

Ministry of Water & Irrigation

## Water Year Book

## METEOROLOGY WATER QUALITY

SPRING SURFACE WATER GROUND WATER

## Hydrological Year 2016-2017

# WATER YEAR BOOK 2016/2017



MINISTRY OF WATER AND IRRIGATION, JORDAN



"Our Water situation forms a strategic challenge that cannot be ignored." His Majesty Abdullah II bin Al-Hussein



"I assure you that the young people of my generation do not lack the will to take action. On the contrary, they are the most aware of the challenges facing their homelands." **His Royal Highness Hussein bin Abdullah** 

## Water Yearbook

## Hydrological year 2016-2017

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#### Foreword

It is highly evident and well known that water resources in Jordan are very scarce. All previous strategic studies and official documents have identified that scarcity of water resources is one of the major barriers facing sustainable development in Jordan that will be further magnified by the impacts of climate change, droughts and other socioeconomic circumstances.

The availability of information about water resources is one of the most important determinants when dealing with the situation and the development of strategies, policies and plans. The information availability contributes to making the right decisions and helps all concerned sectors to understand and accept the decisions that will have an impact on the sectors development and growth.

Consequently, in the face of the water scarcity challenges and to achieve our goal of the successful integration of Jordan's water resources development and management



H.E. Eng. Munir Oweis Minister of Water and Irrigation

practices, the Ministry of Water and Irrigation has been active in issuing reports and studies that improve the understanding of our existing water resources and provide information to all stakeholders.

Based on the above, the Ministry of Water and Irrigation decided to issue the Water Year Book 2016-2017, which illustrates the reality and the status of the surface and groundwater resources, both quantitatively and qualitatively. The availability of information on water resources is one of the determinants for dealing with threats, and formulation of strategies, policies and plans. This is particularly important in identifying options, priorities and alternatives for water resources development projects.

This book is the result of the efforts of the working group from the Water Sector with assistance from the Jordanian-German Technical Cooperation implemented by the Federal Institute for Geosciences and Natural Resources. I am thankful to all of them for putting great efforts to enhance the availability of information about Jordanian water resources.

We hope that the published information will be of assistance to all stakeholders in the water sector, public and private sectors and the public that may have an interest in the water sector in addition to the funding and donor agencies. The Ministry of Water and Irrigation is committed to make available such information in the future on a periodic basis.

H.E. Eng. Munir Oweis

Minister of Water and Irrigation

#### Foreword

The water scarcity is a major challenge for the sustainable development of the Hashemite Kingdom of Jordan. The high population growth, either naturally or due to the influx of refugees, in addition to the agricultural and industrial development are increasing the water demand significantly and put more and more pressure on the limited water resources. Another factor affecting the water resources of Jordan is the climate change, which potentially have a drastic impact on the already scares water resources.

The Ministry of Water and Irrigation is mandated in accordance with its national water strategy (2016-2025) and the policies of groundwater sustainability to provide studies and information on surface and groundwater resources. Therefore, the Ministry of Water and Irrigation developed and is continuously improving the nation-wide monitoring network



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to collect quantitative and qualitative data on the water resources in the country.

Accurate and easily accessible information on the development of the water will create awareness of the limited resources and foster its sustainable management. Moreover, the implementation of projects included in the capital investment plan for the water sector would not be optimal without reference to studies, information and data on the availability of current, alternative and future water resources.

The "Water Year Book" serves this purpose and shows actual water resources monitoring data through maps, figures and trend lines including water quantity and quality. The long-term evaluation as well as the development of the different hydrological and meteorological parameters in the hydrological year (1.10.2016 – 30.09.2017) are presented.

This book is the result of the cooperation between the Ministry of Water and Irrigation and its partners in the Water Authority, Laboratories & Quality Affairs. It was developed with support of the German Federal Institute for Geosciences and Natural Resources, which has been providing assistance and technical support to the water sector, especially in relation to water resources studies over the last few decades.

The Ministry of Water and Irrigation hopes that this book will be beneficial to the Jordanian citizens, the researchers and the decision-makers. We believe that it will show everyone to the importance of water resources, their reality and expected future. The Ministry of Water and Irrigation will continue to publish this book periodically and by all available means.

