Chapter 11

Wajid Aquifer System

INVENTORY OF
SHARED WATER RESOURCES IN WESTERN ASIA (ONLINE VERSION)

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Wajid Aquifer System

EXECUTIVE SUMMARY

The Wajid Sandstones are made up of two permeable formations, the Upper and Lower Wajid Sandstones, which are separated by a less permeable shale formation. They are hydraulically connected over a long distance to constitute a regional aquifer system.

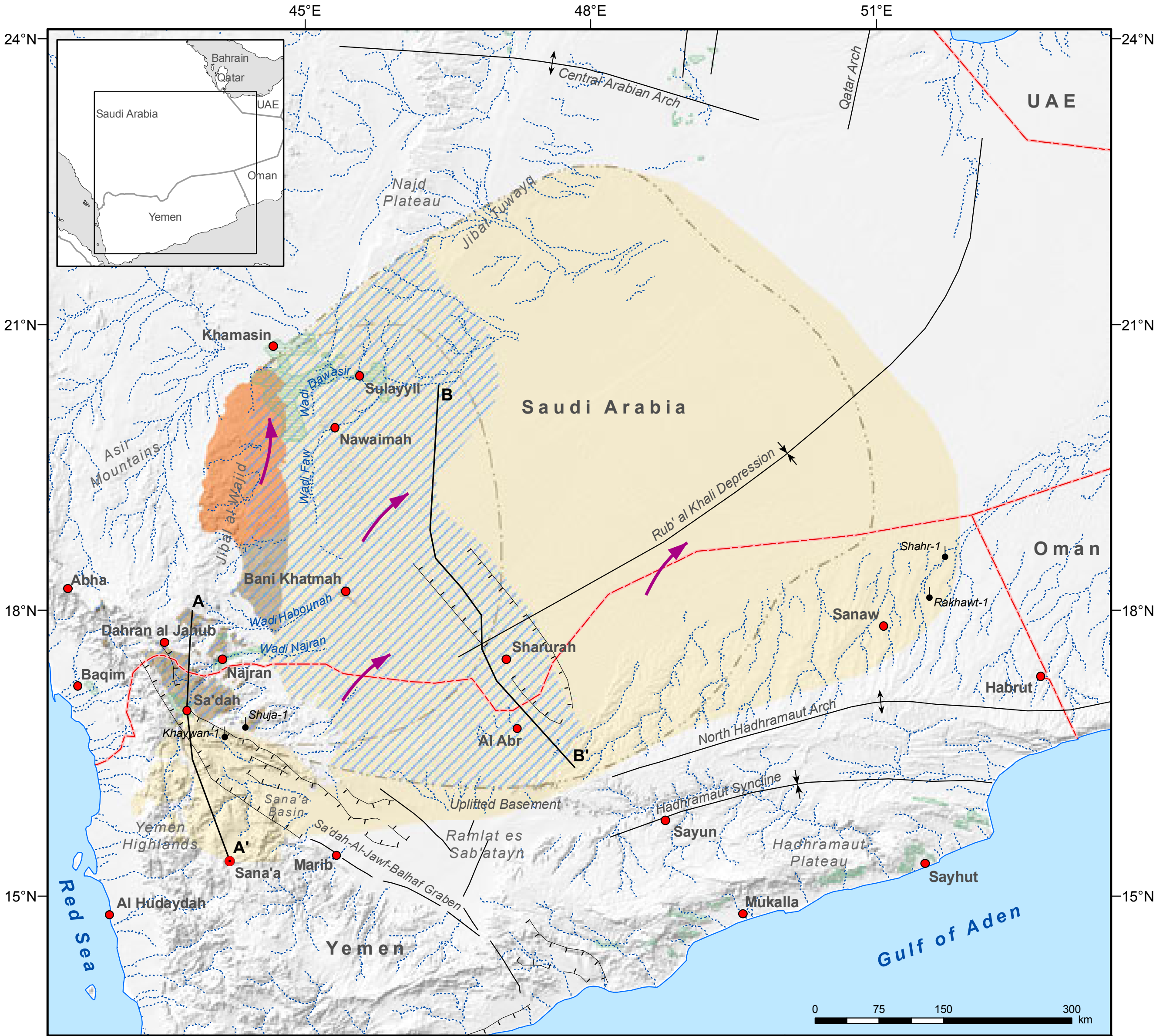
The Wajid Aquifer System extends across the border of Saudi Arabia and Yemen, from the Asir-Yemen Highlands to the Rub' al Khali Depression. In the subsurface, the aquifer system extends from the Wadi Najran area to the eastern areas of the Rub' al Khali and possibly to the Gulf coast. On the surface, the Upper Wajid is found mainly in the Sa'dah-Najran area while only the Lower Wajid is exposed in the Jibal al Wajid further north. The combined thickness of the Upper and Lower Wajid may be anywhere between 100 and 900 m in the areas where it is currently exploited.

The water level in the aquifer system has dropped at a rate of 3 m/yr for the past 20 to 30 years and as much as 6 m/yr in some areas around Wadi Dawasir-Sulayyil (Saudi Arabia) and Sa'dah (Yemen). Heavy abstraction for agricultural development in these areas has led to the exhaustion of the aquifer system in some areas, while other areas are threatened by exhaustion in the coming 10 to 15 years.

