquifer.
- The Lower Cretaceous ferruginous sandstone and the Upper Cretaceous karstified limestone and dolomite.

Figure 2. Overview Map of the Barada Spring catchment area



Source: Compiled by ESCWA-BGR based on Dubertret et al., 1955; Khawlie and Shaban, 2003.

- The unconsolidated Neogene and Quaternary aquifer in the Zabadani Plain.

Besides those major aquifers, local perched aquifers contribute to various spring outlets. The perched aquifers consist of clay-rich sediments, large alluvial fan deposits found perpendicular to the steep hills around the Zabadani Plain, and local basalts deposited along the western slope of Jebel Shaqif.[21]

The Barada Spring discharges mainly from the Jurassic aquifer, the most productive aquifer in the area. The permeability of the Jurassic aquifer is higher than the Cretaceous and two orders of magnitude higher than the Neogene and Quaternary aquifers. However, all aquifer units in the catchment of the Barada Spring are hydraulically interconnected and contribute to spring discharge.

Aquifer thickness

The units of this aquifer system crop out only in the western and southern areas of the catchment, within the limits of the Chir Mansour Mountains, Mount Hermon and Jebel Shaqif. The aquifer system dips under the Aptian strata on the flanks of the mountains. Total thickness reaches 2,000-2,200 m.

Aquifer type

The aquifer system is made up of intensively karstified limestone interbedded with dolomite, dolomitized limestone, marls and spilite.[22] In the outcrops, the carbonate rocks are intensively karstified and all varieties of karstic land forms can be encountered in the field. The zone of karstification can be several hundred metres thick. Karstic features were recorded at a depth of 270 m, while at greater depth (966 m) leakages were recorded, indicating the presence of other karstic caverns.[23] The existence of deep karstification suggests the presence of a thick zone of free water exchange in the Lower and Upper Jurassic formations. No information was available regarding confinement conditions in the aquifer system.

Aquifer parameters

Pumping test data in the Barada Spring catchment does not provide sufficient spatial coverage. Depending on the degree of fracturing, the pumping test data shows high variability.[24] Table 2 shows different transmissivity classes for the Barada Spring catchment.

Table 2. Transmissivity classes in the Barada catchment area

SOURCE	TRANSMISSIVITY (m^2/d)		GEOLOGY
	RANGE	AVERAGE	
GCBAB[a] and private drilling data.	<50	10	Neogene Conglomerates (south-eastern margin)
Selkhozpromexport, 1986.	2-150	40	Neogene and Quaternary Graben fill
Selkhozpromexport, 1986.	70-340	150	Aptian Sandstones (western block)
GCBAB estimation.	25-300	275	Cretaceous, eastern block Zabadani Basin
Selkhozpromexport, 1986.	250-300	275	Cretaceous, western block Zabadani Basin
Selkhozpromexport, 1986.	>1,000	1,500	Jurassic limestone

Source: Compiled by ESCWA-BGR based on Droubi et al., 2008a.
(a) General Commission for Barada and Awaj Basin in Syria.

Recharge

The recharge area of the Barada Spring can be subdivided into three different tectonic blocks: the Chir Mansour Mountain range (Chir Mansour Horst-Anticline), the Zabadani Plain (Zabadani Graben), and Jebel Shaqif (Shaqif Monocline).[25] The catchment area of the Barada Spring was determined on the basis of a regional hydraulic model. Recharge originates mostly from direct infiltration of meteoric water. The mean recharge altitude of the Barada Spring is 1,250 m asl[26] and recharge rates may be as high as 56%-70% from precipitation.[27]

Flow regime

The following flow boundaries are assumed:[28]

- The Chir Mansour Mountain range forms the western border of the aquifer system. The intensive fracturing and jointing of the Jurassic limestone indicate that there is no dip-dominant flow direction.
- The Shaqif Mountain range marks the eastern border of the aquifer system. Both borders can be assumed to be no-flow boundaries for the Barada Spring catchment area.
- The south-eastern border is a no-flow boundary.
- Mount Hermon marks the south-western boundary of the aquifer, which extends southward across the border into Lebanon.