H.E. Eng. Ali Subah Secretary General - Ministry of Water and Irrigation

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## ABBREVIATIONS

BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
	(Federal Institute for Geosciences and Natural Resources)
DWL	dynamic water level
GPS	Global Positioning System
hr	hour
km	kilometer
m	meter
masl	meter above sea level
mbgl	meter below ground level
MCM	million cubic meters
mm	millimeter
MWI	Ministry of Water and Irrigation
R.0	Reverse Osmosis
SWL	static water level
WAJ	Water Authority of Jordan
WWTP	Wastewater treatment plant
yr	year

#### Hydrological exceptions



## Hydrological exceptions

This chapter summarizes the most important findings of the evaluation presented in this Water Year Book. Unusual or critical long-term developments as well as particularities of the last year are identified and described.

The details and the underlying information of these findings can be found in the following chapters that represent and evaluate the different hydrological and meteorological parameters.



#### Hydrological Exceptions

The rainy season in Jordan begins in October and ends in May with the maximum amount of precipitation usually in December, January and February. In some areas, already in May no precipitation is recorded. The **precipitation** of the year 2016-2017 was unusual high in December followed by a lower average rainfall in January, February and March. Additionally, in the dryer areas of Jordan towards the East and the South a relatively high precipitation was observed in April 2017.

The statistical analysis of the yearly precipitation data does not show any significant negative or positive trend. Only for the month of March within the Mediterranean climate zone of the highlands, a clear negative trend could be identified, since the average rainfall in this month decreases by 1-2 mm each year.

All stations show a similar yearly pattern of the **temperature** with the lowest values measured in December, January and partially February, and the highest temperatures in July and August. Apart from the southern station in Aqaba, in all other representative stations unusual high temperatures were recorded in November and at the end of June and the beginning of July, being above the 90% quantile. In most stations, unusual low temperatures were recorded in January and February.

The yearly **evaporation** varies in Jordan between 5000 mm in Aqaba, 3000 mm in Wadi Araba and the eastern desert and 2000 mm in the central and northern highlands. In 2016/17 the evaporation was unusual high in the North and low in the South and center-south.

Jordan has just two **rivers** with continuous flow during the whole year; these perennial rivers are the Jordan and the Yarmouk. All other water courses are dry during most time of the year (ephemeral) and have runoff only during times of heavy rain in form of flash floods. Exceptions are the wadis that transport the discharge of waste water treatment plants, as for example the Wadi Dhuleil below Al-Samra treatment plant, which shows a continuous and yearly increasing runoff.

The spring discharge long-term trend generally shows a continuous reduction over the last decades. An exception are a few springs that show an increase in discharge rates. Since all of these springs are located in or close to an urban area, the most probably explanation for the unusual behavior is the groundwater recharge from leaking water supply networks. The springs originating from limestone aquifers show a clear seasonal variation of the discharge, with an increase of discharge towards the middle of the rainy season, as a delayed response to the occurring recharge, and the lowest flow at the end of the dry season. On the other hand, the springs of the deep sandstone aquifers have no significant seasonal discharge variation. The discharge measurements in the hydrological year 2016/2017 were mostly in the lower range of the historical values, ad exception of the mentioned springs in the urban areas.

The **groundwater levels** in the Basalt and A7/B2 aquifers are declining continuously by up to several meters a year as a result of the over abstraction. In northern Jordan, groundwater levels dropped sharply in many monitoring wells during the last few years as a result of the high abstraction to cover the continuously increasing water demand.



The groundwater level in the other aquifers is stable or decreasing only with minor yearly effects. Aquifers that are not intensively used because of their low water quality, low productivity or high depth, like A1-A6, B4/B5, Kurnub, Zarga and Ram, show water levels that are mostly stable. Only locally, where mayor groundwater exploitation exists the groundwater levels decline considerably. like B4/B5 in Jafer. Kurnub in Balga and Ram in the Disi area. Other aquifers have stabilized after a long period of drawdown, like the Alluvium in Jordan Valley, or recovered their groundwater levels like A1/A6 in Marka and Zarga. The reason therefore may be a stop of water abstraction because of decreasing water quality or augmented groundwater recharge, like in the case of Marka and Zarga from the leaking water supply network and sewage system.