BASIN FACTS

RIPARIAN COUNTRIES	Saudi Arabia, Yemen
ALTERNATIVE NAMES	Bani Khatmah Formation
RENEWABILITY	Very low to low (0-20 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Weak
ROCK TYPE	Porous
AQUIFER TYPE	West: Unconfined East: Confined
EXTENT	~455,000 km^2
AGE	Paleozoic (Permian and older)
LITHOLOGY	Sandstones
THICKNESS	100-900 m (AVG: 300 m)
AVERAGE ANNUAL ABSTRACTION	Saudi Arabia: 2,260 MCM (2004) Yemen: ~100 MCM (2002)
STORAGE	Saudi Arabia: 30-225 BCM Yemen: 4-6 BCM
WATER QUALITY	Fresh to slightly brackish (700-1,000 mg/L TDS)
WATER USE	Predominantly agricultural; limited municipal and industrial
AGREEMENTS	-
SUSTAINABILITY	Water level decline and salinization due to overexploitation, resulting in partial exhaustion of the resource

OVERVIEW MAP



Wajid Aquifer System

- Capital
- Selected city, town
- International boundary
- Intermittent river, wadi
- Exploratory bore-hole
- Anticline
- Syncline
- Graben
- Lineaments
- Lower Wajid Sandstone outcrop
- Upper Wajid Sandstone outcrop
- Approximate subsurface extent of the aquifer formations
- Approximate boundary of exploitable area
- Zone of agricultural development
- Subsurface extent after Ministry of Agriculture and Water in Saudi Arabia, 1984
- Subsurface extent after Edgell, 1997
- Direction of groundwater flow
- A A' Approximate location of cross-section

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Inventory of Shared Water Resources in Western Asia

Disclaimer
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

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Introduction

LOCATION

The Wajid Aquifer System is located at the edge of the crystalline Arabian Shield near the south-western tip of the Arabian Peninsula (see Overview Map). It extends across the border of Saudi Arabia and Yemen.

AREA

The Wajid Aquifer System extends over an area of more than 455,000 km^2 of which 26,300 km^2 is covered with outcrops. Around 307,000 km^2 is located in Saudi Arabia, and the remaining 146,000 km^2 is in Yemen. Recent data[1] from deep exploratory wells suggests that the aquifer system extends over a much larger area than previously estimated.[2] A recent study found that the subsurface extent of the sandstones reaches the eastern shores of the Arabian Peninsula.[3] The aquifer system is bounded by the Asir-Yemen Highlands to the west, the vast Rub' al Khali Desert to the east, the Ramlat es Sab'atayn Desert-Hadhramaut Plateau to the south, and the Najd Plateau to the north.

CLIMATE

In the south-western part of the Arabian Peninsula, where the Wajid Sandstones exist, rain can occur throughout the year, but happens mainly during spring and summer when the region comes under the influence of the Indian Ocean Monsoon system. While maximum annual rainfall levels of 200 mm have been registered, average annual rainfall is 50-100 mm,[4] with two rainy seasons: March-May and July-August. Temperatures vary according to elevation and season, from a minimum of 9°C in December-January to a maximum of 25°C in July in the western plateau areas[5] and about 44°C in August in the desert areas further east.[6] Annual evapo-transpiration was estimated at about 2,150 mm in the Sa'dah area.[7]

POPULATION

Most of the population living within the boundaries of this basin is concentrated in Sa'dah Governorate in Yemen and Najran Province in Saudi Arabia. Population figures for these two regions are not available, but previous estimates suggest a population of around 1.14 million, of which 450,000 live in Saudi Arabia[8] and 695,000 in Yemen.[9] About a third of this population lives in the cities of Sa'dah in Yemen and Najran in Saudi Arabia.

OTHER AQUIFERS IN THE AREA

Two other categories of aquifer systems occur in the area: the alluvial aquifer systems in the Wadi Najran Basin in the western part of the delineated area (Box 1), and the Wasia-Biyadh-Aruma Aquifer System (South) further east (see Chap. 12).

INFORMATION SOURCES

Official sources in both countries provided information on the hydrogeology of the aquifer system, though most of it was not recent. Other data and information on groundwater use was drawn from the literature. The Overview Map was delineated based on various local and regional references.[10]

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

The depositional basin of the Wajid Sandstones is divided by the north-west/south-east Sa'dah-Al Jawf-Balhaf Graben, which divides the system into a southern part along the western boundaries of the graben and a northern part along the eastern boundaries of the graben.

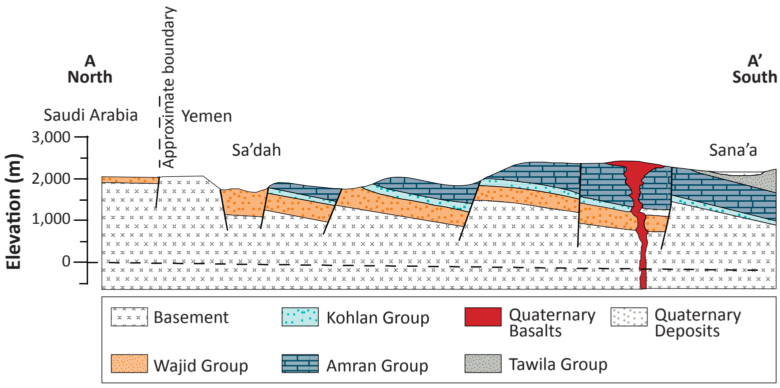
In the southern part and within the graben itself, the Wajid Sandstones occur only in the subsurface of the so-called Sana'a Basin. They were deposited mainly within separate small sub-basins between Sa'dah and Sana'a, which were formed by block faulting related to the opening of the Red Sea (Figure 1).[11] The location and configuration of these sub-basins suggest that the Wajid Sandstones cannot constitute shared systems in this part. Hence they are not considered in this report.