Storage

Total and dynamic storage are unknown, but the relatively high tritium values in the Barada Spring indicate newer groundwater and most probably a smaller reservoir size than in the nearby Figeh Spring (see below).[29]

Discharge

The Barada Spring has an average yield of 3.12 m^3/s (98 MCM/yr). Minimum annual average discharge was $3.2x10^{-1}$ m^3/s (10 MCM/yr) in 2000/2001 and maximum annual average discharge was 4.12 m^3/s (130 MCM/yr) in 1991/1992.[30] Since 2000, the spring falls dry in spring and summer due to intensive pumping in the catchment and in the immediate vicinity of the spring. Due to the lower average recharge height – especially compared to the Figeh Spring – there is no snow-water buffer retention. Two major flow systems prevail in the system: a fast-conduit and slow-matrix flow system. Discharge peaks can be observed shortly after major rainfall events, but the discharge signal of the spring is more damped than the Figeh discharge signal, which may be attributed to a higher degree of karstification (Figure 4).

Water quality

Most of the groundwater in the Zabadani Valley is characterized by a Ca-Mg-HCO_3 water type; the anion sequence is as follows: HCO_3→Cl→SO_4, while Ca+Mg concentration exceeds Na+K concentration.[31] This water type reflects the predominance of calcareous and dolomitic aquifers in the Zabadani Valley.

The three springs in the Zabadani Valley (Barada, Boukein and Nabaa Arak) discharge low mineralized groundwater of Ca-Mg-HCO_3 type. In September 2008, the mineral content was measured as 240 mg/L for calcium (Ca^{2+}), 270 mg/L for magnesium (Mg^{2+}) and 320 mg/L for bicarbonate (HCO_3^-). Similar values were recorded in 1989/1990.

The saturation indices for calcite and dolomite indicate that most of the groundwater samples taken in the Zabadani Valley are slightly over-saturated (SI>0) with respect to calcite and slightly under-saturated (SI<0) with respect to dolomite. The predominance of calcium over magnesium is also reflected by low Mg/Ca ratios (0.08 to 0.47). It might also be an indication of rapid groundwater recharge and short groundwater residence time. Groundwater in equilibrium with a limestone aquifer would have Mg/Ca ratios in the range 0.5 to 0.7.

GROUNDWATER USE AND SUSTAINABILITY ISSUES

Groundwater use

No precise data regarding abstraction and use was available for the Barada Spring. However, population growth in the Damascus Plain has led to a sharp rise in demand from the agricultural and domestic sector over the last 60 years.

Historically, the Barada River formed the main source of water for Damascus, with water from the Barada and Figeh Springs (see below) supplying farmers and domestic users in the Barada Valley and the Damascus Plain (Damascus City and surrounding villages). The main agricultural area is the Damascus Ghuta, a 25,000 ha agricultural plain that once fully surrounded the Syrian capital.[32]

However, rapid population growth over the last 60 years has led to a sharp rise in demand, resulting in intersectoral competition over the limited resources, particularly during the irrigation season from late spring to autumn. Local farmers have dug dozens of licensed and unlicensed wells in the Barada Spring catchment area in recent years. The wells are used for irrigation and domestic purposes in the Zabadani Valley.[33] In addition, a well field made up of 22 wells in the Barada Spring catchment area pumps water to the Figeh Spring and on to Damascus. The well field was commissioned in 1995 and became fully operational a year later with a pumping rate of 1 m^3/s (15.76 MCM/yr).[34] An additional well field at Jabous in a different area of the Barada catchment supplements drinking water supply.[35]

Sustainability issues

Over-abstraction from the Barada Spring catchment area and the Barada River has led to a gradual decrease in spring discharge, with the Barada Spring today only flowing for a period of seven to eight weeks a year. Climate change and the predicted decrease in rain- and snowfall is likely to further impact spring flow and pose a growing threat to the sustainability of the Barada Spring.

The Figeh Springs

INTRODUCTION

The Figeh Springs[36] are located around 15 km north-west of the Syrian capital Damascus. The springs have four main outlets: Figeh Main, New Figeh Side, Old Figeh Side and Haroush Springs. The springs have been utilized since Roman times or before, with canals from the spring supplying several towns and villages in the area. Figeh spring water provides up to two thirds of the water supply for the Damascus.

Area

No detailed information was available on the limits of the hydrogeological catchment. The boundaries of the Figeh Springs as shown in Figure 3 represent the boundaries of the protection zone. The protected area covers approximately 658 km², of which 16% is located in Lebanon and 84% in Syria. The actual hydrogeological catchment is probably smaller.