Regarding the quality of the groundwater resources, this Yearbook shows an analysis of the parameters nitrate. electrical conductivity and heavy metals. The nitrate concentrations generally show a high variability within one aguifer. Only the Ram-Zarga aquifer has constantly low nitrate levels. Despite the high variability, a negative trend of the nitrate levels could be identified in almost all wellfield, i.e. the nitrate concentration seems decreasing over time. An exception are areas with high agricultural activities, such as B'aga or the southern part of AWSA well field near to Azraq. The electrical conductivity is stable in the selected well fields of the A7/B2 aquifer, while it is increasing slightly in all other aquifers. The only exception is the Ezgeig well field in the A1/A6 aguifer with a negative trend. The very high variation in the B4 aguifer, also in the same well field, make a trend difficult to identify. The concentration of metals in most of the groundwater resources of Jordan are very low, mostly below the quantification level. Only, in the Wadi Al-Arab Well field unusual levels of Nickel/Molybdenum could be found. The range of concentration for Nickel/Molybdenum is from 0.01 to 0.22 mg/L and 0.01 to 0.77 mg/L respectively. The use of the water from this source for drinking water purposes requires the already implemented treatment through blending or advanced technologies. Since there is a certain risk, that the elevated metal concentration origins from the geological unit overlaying the aquifer, it is highly recommended to assess the local hydrogeological features before planning new wells and consider the geological characteristics in the construction and cementing of the well.

The Jordan Valley Authority is monitoring the **discharge of the major dams** in Jordan. The discharge from the dams is used for irrigation, drinking water supply or artificial recharge. Over the last few years, the discharge off some important dams is decreasing, while most dams show a variable but stable effluent volume.

The overall amount of **treated water** has increased from the previous years, including waste water treatment, desalination and treatment for drinking water production.



## Chapter 1 - Topography and Geology

This chapter gives a short introduction into the general topography of Jordan, since the local climate as well as the characteristics of rivers, springs and aquifers depend strongly on the elevation and shape of the land surface.

Further, this chapter outlines the basic geology of Jordan as it is required for a better understanding of the evaluation of groundwater level and quality data presented in this Year Book.

## 1.1 Topography

The topography of Jordan shows extreme variations especially in the western side of the country where the mountain heights meet the Jordan Valley. Jordan has three main geographic regions: the Jordan Valley, the Mountains Heights Plateau and the Eastern Desert or Badia region (Figure 1-1).



Figure 1-1.Elevation and climatic zones in Jordan 1.1.1 The Jordan Valley

The Jordan Valley, which extends along the western part of the country, is part of the Great Rift Valley that starts in the southern part of Turkey, passes through Lebanon and Syria down to the Dead Sea and continues through the Red Sea until eastern Africa. This huge depression was formed because of the tectonic movement along the Dead Sea Transform Fault. Most of the terrains in the Jordan Valley situate below sea level and reach the lowest elevation on the surface of the Dead Sea at 422 meters below sea level. On the eastern slopes of the valley the elevation increases within a relatively short distance to more 1.1.2 The Mountains Heights Plateau

The highlands of Jordan extend within the Jordan Valley and the plains of the eastern desert. It is the region with the highest population density and most of the cities.

#### 1.1.3 The Eastern Desert or Badia Region

This region comprises around 75% of Jordan's total surface. It forms part of the North Arab Desert, which stretches into Syria, Iraq and Saudi Arabia.

than 700 meters above sea level, resulting in a high gradient and rough landscapes with cut through narrow canyons that drain the water from the highlands.

The elevation in the highlands varies from 600 meters to more than 1600 meters above sea level, with temperature and rainfall patterns varying accordingly.

The elevations in the Badia Region vary between sea level and 900 meters above sea level.

#### 1.2 Geology

Jordan enjoys varied and rich geological and geomorphological features.

The majority of the rocks in Jordan are sedimentary, but in the southern part igneous rocks are exposed over a big area. The igneous rocks, mainly granitic rocks, are the oldest formation found in Jordan with an age of more than 600 million years. Commonly they are called "the basement rocks" since they constitute the bottom of the geologic rock's sequence.

The sedimentary rocks mainly consist of carbonates and sand. They cover large areas of the norther, central and eastern parts of the country. In the thick sedimentary sequences, sandstone with different colors and levels of cementation alternates with carbonates, such as limestone, chalk and marl. The sedimentary rocks constitute the most important aquifers.

In the northeastern desert of Jordan, Basalt rocks overlay the sedimentary sequence.

Outflows of basalts from point sources cover large areas of the desert, forming the typical basaltic Harrat landscape.

Alluvium deposits and soils are considered as recent overburden found particularly in wadi courses, flat areas and some hill slopes. Only in the depression of the Jordan Valley and the Wadi Araba they can be found in high thickness up to a few kilometers.