On the northern side of the graben, outcrops of the Wajid Sandstones are found along the edges of the Basement of the Shield. In the Wadi Najran area, the sandstones form a thin cover over the Basement but are partly removed in places where they have been cut by drainage.[12] In some areas, isolated outcrops form spectacular cliffed outliers.[13] Further east, the sandstones are found in the subsurface, dipping gently under Permo-Carboniferous and Mesozoic strata of the south-western Rub' al Khali Depression. Towards the south in the direction of the Northern Hadhramaut Arch, which is the structural boundary of the sedimentary basin, the thickness of the sandstones is reduced from about 900 m in Saudi Arabia to 350 m in Yemen. The depth to the top of the formation is reduced from about 1,650 to 600 m bgl (Figure 2).[14]

STRATIGRAPHY

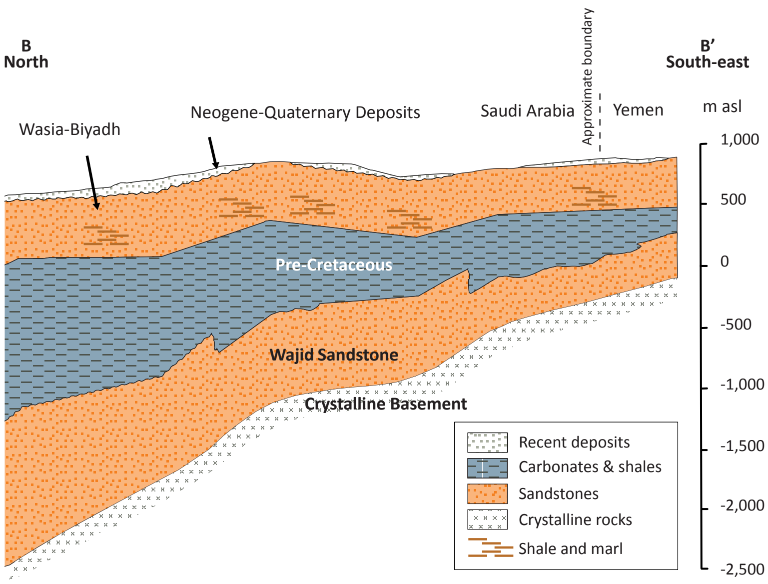
A comprehensive study has shown that the sandstones in the Dahran al Janub-Najran are coarse to conglomeratic with some siltstones near the top, which indicates that they were deposited in a braided-stream environment, while those in Jibal al Wajid are finer with no evidence of channelling, suggesting a shallow-marine environment.[15] Further studies[16] have shown that the Wajid Sandstones comprise an upper and a lower formation (see Overview Map). The Lower Wajid (in the Jibal al Wajid area) is restricted mainly to the Cambro-Ordovician Period while the Upper Wajid (in the Sa'dah-Najran-Bani Khatmah area) contains Late Permian fossils. In Saudi Arabia, a recent study has shown that the Wajid Sandstones represent two individual fractured aquifers in the subsurface separated by an aquitard. The lower aquifer (Lower Wajid) comprises two formations (Dibsiyah and Sanamah) and is effectively separated from the upper aquifer (Upper Wajid), which comprises the Khusayyan and Juwayl Formations, by the siltstones and shales of the Qusaiba Shale equivalent.[17]

Figure 1. Geological cross-section of the Wajid Sandstones in the Sa'dah-Sana'a area in Yemen



Source: Modified by ESCWA-BGR based on Van der Gun and Ahmed, 1995.

Figure 2. Geological cross-section of the Wajid Sandstones across the border of Saudi Arabia and Yemen



Source: Modified by ESCWA-BGR based on Edgell, 1997.

Figures 2 and 3 show the aquifer system's subsurface extension into Yemen. Exploratory bore-holes indicate that the Wajid Aquifer System extends at least into eastern Yemen.

AQUIFER THICKNESS

The thickness of the Wajid Sandstones generally increases away from the graben and the uplifted Basement in north and north-easterly directions. In the Sa'dah Plain in Yemen, where the sandstones have been largely removed by erosion, the sandstones have a thickness of around 100 m,[18] while thicknesses of around 600 m occur around the town of Sa'dah in downthrown blocks of the graben.[19] Further north in Saudi Arabia, a thickness range of 11 m (at 19°30' N and 44°00' E) to 365 m (at 19°43'N and 44°41'E) has been measured.[20] Available data indicates a thickness of up to 950 m[21] in the Rub' al Khali Depression, where both sandstone formations are preserved at depth (Figure 2 and 3).

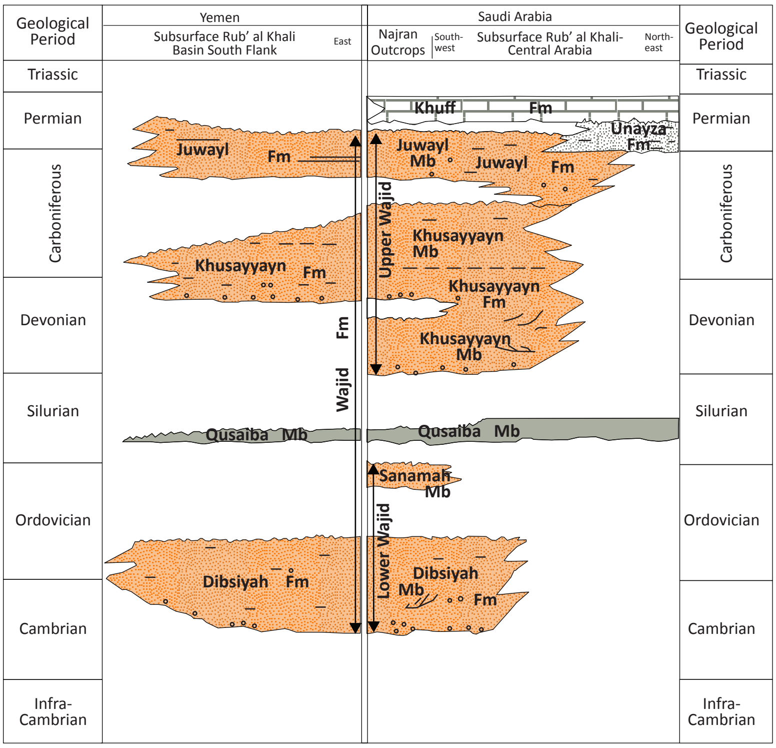
AQUIFER TYPE

The numerous outcrops around the town of Najran in Saudi Arabia form unconfined aquifer zones.[22] In the nearby Sa'dah area in Yemen, the sandstone aquifer is also mainly unconfined except in areas where it is overlain by relatively thick deposits of Jurassic (Amran) Limestone.[23] Further east in the Rub' al Khali, where the two sandstone formations are separated by shale, the Upper Wajid is unconfined, while the Lower Wajid acts as a confined aquifer over an area of 170,000 km² in Saudi Arabia.[24]

AQUIFER PARAMETERS

Data on the hydraulic parameters of the aquifer system is limited. Nevertheless, the transmissivity values obtained from the southern (Sa'dah) and northern (Dawasir) parts of the basin are remarkably similar, indicating that they most likely represent the same aquifer system. Field measurements in the Sa'dah area showed significant differences in transmissivity (Table 1), which reflect the variations in the hydraulic permeability and thickness.[25] Also the wide range of values for storativity reflects the variability of the confining pressure due to differences in lithology and thickness of both the aquifer and the overlying formations, particularly toward the south-eastern edge of the system.