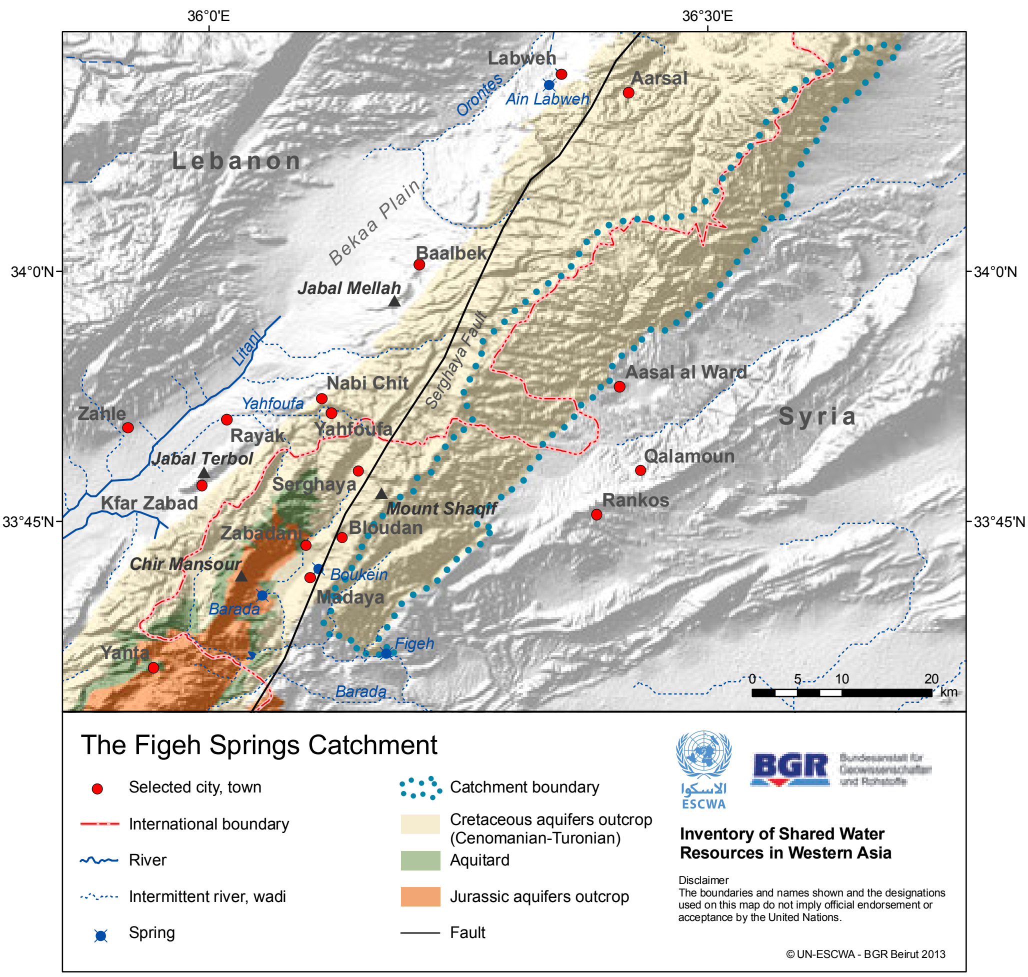
HYDROGEOLOGY

Aquifer configuration

The exposed rocks in the Figeh Springs catchment area belong to the Cretaceous Period. The aquifer system of the Figeh Springs comprises limestones and dolomites of the Upper Cretaceous, from the Cenomanian and Turonian stages.[37]

The recharge area of the Figeh Springs includes a north-east-trending part of the Anti-Lebanon

Figure 3. Overview Map of the Figeh Springs protection zone



Source: Compiled by ESCWA-BGR based on Dubertret et al., 1955; Khawlie and Shaban, 2003.

Mountain range. The eastern and south-eastern boundaries are marked by a Tertiary Basin.[38] The dominant structure of the Figeh Springs catchment area is a south-east dipping monocline, which originates near the Serghaya Fault in the west. The eastern boundary of the Figeh catchment is marked by the Jarajeer lineament, which separates the Cretaceous-age rocks from the Tertiary.[39]

Aquifer thickness

The most complete section of the Cretaceous sequence is exposed near Bloudan and has a thickness of around 1,800 m.[40] The thickness of the Cenomanian and Turonian aquifers varies from around 680 m in the south[41] to 480 m in the north.[42]

Aquifer type

For most of the catchment, the aquifer is assumed to be unconfined, becoming confined or semi-confined towards the outlet of the different springs. The confining beds consist of the uppermost Cretaceous to Eocene chalks and chalky limestones. Several small local perched aquifers exist within the catchment area of the Figeh Springs, none of which discharges significant amounts of spring water.