The most important geological-structural feature of the region is the Dead Sea Rift Valley. The north –south trending rift valley was formed by a left-lateral strike-slip movement of more than 100 km of the Arabian plate in respect to the African plate. The sedimentary sequence of the Arabian plate was extensively affected by the formation of the rift valley, resulting in a general tilt towards the east of the strata in the eastern desert areas.





## Chapter 2 - Meteorology

The Ministry of Water and Irrigation collects meteorological data in several stations distributed over the entire country. Most of these stations are measuring the precipitation only; others register furthermore evaporation, air temperature, solar radiation, wind speed and direction. Map 2 annexed to this report gives an overview on the monitoring network operated by MWI.

To show the long-term trend of precipitation, temperature and evaporation as well as the yearly variations during the hydrological year (1.10.2016 - 30.09.2017) six stations with continuous historical data and located in the different climatic zones of Jordan have been selected.



#### 2.1 Introduction

Jordan has three very different climatic zones: the Jordan Valley, the Mountains Heights Plateau and the Eastern Desert or Badia region (Figure 1-1). The climate in the Jordan Valley is arid to semi-arid with a hot dry summer and a warm winter. The yearly average precipitation is very low with mostly less than 200 mm/yr. The northern and central parts of the Mountains Heights Plateau of Jordan are characterized by Mediterranean climate with a hot, dry summer, a cool, wet winter and two short transitional seasons. This climatic zone receives Jordan's highest amounts of precipitation, which fall during winter from October until May with the peak usually during December, January and February. Precipitation is mainly in the form of rainfall, with snowfall occurring once or twice a year. The temperature in the Eastern desert and Badia Region changes sharply between day and night, and between summer and winter: daytime summer temperatures can exceed 40°C, while winter nights can be very cold, dry and windy. Precipitation is minimal throughout the year, averaging less than 100 mm per year.



Figure 2-1. Location map of the meteorological stations



Jordan has around 155 meteorological stations. They are mainly located in the highlands, and in the areas with the highest precipitation. Towards the East the density of stations decreases, as the precipitation becomes rather minor.

Most of these stations register the rainfall only, while around 42 stations are collecting also temperature and evaporation data.

In 2016-2017 154 precipitation stations have been monitored; only one was inactive. Out of the 42 available climate stations, six were selected for this Year Book in order to show the long-term trend reflecting the situation in the different climate zones. The selection criteria were data availability, data continuity and data quality.



#### 2.2 Precipitation

Figure 2-2. Yearly precipitation distribution 2016/2017 The above figure shows the vearly precipitation distribution all over the country interpolated based on the yearly precipitation sum registered 153 in

stations. The North of Jordan has the highest amount of precipitation up to a maximum of 700 mm/yr. Towards the South along the highlands in the



Mediterranean climatic zone the precipitation is still significant with values around 300 mm/yr. Towards the East, the South, and the Jordan Valley the

precipitation decreases considerably to less than 100 mm/yr. The precipitation in the southeastern dessert is neglectable.

#### 2.2.1 Long term trends and seasonal variation

In the following for each of the six selected stations the long-term historical development and the seasonal variation in the hydrological vear 2016-2017 is represented. The first chart shows the monthly precipitation as well as the yearly precipitation sum. Additionally, the longterm trend of the yearly precipitation sum is presented<sup>1</sup>. The second chart presents the seasonal or monthly variation of the precipitation in the hydrological year 2016 /

2017 and compares it to historical data. Therefore, all available historical data is analyzed and the main statistical parameters (median and quantiles of 10%, 25%, 75% and



90%) are calculated for each month and plotted on the graph. The box plot of the statistical parameters allows evaluating easily the precipitation pattern in each month: the box within the 25% and 75% quantile shows the most common range of the monthly precipitation in which 50% of all historical data are. The line shows the range down to the 10% quantile and up to the 90% quantile; any value outside of this range, which covers 80 % of the historical data, can be identified as unusual monthly precipitation value. Further, the spacing between the different parts of the box indicate the degree of dispersion and skewness in the data. The precipitation values of the current hydrological year are presented in blue and can be compared to the historical data.

nonparametric Sen's method. Where no trend was found, the long-term median was calculated and plotted in the graph.



<sup>&</sup>lt;sup>1</sup> The nonparametric Mann-Kendall test was applied for identifying a statistically significant increasing or decreasing trend in the yearly precipitation sum. The slope of the linear trend was estimated with the



Samar Station is located in Northern Jordan in the area with high precipitation. The yearly precipitation can vary between less than 300 mm/yr (dry year) and up to 900 mm/yr (wet year).