Figure 3. Correlation of the lithostratigraphy of the Wajid Formations in Saudi Arabia and Yemen



Source: Redrawn by ESCWA-BGR based on Stup and Van Der Eem in Beydoun et al., 1998.

Table 1. Hydraulic parameters of the Wajid Aquifer System

TRANSMISSIVITY (m²/s)	STORATIVITY			COMMENTS	SOURCE
	CONFINED	UNCONFINED	RANGE		
$5.7x10^{-4}$-$2.1x10^{-2}$ AVG:[a] $1.5x10^{-2}$	AVG: $4.0x10^{-2}$	$2.0x10^{-1}$	$2.0x10^{-4}$-$4.0x10^{-4}$	Values obtained mainly for the Wadi Dawasir area in 1965.	Ministry of Agriculture and Water in Saudi Arabia, 1984.
$2.2x10^{-4}$-$8.1x10^{-3}$	..	AVG: $7.5x10^{-2}$	..	Values obtained for the Sa'dah Plain.	Van der Gun, 1985.
$2.3x10^{-4}$-$4.6x10^{-3}$	..	..	..	Values obtained mainly for the Sa'dah area in Yemen in the early 1990s.	Al-Sakkaf et al., 1999.
$5.8x10^{-4}$-$8.1x10^{-2}$ AVG: $1.4x10^{-2}$	..	..	..		Al Shami and Al-Dubby, 2004.

Source: Compiled by ESCWA-BGR.
(a) AVG refers to average values.

Hydrogeology - Groundwater

RECHARGE

Carbon-14 dating of groundwater in the Wajid Aquifer in Saudi Arabia shows that the water is more than 30,000 years old[26] and thus represents 'fossil water'.[27] Judging from isotope studies, groundwater from deep wells in the Wajid Sandstones in Wadi Dawasir is older than the groundwater in the Tuwayq Mountains, which was recharged after the last pluvial period.[28] Since rainfall in most of the basin is less than 200 mm/yr,[29] it is unlikely that significant recharge takes place in the northern (Wadi Dawasir) part of the basin. However, direct and indirect recharge has been reported in the southern Sa'dah-Najran area where average rainfall is 250-300 mm/yr. In Yemen, it is estimated that a total recharge (natural sources plus irrigation return) of 17.7 MCM/yr[30] occurs in this escarpment zone, which is equivalent to 7.9 mm/yr,[31] although lower (4.4 mm/yr,[32] 3.2 mm/yr[33]) values have been suggested. In Saudi Arabia a recharge of 114 to 240 MCM (equivalent to 4.4[34] to 19.2 mm/yr[35]) has been estimated.

Table 2. Groundwater reserves in the Wajid Aquifer System

COUNTRY	RESERVES (BCM)	COMMENTS	SOURCE
Saudi Arabia	30	Based mainly on data from the Wadi Dawasir area.	Ministry of Agriculture and Water in Saudi Arabia, 1984.
	225	Represents groundwater exploitable by lowering depth to water level to 300 m.	Al Alawi and Abdulrazzak, 1993.
	69 (1984) 40 (Estimated, 1996)	Based on data from the Ministry of Planning in Saudi Arabia.	Al Sheikh, 2000.
Yemen	5.7	Estimation takes into consideration the economic pumping lift of 150 m for irrigation purposes.	HWC, 1992 (cited in Al Shami and Al-Dubby, 2004).
	3.7	Based on data from Sa'dah area.	WikiADAPT, 2009.

Source: Compiled by ESCWA-BGR.
Note: The values for Saudi Arabia are assumed to cover the total area of the Wajid as delineated by Ministry of Agriculture and Water in Saudi Arabia, 1984 (see Overview Map), while the values from Yemen are for the much smaller area around Sa'dah, though none of the studies specifically mentions the area.

FLOW REGIME

Groundwater flows from the recharge area in the south-west corner of the basin (Asir Mountains-Yemen Highlands) towards the north and north-east, where groundwater seeps into the alluvium of Wadi Dawasir[36] or sinks into the Rub' al Khali Depression. Groundwater flow across the political border has presumably been disrupted by the heavy abstraction in the Sa'dah-Najran area since the late 1970s. However, available data does not reveal the impact of this cone of depression on the groundwater dynamics of the aquifer system.

STORAGE

Table 2 indicates that the values obtained for groundwater storage in the Wajid Aquifer System in Saudi Arabia are very diverse. Official data states a much smaller storage volume, but also suggests that much of the water lies at great depth.[37] There is also a difference in the values reported by different sources.[38] The available groundwater reserve in the Sa'dah area is an order of magnitude lower than in Saudi Arabia. However, no data is available on the Rub' al Khali Basin, which has much larger storage at substantially greater depths.

DISCHARGE

Up until about 1980, natural discharge from the sandstones occurred from springs (in the mountainous areas) or as base flow into wadi beds (in the desert plain further east and north-east). Many springs in the Sa'dah area were located near the contact with the underlying basement and were therefore considered an alternative to drilling.[39] In Saudi Arabia, natural discharge in the form of sabkhas occurs between Khamasin and Nawaimah (in Wadi Faw) and to the west of the Tuwayq Mountains along fractured zones extending between Wadi Dawasir and Wadi Faw.[40] Almost all base flows in Wadi Dawasir and Wadi Faw used to originate from groundwater discharge from the Wajid.[41] Flowing wells located to the east of Wadi Dawasir and towards the Rub' al Khali area used to discharge to the surface.[42] However, as the groundwater level have dropped significantly over the past 25-30 years due to heavy abstraction, most springs have dried up and the surface water/groundwater dynamics have changed. In the Wadi Dawasir area, for example, an inversion of flow occurred, with the result that water from the Wadi Dawasir bed now infiltrates into the drained Wajid Aquifer.