Aquifer parameters

Due to its karstic nature, two flow components prevail within the aquifer: a fast-conduit-controlled and a slow-matrix-controlled flow component. This discharge behaviour is reflected in the discharge curves of the spring (Figure 4).

Recharge

The recharge area lies in the north-east-trending part of the Anti-Lebanon Mountain range. Stable isotope analyses estimated a mean recharge altitude of around 2,100 m asl.[43] The total extent of the catchment was previously estimated to cover a limestone outcrop area of 665 km^2.[44]

Present-day recharge consists solely of infiltration from precipitation. More than 70% of the precipitation falls as snow, thus forming an important intermediate storage buffer of water in the mountains. Climate change may considerably affect the high snow quota and result in the loss or severe reduction of the temporary snow-water buffer.[45]

The mostly drought-resistant vegetation with very sparse ground cover results in low soil moisture retention capacity in the recharge area. An infiltration rate of around 60% of the annual precipitation volume was recorded at two low-altitude locations (1,500 m asl) in and near the Figeh catchment.[46] Since more than 90% of the Figeh catchment is located at more than 1,500 m asl, the infiltration rate is probably higher.[47]

Flow regime

Limited information is available on water levels and flow directions in the Figeh catchment. During a study undertaken in the 1970s, several deep observation wells were drilled within a radius of a few hundred metres around the Figeh Main Spring.[48] Today the wells are blocked or refilled. As there are no other observation wells in the catchment area, groundwater levels, divides and flow patterns can only be estimated.

Hydraulic (flow/no-flow) boundaries can be outlined as follows:

- To the north-west and west, the Serghaya Fault acts as a no-flow boundary. In the area between Madaya and Serghaya, the fault has a vertical displacement of more than 1,000 m.
- The Barada River marks the southern boundary of the spring catchment. In the south-western part of the boundary, stable isotope investigation showed that no or very limited groundwater arrives from the high-altitude Figeh catchment area. It remains unclear whether groundwater in the catchment area flows beyond the surroundings of the spring outlet in the south-east.

The Anti-Lebanon Mountain range near Bloudan, Syria, 2009. Source: Cristen Rene.

- Towards the east and south-east, the Jarajeer lineament forms the eastern boundary between the Cretaceous Anti-Lebanon Mountain range and the Tertiary-Quaternary Qalamoun Basin. The boundary is not a no-flow boundary, since stable isotope samples from wells drilled to the east of it indicate high-altitude recharge. Therefore the groundwater recharge area is related to the high mountains in the Figeh catchment area and indicates a certain leakage through the boundary.

The Cenomanian-Turonian strata are intensively fractured. Groundwater infiltration and flow in the central part of the recharge area are controlled by the south/south-eastern stratigraphic dip. The flow path is also controlled by the south/south-east-trending normal faults and the north-south-trending fault system, which carry water towards the Figeh Spring outlets.

Storage

The maximum storage capacity of the Figeh Springs reservoir is 3.9 BCM, while the residence time of groundwater is 50 to 60 years.[49]

Discharge

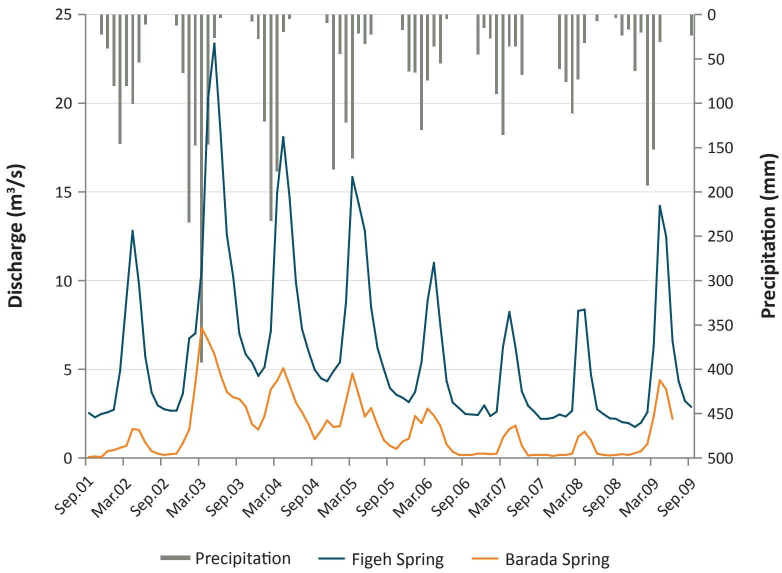
The grey massive-bedded dolomites and dolomitic limestones of the Turonian stage host the Figeh Spring outlets.[50] The long-term average discharge of the Figeh Springs is 243 MCM/yr or 7.7 m^3/s.[51] The discharge of the Figeh Spring is, however, highly variable with fluctuations of between 1.4 and 28.3 m^3/s at the Figeh Main Spring outlet.[52] The highest discharge at the Figeh Main Spring is usually observed during and after the rainy season. Lowest discharge occurs before the beginning of the rainy season (Figure 4).