The precipitation of 2016/ 2017 is slightly below the

long-term average. In the years 1987, 1991 and 2002 extra-ordinary high rainfall was registered. The years 1988, 1998, 2000 and 2013 were unusual dry, while no data is available for 1996, 2001, 2004 and 2014. The yearly precipitation does not show any statistical significant negative or positive trend. Only for the month of March, a clear negative trend could be identified: the average rainfall in this month decreases by -1.9 mm each year.

The chart of the monthly rainfall shows that the Northern rain in Jordan falls mostly in the months December, January, February and March, as well as to a minor degree in October. November and April. The rainfall

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of the hydrological year 2016 / 2017 concentrates mostly in December and partly in January, whereas the precipitation in the others months of the rainy season is neglectable and below the usual range.



Yearly precipitation at the Amman Airport station is 250 around mm/yr. Although the precipitation is lower than in Northern Jordan, long-term the behavior is very similar: in 2016/2017 nearly average rainfall was reached and

high precipitation registered in 1987, 1991, 2002. While 1986 and 1998 had a very low yearly precipitation. No long-term changes of the yearly precipitation could be identified. Except the monthly precipitation of March shows a negative trend of -0.9 mm/year.



The monthly chart shows that the rain falls usually from November until March. with higher amounts from December till February. In 2016/2017 the precipitation in December was above the usual range, while in the other months of

the rainy season the values were at the lower end of the regular range.



The third station within the Mediterranean climatic zone, the Rabba Station close to Karak, has а yearly precipitation of 300 mm average that varies between 150 and 500 mm/yr. In 2016/2017, almost average



rainfall was reached. Dry years were 1986, 1998 and 1999, wet years 1987 and 1991. There is no clear long-term trend of the yearly precipitation, whereas the average monthly rainfall of March shows a negative trend of -1.5 mm/year in the long term.



The monthly variation chart shows an identical pattern as the stations further north: unusual high precipitation in December and relatively low in the other months of the rainy season.



yearly precipitation at the AI Risheh station in Wadi Araba is never above 80 mm/yr. The average is 24 mm/yr. In the years 1999 and 2011 the precipitation is almost 0 mm. The 2016/2017 year was slightly above



average, but almost no rain during January, Febraury and March.



The yearly precipitation at the Aqaba station is very small with a median of 12 mm/yr. The highest yearly precipitation was recorded in 2016/2017. because of one heavy rain event,



#### Meteorology

with 46 mm on October 28. In the other months, there is hardly any precipitation at all.





The H5 station in the eastern desert shows а low precipitayearly tion with generally less than 100 mm. Frequently, the precipitation is less 50 than mm/yr. Only in 1988 and 2015 higher values were recorded. In 2016/2017

around 100 mm, above average were reached. No long-term trend in the yearly or monthly

values was identified. The chart of monthly rainfall shows relatively high precipitation in December, March and April, while no or very few rain in November, January and February was recorded.





### 2.3 Temperature

The analysis of the temperature in the hydrological year 2016/2017 is based on the data of the six selected climate stations. The recorded temperature data was validated, statistically analyzed and plotted on the following charts.

The temperature chart shows multiple The information. historical data is represented as long-term average as well as the range of usual fluctuation. Here we have the range between the 25% quantile and the 75% quantile; within this range 50% historical temperature of all measurements are located. Additionally, the 10% quantile and 90% quantile is shown in order to identify unusual values; current values that are not in the range from the 10% to the 90 % quantile may be considered as outlier. Considering the historical data, the present temperature data can be evaluated. The temperature measured in the hydrological year 2016-2017 in comparison to the historical data is shown as an orange line above the



historical data. Additionally, the long-term trend of the average yearly temperature is presented<sup>2</sup>.

Samar is station located in Northern Jordan. Here. unusual high temperatures were recorded in November. April. May, June and July, frequently being 90% the above quantile. For January, no data is available. The statistical analysis



shows a significant positive trend of +0.04°C/year in the long term average yearly temperature.

nonparametric Sen's method. Where no trend was found, the long-term average was calculated and plotted on the chart.



<sup>&</sup>lt;sup>2</sup> The nonparametric Mann-Kendall test was applied for identifying a statistically significant increasing or decreasing trend in the average yearly temperature. The slope of the linear trend was estimated with the



At the Amman Airport station, unusual high values were recorded from April until September with temperatures frequently being well above the 90% Quantile. However, the temperatures in the winter months Januarv and February were below

average near the 10% Quantile. The trend of the average yearly temperature is significant positive with +0.06°C/year.