WATER QUALITY

In Saudi Arabia, Total Dissolved Solids (TDS) of groundwater in the Wadi Dawasir ranges between 700 and 1,000 mg/L, although it can be as high as 3,000 mg/L.[43] The higher values are found west of Wadi Dawasir where the water level lies at 90-100 m bgl. In the confined areas towards the east (e.g. Sulayyil), water quality improves and TDS can be as low as 450 mg/L.[44] In Yemen, the average TDS calculated from 60 representative samples from the Sa'dah area was found to be 740 mg/L in 2004.[45] This represents an increase over average values measured in 1983 and 1992 of 124 mg/L and 67 mg/L respectively, and would signify a gradual increase in groundwater salinity over the years.

EXPLOITABILITY

Both depth to groundwater (approx. 100-150 m bgl) and water quality (≤1,000 mg/L TDS) are within the limits of the criteria selected for exploitability. Hence the depth to the top of the aquifer system is the limiting factor for exploitability here. Information from the Middle East Geological Map Series (MEG-Maps)[46] suggests that the eastern margin of the outcrops and the adjacent subsurface areas are exploitable with modern technology, in the area delineated in the Overview Map. Based on this information, the total exploitable area has been calculated at around 157,000 km^2, of which around 120,000 km^2 is in Saudi Arabia and the remaining 37,000 km^2 in Yemen.

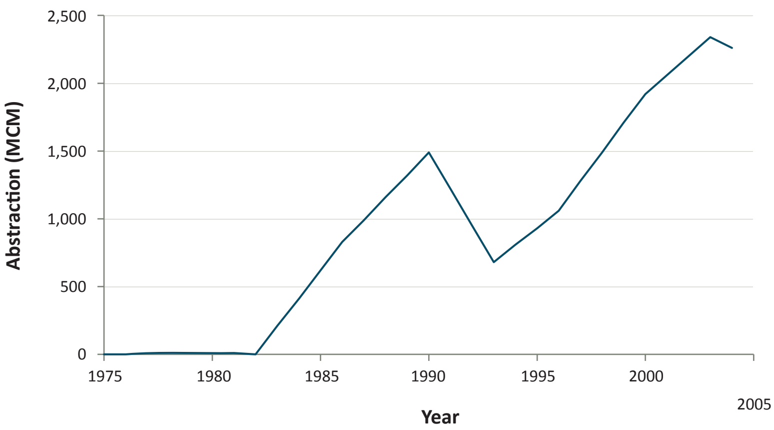
The Sarawat Mountains, Saudi Arabia, 2012. Source: Amru Essam.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

Exploitation of the Wajid in Saudi Arabia began with the development of Wadi Dawasir in 1965. In 1968, abstraction from the aquifer amounted to 11 MCM/yr, increasing gradually to 25 MCM/yr by 1977[47] and more rapidly throughout the 1980s and 1990s to reach 2,260 MCM/yr in 2004. In Yemen, exploitation of the aquifer system did not take off until 1978. Since then, there has been a sharp increase in groundwater abstraction.
The volume of groundwater abstracted in the Sa'dah Plain in 2002 was estimated at 98 MCM/yr.[48] The heaviest abstraction was and still is mainly in two areas: the Wadi Dawasir-Sulayyil area in Saudi Arabia and the Sa'dah-Baqim area in Yemen.

Figure 4. Historical abstraction from the Wajid Aquifer System in Saudi Arabia (1975-2004)



Source: Compiled by ESCWA-BGR based on Water Watch, 2006.

Wadi Dawasir-Sulayyil area (Saudi Arabia)

Water from the Wajid Aquifer System has mainly been used for agricultural development in the dry desert plains of the Wadi Dawasir-Sulayyil area, where large farms use centre-pivot irrigation systems to irrigate crops.[49] Throughout the 1980s and 1990s, wheat was the major crop but since then the agricultural pattern has changed. The volume of groundwater abstracted from the Wajid Aquifer increased steadily until 1990 when a significant drop occurred, most likely due to a reduction in wheat production. Wheat was mostly replaced by forage crops during the 1990s, and abstraction rose again (Figure 4) as fodder, unlike wheat, is harvested up to three times a year. Overall, abstraction increased from 210 MCM/yr in 1983 to 2,260 MCM/yr in 2004.[50] Cumulative abstraction for the period 1975-2004 was 29 BCM or 29 times what was predicted in 1984 (1,000 MCM).[51] The drop in abstraction in the early 1990s is most likely due to a decrease in global wheat prices, which was also reflected in other basins. Currently, wheat is the main winter crop and, together with fruit and vegetables (potatoes, tomatoes and watermelon), constitutes about 35% of the total annual crops. The remaining 65% is forage.[52]

When abstraction started, many of the wells in this area flowed and water levels were well above ground level. One of the bore-holes reportedly gushed with such a strong flow that water shot up about 30 m in the air and formed a large lake that attracted migratory birds to the area.[53] Many of these flowing wells discharged groundwater on the surface at a rate of up to 50 L/s.[54] Substantial abstraction has taken place since then, and as a result groundwater levels have dropped significantly. Judging from the normal practice of pipe-lowering as wells are deepened by farmers, it is estimated that the water level is dropping at an average rate of 3 m/yr and up to 6 m/yr in some areas. Currently the water level stands at around 150 m bgl.[55]

Sa'dah-Najran area (Saudi Arabia-Yemen)

Over the past 30 years, the use of the Wajid Sandstones and the overlying alluvium has been limited to the Sa'dah and Najran areas within the upper catchment of Wadi Najran. Water use in these areas has been limited to agricultural development and, to a much lesser extent, domestic water supply.