Water quality

The water of the Figeh Springs is only slightly mineralized and salinity ranges from 200 to 600 mg/L in the Cenomanian-Turonian age formations.[53] The predominant water type is Ca-Mg-HCO_3 and the Mg/Ca ratios above 0.7 indicate that most of the groundwater samples that have been analysed correspond to a dolomitic aquifer environment. The salinity of groundwater abstracted from the Upper Cretaceous ranges from 360 to 430 mg/L TDS.[54]

Variations in ion concentrations and specific electrical conductivity are relatively small during the dry season. However, their values decrease during peak-flow season. The Old

Figure 4. **Hydrographs of Figeh and Barada Springs and monthly precipitation at Bloudan**



Source: Redrawn by ESCWA-BGR based on Al-Charideh, 2012.

Haroush Spring and Old Side Spring as well as the Barada River show a sharp decrease in calcium (Ca^{2+}) concentration and a less pronounced in magnesium (Mg^{2+}) concentration during the high-flow season (flood period). This may suggest rapid recharge from precipitation or even a hydraulic contact between the river and surrounding springs. On the other hand, Figeh Main Spring exhibits a sharp decrease in magnesium concentration and a slight increase in calcium concentration, suggesting rapid recharge and a stronger influence of dolomitic layers during the dry season.[55]

GROUNDWATER USE AND SUSTAINABILITY ISSUES

The Figeh Springs provide around two thirds of the water supply for Damascus. Supply and distribution is managed by the Damascus Water Supply and Sewerage Authority (DAWSSA), which operated under the umbrella of the Syrian Ministry of Housing and Construction until June 2012. Besides a small share used by local farmers in the village of Ain al Figeh, water from the Figeh Spring is used for domestic purposes. Law No. 10 of 1989 established a protection zone in the catchment area (Figure 3). The law banned well drilling, construction and any commercial, industrial and agricultural activities in the area and outlined how landowners affected by the implementation of the law are to be compensated, as well as the punishments that follow violations of the restrictions.

During the high-flow period, the natural outflow of Figeh Main Spring is sufficient to cover demand from Damascus. When spring discharge exceeds demand from Damascus, excess water is discharged into the Barada River. During the medium- to low-flow period, additional wells and caissons near the springs pump water from the aquifer to increase water production. Over-exploitation has affected groundwater flow patterns and water quality. Changes in hydraulic flow conditions suggest that the delineation and definition of the protection zone need to be reassessed.

Groundwater quality issues

The protection area delineated in Law No. 10 of 1989 extends beyond the Figeh Springs catchment.[56] Prior to the issuing of the law, increased abstraction and over-exploitation affected groundwater flow patterns in the vicinity of the spring outlets, resulting in infiltration of contaminated water from untreated domestic wastewater in the Barada River. Water quality increased significantly when DAWSSA took measures to protect the groundwater.

Sustainability issues

In the past, Figeh Spring discharge met Damascus water demand, but today additional resources are needed to overcome reduced discharge and growing demand, especially in the summer months. Additional well development and groundwater abstractions from the aquifer feeding the Figeh Springs has already affected water quality as discussed above. DAWSSA is implementing measures to safeguard the quality of the Damascus water supply. However, in the longer term additional water resources will be needed to meet the growing needs of the capital and investigations in other parts of the Anti-Lebanon Mountain range are ongoing.

The Anti-Lebanon Mountain range near Bloudan, Syria, 2009. Source: Cristen Rene.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for any part of the Anti-Lebanon Mountain range, nor for the three shared spring catchments described in this chapter.

COOPERATION

The two riparians coordinate shared water resources management issues through the Syrian-Lebanese Joint Committee for Shared Water, which also implements the agreements in place over the Nahr el Kabir and the Orontes River (see Chap. 7 and 8). However, it is not clear whether the shared aquifer systems in the Anti-Lebanon Mountain range have been addressed under this umbrella for cooperation.