Close to Karak at the Rabba Station, besides the high temperature outliers in June and July, exceptional low temperature was recorded in November, May and August, being below the 10% quantile. In most of the winter months, the



temperature was below average. The long-term average yearly temperature trend is negative with -0.08°C/year, contrary to the pattern found in the northern and central highlands.



In Wadi Araba at the Risheh station, AI unusual high temperatures were measured at the end of February and in July, being above the quantile. 90% In October, December and January the temperature was below the average.

No statistically significant trend was found.

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The overall temperature at the Aqaba station appears to be very unusual, showing extreme variations in both directions. Warm winter months, followed by cool summer months, being well below the 10% quantile. No data is

available from October until December 2016.

The H5 station in the eastern desert has gaps some data between April and June. January 2017 is an unusual warm winter month with values well above the 90% quantile, whereas December and February are rather cold months, with daily temperatures below the long term average.



### 2.4 Evaporation

Evaporation is the transformation of water in liquid form to vapor. The water from the surface of oceans, dams, lakes or stored in moist soil turns into vapor, then rises up and can form clouds. The evaporation rate depends on the solar radiation, air temperature, air humidity, wind. The evaporation is measured with water filled pans and is an important factor to estimate the irrigation water needs and the shares of rainfall that will return to the atmosphere and will infiltrate into the soil and recharge the groundwater.

The 42 climate stations located in Jordan also measure evaporation. For the six representative meteorological stations the yearly and monthly long-term evaporation



as well as the long-term trend<sup>3</sup> are shown in the first type of graph. The second graph shows the monthly variations throughout the hydrological year 2016/2017 and compares it with a descriptive statistical analysis of the long-term variations for all measured values in a specific month. It shows the range (25% - 75% quantile, box) in which 50% of all measurements are, as



well as the range down to the 10% quantile and the 90% quantile (line).



The yearly evaporation in the Samar station is high very with 2000-4000 mm. It shows an increasing trend, with a significant rise in 2001 by 600 more than mm. In the following years, evaporation the was continuously

#### higher.

In 2016/2017 the evaporation was around 3600 mm. The monthly variation graph shows that the evaporation was unusual high throughout the year, with high records in almost all the months.



<sup>&</sup>lt;sup>3</sup> The nonparametric Mann-Kendall test was applied for identifying a statistically significant increasing or decreasing trend in the average yearly evaporation. The slope of the linear trend was estimated with the

nonparametric Sen's method. Where no trend was found, the long-term median was calculated and plotted on the chart.





Amman In the Airport station, the yearly evaporation appears relatively constant around 2000 mm with a slightly decreasing trend. Overall, the yearly evaporation is the lowest here in comparison to the other stations,

most probably of because the relatively low temperatures in Amman. No data has been recorded since June 2017; therefore. the unnatural drop down to 1000 mm. During the recorded time in



2016/17, the monthly temperature values were mainly within the normal range, although at the lower end of the regular range during the winter months.



In the Rabba Station close to Karak, the yearly evaporation is rather high with 2800 mm and it appeared to be slightly increasing until 2007. In 2014 the yearly evaporation dropped significantly from 2700 down to 1300 mm and did not increase significantly since.

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The monthly evaporation in the Rabba station is exceptionally low during the whole year, mainly below the 10% quantile.





The yearly evaporation at AI the Risheh station in Wadi Araba was increasing up to 4500 mm in 2003 followed by a slight decrease to around 4000 mm a year. In 2014 and 2015 а significant drop occurred, caused

by big data gaps. In 2016/17 the evaporation stays with 3900 mm just below the overall median. The monthly variation chart shows evaporation values within average range till followed March, by high and low outliners. From



April to June and in September the measurements are just below average while in August they are rather high.





The Aqaba station has the highest recorded evaporation with partially more than 5000 mm/year. In 2006, and 2013 unusual low values were calculated because of big gaps in the data time series. For 2012 and 2013 no

data is available at all. The negative trend is most probably caused by the data gaps in these years, too. In 2016/2017, a regular yearly amount of 4400 mm was recorded.

The monthly variation was very In irregular December, February, March and August below the historical range and in January above. No data was registered in May.





#### Meteorology



The H5 station not have does continues data. Theses years with a gap in data appear to have a very low evaporation, which is not reflecting the actual situation. In without yeas gaps, the yearly evaporation is

In 2016/2017 nearly average conditions were reached. Only in January 2016 and in June 2017 the monthly evaporation was below the long term usual range.