In the Najran area, most of the groundwater is pumped from the alluvium, although the deepening of wells over the years must have reached the Wajid in some areas. The Wadi Najran alluvial system is mainly linked to the Wajid Aquifer System through its recharge potential, although this potential may have been reduced over the years.

In Yemen, the Wajid Aquifer System is considered a poor to moderate aquifer rock, with the upper layers displaying a higher primary porosity.[56] Hence the response of the aquifer to increased abstraction is expected to change as water is pumped from deeper horizons with progressively less permeability, and storage is gradually depleted. In 1983, the average depth to groundwater was 20-40 m bgl and by 2002 it had

Table 3. Groundwater abstraction and changes in bore-hole characteristics in the Sa'dah Plain, Yemen

YEAR OF WELL INVENTORY	NO. OF BORE-HOLES IN WAJID	AVERAGE DEPTH TO WATER (m)	AVERAGE BORE-HOLE DEPTH (m)	AVERAGE DRAW-DOWN (m)	AVERAGE YIELD (L/s)	AVERAGE WELL ABSTRACTION (m^3/yr)	TOTAL ABSTRACTION (MCM)
1983	1,293	20-40	102	3	6.7	47,700	53
1992	2,285	60-80	174	4.5	3.3	34,300	80
2002	3,234	100	200	3.1	3	31,200	98

Source: Compiled by ESCWA-BGR based on Al Shami and Al-Dubby, 2004.

dropped to 100 m bgl. A decrease in the average well yield was observed during this period from 6.7 to 3.0 L/s and water levels are currently dropping at a rate of about 3 m/yr. Table 3 shows that abstraction almost doubled over the 20-year period between 1983 and 2002.

In the Sa'dah area, water abstracted from the Wajid is mostly consumed in the agricultural sector. Until the mid-1970s, agriculture in the catchment relied mainly on rainwater, spate flows and water harvesting. The cultivated lands were scattered along the wadi beds and in plain areas. Over the years, the use of groundwater for irrigation increased in the Sa'dah-Baqim area, giving farmers the flexibility to grow different crops throughout the year. As a result, pump irrigation spread widely in the area, with groundwater supplying 92% (74 MCM) of total requirements in 1992 and 97% (95 MCM) in 2002.[57] Domestic demand has increased progressively as the population in the Sa'dah area grew from 45,000 in 1975 to 53,000 in 1983 and 230,000 inhabitants in 2002. On the basis of an average daily consumption of 35-40 L/cap./d, it was estimated that the domestic sector consumed an annual amount of about 3 MCM in 2004.[58]

GROUNDWATER QUALITY ISSUES

National data from Yemen shows that groundwater remains suitable for drinking purposes in the Sa'dah Plain.[59] There are, however, two threats to groundwater quality: increased salinity and pollution. Salinity levels may rise as a result of the leaching of salts from irrigated fields and percolation through thin soils into the Upper Wajid Formation unit (agricultural return flows). Other sources of salinization include the overlying and/or outcropping sediments/formations such as the Akbara Shale and Amran Limestone. Irrigation return flow is also a potential source of pollution because of the continued percolation of pesticides and nutrients from fertilizers, domestic and industrial waste from petrol stations, etc.

Further east in the Wadi Dawasir-Sulayyil and Sharurah-Al Abr areas, groundwater salinity may increase due to the effect of evaporite

Vineyards in the area of Najran, Saudi Arabia, 2011. Source: Charles Roffey.

deposits (Hith Anhydrite deposits of the Arab Formation in Saudi Arabia and Ramlat es Sab'atayn Formation in Yemen), which contain highly mineralized water; and the Wasia-Biyadh Formations that contain groundwater of variable salinity levels.

Groundwater in the Wajid Sandstones may contain significant amounts of radionuclides of natural origin, such as radon (Rn), which are potentially hazardous to human health.[60] This natural source of contamination constitutes a potential risk to water quality and is a major challenge to groundwater management due to its unpredictability.

SUSTAINABILITY ISSUES

The current heavy abstraction of groundwater reserves is leading to the rapid depletion of groundwater reserves in the aquifer system and it is only a matter of time before the proven reserve is exhausted. Furthermore, it is difficult to predict the lifetime of the aquifer because of significant discrepancies in the estimated reserves. Nevertheless, a number of studies have already predicted that the aquifer will soon be economically exhausted in certain areas. For the unconfined part, the Sa'dah Plain may be most threatened. Table 4 presents estimates for the exhaustion of the aquifer system in this area, which shows that the predicted exhaustion date is progressively revised downward as abstraction progresses. Assessments indicate that it is a matter of 10 to 20 years before this aquifer is locally completely exhausted.

For the confined part, the Wadi Dawasir-Sulayyil area may be the most threatened. The results of early groundwater modelling indicated that the prevailing abstraction rates could be sustained only until 2011, beyond which the drop in groundwater level and water hydrostatic pressure was expected to become critical.[61] This would suggest that the Wajid is already in a critical condition in this area due to heavy pumping. If the discrepancy over the recharge rate is also taken into account, water level could be even lower. However, no data was available to verify the current status.

Table 4. Projected dates for the economic exhaustion of the Wajid Aquifer System in the Sa'dah Plain

YEAR OF STUDY	ESTIMATED EXHAUSTION (yr)	COMMENTS	SOURCE
1999	2032	Based on 1994 data.	Al-Sakkaf et al., 1999.
2002	2030	Based on 2002 data.	Techniplan, 2002 cited in Al Shami and Al-Dubby, 2004.
2009	2024	-	WikiADAPT, 2009.

Source: Compiled by ESCWA-BGR.

BOX 1

The Wadi Najran Basin

INTRODUCTION

The Wadi Najran Basin comprises the main Wadi Najran with its headwaters in the Yemen Highlands, and two smaller wadis (Habaunah and Idimah) that originate in the Asir Mountains in Saudi Arabia. The basin, as delineated in this Inventory (Figure 5), covers an area of 33,500 km^2, of which about 28,500 km^2 is in Saudi Arabia and 5,000 km^2 in Yemen.