OUTLOOK

There is limited understanding of the shared aquifer systems presented in this chapter as well as other surface and groundwater basins in the Anti-Lebanon Mountain range. The riparian countries could benefit from closer cooperation in the domain of joint research into shared catchments, including the detailed delineation of catchment areas and protection zones, the determination of water balances and the potential impact of climate change.

Bekaa Valley, Lebanon, 2011. Source: Karan Jain.

Notes

1. The border delineation applied by the United Nations is based on the 1920 French Mandate border, which was never formally changed.
2. Service Météorologique du Liban, 1977.
3. Verdeil et al., 2007, p. 72, 78.
4. Central Bureau of Statistics in the Syrian Arab Republic, 2005. According to a 2004 population census.
5. Ibid. According to a 2004 population census.
6. El-Hakim, 2005. However, according to GIS calculations the value is 2,200 km^2, from the map, Dubertret and Vautrin, 1950.
7. The spring is also known as Liddan in Arabic.
8. Sabbagh, 1961.
9. Information on the Anjar-Chamsine Springs is mainly drawn from El-Hakim, 2005, who undertook the most detailed study of the springs to date.
10. Plans to transfer water from the Lake Qaraoun out of the Litani Basin are currently being implemented. The water is intended for irrigation development in southern Lebanon and domestic use in Beirut.
11. Surface runoff feeds additional water for recharge at the eastern margins of the Cenomanian-Turonian outcrop.
12. Water budget calculations by El-Hakim, 2005 indicate that the catchment area may be up to 265 km^2, which probably includes the aquiclude area.
13. UNDP, 1970; Din, 1971; El-Hakim, 2005.
14. Transmissivities and other aquifer parameters in such a karstified aquifer are highly variable.
15. According to the GIS calculations, the catchment area is 248 km^2, as mentioned above. However, in El-Hakim, 2005, the recharge is calculated on an area of 220 km^2.
16. Based on an average annual rainfall of 750 mm, mean annual air temperature of 10.9°C, a mean elevation of 1,370 m asl and with area calculations based on El-Hakim, 2005.
17. The estimate is calculated from the recession curve. The dynamic storage corresponds to the volume of groundwater flowing at the beginning of the recession stage, which is lower than the total stored volume.
18. Residence time in karst aquifers is usually shorter than six months.
19. El-Hakim, 2005.
20. Information on the Barada Spring is mainly based on Droubi et al., 2008a and Droubi et al., 2008b.
21. Droubi et al., 2008a.
22. Selkhozpromexport, 1986.
23. Ibid.
24. According to pumping tests undertaken by Selkhozpromexport, 1986.
25. The structure of the units is described in detail in Droubi et al., 2008a and Dubertret and Vautrin, 1950.
26. Kattan, 1997.
27. Selkhozpromexport, 1986.
28. The description of boundaries is based on Droubi et al., 2008b.
29. Kattan, 1997.
30. Alammareen, 2010.
31. Selkhozpromexport, 1986.
32. de Chatel, 2013.
33. JICA, 1996.
34. Ibid.
35. The creation of the well field had a severe impact on river flow and after the wells started pumping water out of the catchment in 1996, the level of the Barada River dropped dramatically (de Chatel, 2013.)
36. Information on the Figeh Springs is largely drawn from Lamoreaux et al., 1989, who produced the most detailed published study of the springs to date.
37. Dubertret and Vautrin, 1950.
38. Lamoreaux et al., 1989.
39. Ibid.
40. Ibid.
41. Dubertret and Vautrin, 1950.
42. Al Hafez et al., 1999.
43. Al-Charideh, 2011.
44. SOGREAH, 1973.
45. Ulbrich et al., 2006.
46. Lamoreaux et al., 1989.
47. That is based on the assumption that precipitation is higher and evaporation rates are lower at higher elevations. Lamoreaux et al., 1989.
48. SOGREAH, 1973.
49. Al-Charideh, 2011.
50. Over time, an extensive cave system developed. According to Lamoreaux et al., 1989 the continuous cave evolution has and will lead to cave collapse and might change the Figeh outlet points with time, as indicated by 70 m of breccias which deposited on a cave floor.
51. Al-Charideh, 2011.
52. Kattan, 1997.
53. Selkhozpromexport, 1986.
54. Burdon and Safadi, 1964.
55. All information in this paragraph based on Kattan, 1997.
56. In particular, the middle and northern part of the protection zone may also contribute to recharge in the Qalamoun Basin, a high plateau located to the east of the Anti-Lebanon Mountains.

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