## Chapter 3 - Rivers and Wadis

Jordan has 15 surface water basins including internationally shared basins. The main rivers are the Yarmouk and the Jordan River, which are the only watercourses in Jordan with perennial flow. All other watercourses, the wadis are characterized by seasonal flow, mostly in the form of flash floods.

Many runoff-measuring stations are installed in the watercourses in Jordan in order to record the base flow and flood flow during rainy season. Map 2 gives an overview on the water resources monitoring network. Six stations were selected in order to show the long-term trend as well as the seasonal variations of runoff in the wadis during the hydrological year (1.10.2016 - 30.09.2017).





#### 3.1 Introduction

Renewable freshwater resources in Jordan originate in precipitation over its territories and superficial and subsurface inflows from the northern and eastern neighboring countries. Surface water resources in Jordan vary considerably from year to year depending on the amounts of precipitation and the flow from the international watercourses. Jordan has 15 surface water basins including internationally shared basins (see figure below).

Amman Zarqa Basin is one of the most important surface water basins since it

contains the most densely populated area in Jordan, comprising more than 60% of the country's population and 80% of its industries in addition to many agricultural areas.

Other important surface water basins are the internationally shared watersheds of the Yarmouk and Jordan River, which are the only watercourses in Jordan with perennial flow. Further, both constitute essential resources for the drinking water supply and the irrigated agriculture.



Figure 3-1. Surface Water Basins

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#### **Rivers and Wadis**

Surface water stations are measuring the discharge of the major wadis and rivers. In some cases, the runoff will run into the Jordan Valley, the Yarmouk river or it will be captured in a dam, located in the wadi. Jordan has 57 surface water stations, but only 36 of them are still classified as active, according to the Waster Information

System of the MWI. Six stations were selected in order to show the long-term trend as well as the seasonal variations of runoff in the wadis during the hydrological year (1.10.2016 – 30.09.2017). Runoff varies strongly throughout the county. In some stations no runoff was measured during the entire year.



Figure 3-2. Overview of active run off stations.





## 3.2 Long term trends and seasonal variation of the runoff

Wadi Shalala station measuring the runoff surface flowing into Yarmouk river, just before the Wehdeh Dam. The flow varies strongly between 11 m³/sec to 0, depending on single rainfall events. The average yearly volume runoff 0.2 MCM reaches

only, although in with vears high rainfall like 2002 or 2004 it can go up to 2 MCM. The monthly chart shows that the flash floods occur mainly between December and February. The highest amounts are recorded usually in February, although



for 2016/ 2017 only in December and January runoff was registered.



The runoff measured at Wadi Dana station will flow into the Jordan Valley. The main source is rainfall, as the area is not highly irrigated and return flow is probably neglectable. In some years, no runoff is recorded at all. Almost no base flow is recorded, the flow



is characterized by short flood events. The yearly runoff volume has a very low average of 0.01 MCM, but can reach 1.0 MCM in years with frequent flash floods like in 2013. During the hydrological year 2016/2017 no runoff was measured.



which is not uncommon for Wadi Dana. The runoff events occur generally in October, January and February.



Wadi Ruweished in the very East of Jordan shows also strong discharge fluctuations between 14 m<sup>3</sup>/sec and 0. In the years 2002, 2005-2009 and 2010-2012 no runoff was registered at all.

In the hydrological year 2016/2017, only in March runoff was recorded, which was well above the 90% quantile and therefore unusual high for the area. It is not uncommon that there is only one flash flood event and no further runoff throughout the year.







The runoff measured in Wadi Elkarak is running into the Jordan Valley and is highly depending on the precipitation. The discharge can be above 25 m<sup>3</sup>/sec, but is mainly below 4 m<sup>3</sup>/sec. The yearly runoff volume discharge appears to be decreasing since

2014, what may be caused by gaps in the data. Nevertheless, no statistically significant trend could be identified. 2016/2017. the runoff in November and December is normal, whereas the measurement in February is slightly below average and



in all other months no runoff occurred.

In the Wadi Rajil station the runoff seems to be increasing since 2015 from normally around



0-2 MCM/year to 12 MCM/year. The precipitation in the last year was good in the area and influenced the surface runoff. In previous years, the gaps in data records makes an analysis impossible.