SEDIMENTOLOGICAL PROPERTIES

The ground elevation in the basin ranges from 1,280 m to 2,900 m.[62] The wadi valleys are mainly cut into the Basement and, to a lesser extent, into the Wajid Sandstones.[63] Since probably the Late Pliocene-Early Pleistocene time, the wadis have carried the sediments from these rocks and deposited them around the edge of the Rub' al Khali Basin to form a large alluvial fan.[64] The valley depressions are filled with a thick gravel accumulation (approx. 30 m thick) covered by silty material that usually does not exceed 4 m in thickness.[65]

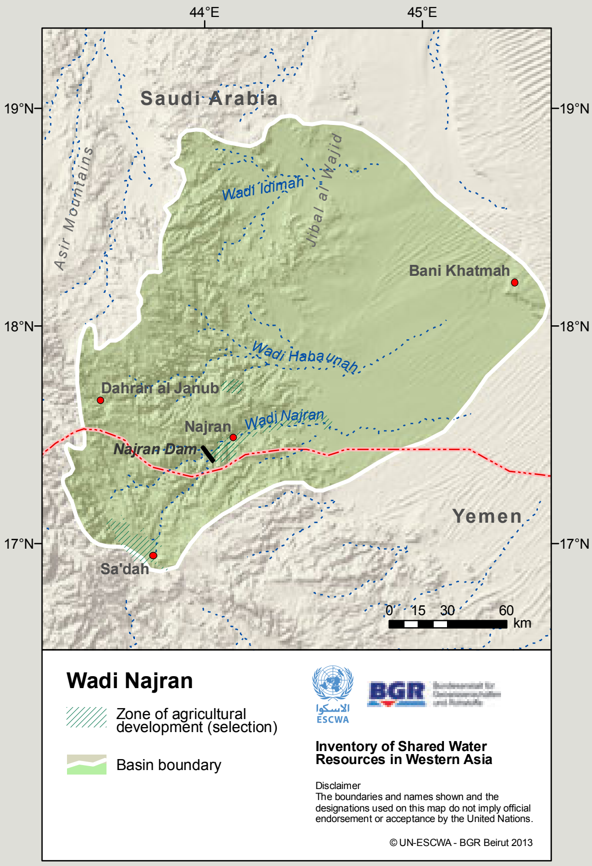
HYDROLOGICAL FEATURES

The three wadis in the basin join in an old drainage system that once extended north-eastward to connect with the Wadi Dawasir system during older wetter periods, probably between 17,000 and 36,000 years ago.[66] Today, the average annual rainfall ranges from 80 to 500 mm.[67] Storms, which can occur year-round and particularly following summer monsoon rains, usually generate high-intensity rainfall with short-lived associated runoff.[68] The Wadi Najran Basin is the second-largest runoff-producing area in the inland drainage system after Wadi Dawasir.[69] The annual runoff in the wadis has been assessed at 3.17 m^3/s in Wadi Najran, 0.95 m^3/s in Wadi Habaunah and 0.16 m^3/s in Wadi Idimah.[70]

HYDROGEOLOGICAL CHARACTERISTICS

The Wadi Najran Basin is a closed shallow basin, in which groundwater potential depends mainly on the unusually high transmissivity of the alluvial deposits in the basin.[71] Infiltration rates were found to be as high as 95% of total runoff over a 50 km reach.[72] Annual recharge in the wadi system is approximately 100 MCM.[73] Estimates show that 33,350 MCM was stored in this basin in the early 1980s.[74]

Figure 5. The Wadi Najran Basin



Source: Compiled by ESCWA-BGR based on Van der Gun, 1985; Haidar, 1984.

GROUNDWATER ABSTRACTION

In Yemen, many of the wells abstracting water from the Wajid Sandstones were actually drawing water from the overlying alluvial aquifer before depletion of this upper aquifer in several areas prompted the deepening of wells to reach the sandstones.[75] However, no abstraction data could be found during the course of this study. In Saudi Arabia, a total of 2,086 tube wells provided irrigation water to 3,145 farms in the Wadi Najran alluvial system in 1980, with a total annual abstraction of 255 MCM.[76] Most of these wells withdrew water from the alluvial deposits but some may have reached the bedrock, especially in the foothill zones where fractured rocks can be found at shallow depths. The total abstraction may have increased to about 475 MCM/yr since there were plans in 1980 to increase the number of tube wells to about 3,900.[77] However, in 2003, only about 250 MCM/yr was being abstracted,[78] which would suggest that actual abstraction may have been different than what had been planned (Figure 6). The alluvial aquifer system is also used for domestic purposes, mainly by the population of the city of Najran, which had an estimated population of around 265,000 people in 2004.[79] Already in the 1980s, the Wadi Najran alluvial aquifer system experienced a groundwater deficit of 150 MCM, which was expected to increase to 375 MCM in the following years.[80]

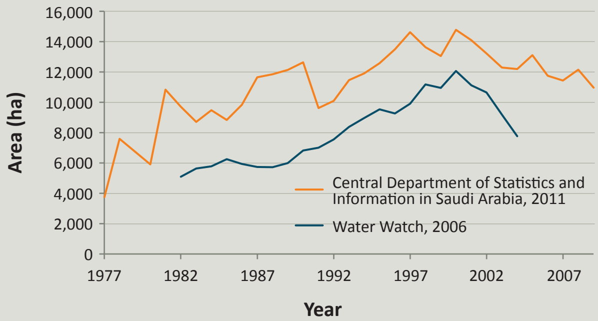
SUSTAINABILITY AND MANAGEMENT ASPECTS

A 73 m-high dam with a storage capacity of 86 MCM was constructed in 1980 in a gorge where Wadi Najran cuts across the crystalline rocks of the basement. The dam was built to regulate water flow and ensure the supply of freshwater for irrigation throughout the year, and to recharge the alluvial aquifer.[81] Since this aquifer is usually in hydraulic connectivity with the lower aquifers (Wajid Sandstones and fractured basement), some of this recharge may eventually seep to the lower aquifers, particularly in areas where runoff occurs in fractured bedrock with thin alluvial cover.

Figure 6. Historical abstraction in Najran in Saudi Arabia (1977-2004)

Source: Compiled by ESCWA BGR based on Water Watch, 2006.
Note: The Water Watch, 2006 study does not explain whether these values are for Najran Province or only for Wadi Najran. However, as the total abstraction of 25 MCM was already reported in 1980 (Haidar, 1984 based on data from the Ministry of Agriculture and Water in Saudi Arabia, 1984), it is likely that values are for Wadi Najran.

Figure 7. Total cropped area in Najran Province in Saudi Arabia (1977-2009)



Source: Compiled by ESCWA-BGR.

Flax and vineyards in the area of Najran, Saudi Arabia, 2011. Source: Charles Roffey.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the Wajid Aquifer System which is shared between Saudi Arabia and Yemen.

COOPERATION

No information was available regarding cooperation between the riparian countries on the aquifer system. Yemen has underlined the need and its willingness to cooperate over the management of shared groundwater resources in the aquifer system, particularly with regards to reducing the risk of aquifer depletion.[82]

OUTLOOK

Western part (Najran-Sa'dah area): Further investigation would contribute to delineating and protecting recharge areas, and to estimating how much groundwater flows in the Wajid Sandstones across the political border.

Eastern part (Sharurah-Al Abr area): The availability of more field data would improve the knowledge base on the aquifer system. In particular, future work would need to clarify if and how the hydraulic properties of the Upper and Lower Wajid Sandstone units are different, how they are related, and how they might affect each other in response to abstraction in the future.

The region of Asir, Saudi Arabia, 2006. Source: Walter Callens.

Notes

1. Beydoun et al., 1998.
2. Ministry of Agriculture and Water in Saudi Arabia, 1984; Edgell, 1997.
3. Schubert et al., 2011.
4. Van der Gun and Ahmed, 1995.
5. National Water Resources Authority in Yemen, 2012.
6. Central Department of Statistics and Information in Saudi Arabia, 2011.
7. National Water Resources Authority in Yemen, 2012.
8. Central Department of Statistics and Information in Saudi Arabia, 2011.
9. Kruck and Thiele, 1983.
10. Ministry of Agriculture and Water in Saudi Arabia, 1984; Alsharhan et al., 1991; Edgell, 1997; Beydoun et al., 1998; and PSRCE, 2007.
11. Van der Gun and Ahmed, 1995; Beydoun et al., 1998.
12. Beydoun et al., 1998.
13. Edgell, 1997.
14. Ibid.
15. Dabbagh and Rogers cited in Alsharhan et al., 1991.
16. Alsharhan et al., 1991; Al Shami and Al-Dubby, 2004; Beydoun et al., 1998.
17. GTZ/DCo 2010, cited in Al-Ajmi et al., 2011.
18. Al Shami and Al-Dubby, 2004.
19. National Water Resources Authority in Yemen, 2012.
20. Powers et al., 1966.
21. Edgell, 1997.
22. Ibid.
23. Van der Gun, 1985.
24. Ibid.
25. National Water Resources Authority in Yemen, 2012.
26. Ministry of Agriculture and Water in Saudi Arabia, 1984.
27. Edgell, 1997.
28. Job et al. cited in BGR et al., 1999.
29. PSRCE, 2007.
30. High Water Council cited in Al Shami and Al-Dubby, 2004.
31. Assuming that recharge occurs mainly in the outcrop areas (2,250 km^2 in Yemen; 26,000 km^2 in Saudi Arabia).
32. Yominco/TNO, 1983 cited in Al Shami and Al-Dubby, 2004.
33. DHV, 1991 cited in Al Shami and Al-Dubby, 2004.
34. Ministry of Agriculture and Water in Saudi Arabia, 1984.
35. PSRCE, 2007.
36. Ministry of Agriculture and Water in Saudi Arabia, 1984.
37. Ibid.
38. Ibid; Al Sheikh, 2000.
39. Dreilbatt, 1982.
40. Othman et al., 1986.
41. UN-ESCWA, 1981.
42. Ministry of Agriculture and Water in Saudi Arabia, 1984.
43. Othman et al., 1986.
44. Edgell, 1997.
45. Al Shami and Al-Dubby, 2004.
46. Christian, 2000.
47. Ministry of Agriculture and Water in Saudi Arabia, 1984.
48. Al Shami and Al-Dubby, 2004.
49. See PSRCE, 2007, p. 139.
50. Water Watch, 2006.
51. Ministry of Agriculture and Water in Saudi Arabia, 1984.
52. Bashour, 2009.
53. Ibid.
54. Ministry of Agriculture and Water in Saudi Arabia, 1984.
55. Bashour, 2009.
56. HWC, 1992 cited in Al Shami and Al-Dubby, 2004.
57. Al Shami and Al-Dubby, 2004.
58. Ibid.
59. National Water Resources Authority in Yemen, 2011b.
60. Al-Saud et al., 2011.
61. Ministry of Agriculture and Water in Saudi Arabia, 1984.
62. Haidar, 1984.
63. Jado and Zotl, 1978.
64. Edgell, 2006.
65. Ibid.
66. Ibid.
67. Haidar, 1984.
68. Vincent, 2008.
69. Ministry of Agriculture and Water in Saudi Arabia, 1984.
70. Ibid.; Vincent, 2008.
71. Haidar, 1984.
72. Bennie and Partner, 1975 cited in Abdulrazzak, 1995.
73. Ibid., cited in Haidar, 1984.
74. Ministry of Agriculture and Water in Saudi Arabia, 1984.
75. Van der Gun, 1985.
76. Haidar, 1984.
77. Ibid.
78. Water Watch, 2006
79. Central Department of Statistics and Information in Saudi Arabia, 2004.
80. Haidar, 1984.
81. Ibid.
82. National Water Resources Authority in Yemen, 2011a.

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