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### **Rivers and Wadis**

In the hydrological year 2016/2017, the runoff was well above normal during December and March, even above the 90% quantile. The variations in Wadi Rajil are very high during the rainy but season the average is below 0.5



MCM and 0 in the dry season.



Wadi Dhuleil, In which enters the King Talal Dam, the surface runoff is increasing, with a trend of +5 MCM/yr. This is most probably the result of the increasing discharge of treated wastewater from the Al-Samra treatment plant, which was continuously extend

during the last years. Last year a significant drop can be observed, which most probably does not reflect a decreasing flow but is due to technical issues in the gauge station. Also, in the

years 2002, 2004 and 2006-2007 no data was recorded.

The monthly chart for 2016/2017 shows high runoff above the 90% quantile from October until December.

Afterwards, almost no further runoff was recorded probably because a technical





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# Chapter 4 - Springs

Jordan has around 861 springs originating from different aquifers and a wide range of discharge behaviors.

In this chapter the long-term trend of the discharge as well as the seasonal variations in the hydrological year (1.10.2016 - 30.09.2017) are presented for selected springs of each aquifer. Further, the flow pattern of the main springs used for drinking water supply is presented.



## 4.1 Introduction

Jordan has 861 springs, which are mainly located in the highlands. They are originating from the Alluvium, B4, A7/B2, A4, A1/2 and Kurnub aquifer. 478 springs have a perennial discharge, 16 springs show a seasonal dry behavior and 130 springs have dried out over the last years



Figure 4-1. Overview of all springs

Out of the 861 springs, 520 springs have been monitored in 2016/2017. The monitoring frequency has decreased over the years from mostly monthly measurements to to now 1 4 measurements during the hydrological year 2016/17. 237 springs have and unknown status, which means that they have not been monitored in the last two year, however, the previous measurements did not indicate, that the springs are dry. The springs have a significant variation in discharge from less than 1 m<sup>3</sup>/hr up to 1000m<sup>3</sup>/hr.

Based on the data of the last 5 years (October 2012 to September 2017), the



average yearly discharge from all springs can be estimated to be around 125 MCM/yr.

### 4.2 Long term trends and seasonal variation of the spring discharge

For each aquifer, one to two springs have been selected based on data availability, data continuity, data quality, discharge amount and local importance.



Figure 4-2. Location of selected springs

The long-term trend as well as the seasonal variation for the selected springs will be discussed in this chapter. The seasonal variation shows a descriptive statistical analysis (box plot) of the monthly discharge volumes. It shows the range (25% - 75% quantile) in which 50% of all measurements are, additionally to the range down to the 10% and the 90% quantile. The spacing between the different parts of the box indicate the degree of dispersion and skewness in the data, and

permits identifying outliers. The discharge values of the hydrological year 2016/2017 are presented in blue above the box plot



and may be easily evaluated if in the normal range (between 25% and 75%), unusual (between 10% and 90%) or outliers (below 10% or above 90%).



For the analysis of the long-term trend, all measured values were plotted on a chart and the linear trend was estimated with the method of least squares.



The Nukheil spring is located in the Alluvial aquifer in the Jordan Valley. The fluctuations around the long-term trend are ±50 m<sup>3</sup>/hr. The long-term average decrease in discharge is around . 3.4 m³/h/a, which is very similar to the trends of the nearby springs of the A4

(AH0510) and A1/2 (AJ0520) aquifer. Since 2013 the number of measurements has decreased, but the discharge values are all above the trend with a few higher values in 2013-

2014 of around 150 m<sup>3</sup>/hr. The discharge is homogeneous throughout the year, with minor seasonal variations. This year's measurements are within the 50%

range, which means that the discharge is in normal range for the measured month.





The El Balad spring is dewatering the B4 aquifer and is located in the very North of Jordan near the Yarmouk River. The long-term average is minor with 20 m³/hr and has a slight negative trend of -0.6 m³/hr/yr. At the beginning, the monitoring interval was very regular,



almost monthly, so it is possible to identify a minor seasonal variation. As monitoring is not



continuous, these variations can no longer be analyzed. The discharge varies mainly between 15 m<sup>3</sup>/hr and 40 m<sup>3</sup>/hr, with highest the values in March with up to 120 m<sup>3</sup>/hr. The two measurements of 2016/2017 are at the lower end of the usual range.

The Sarah spring is near Karak and is dewatering the A7/B2 aquifer with an average discharge

400 of m<sup>3</sup>/hr, decreasing by 12 m<sup>3</sup>/hr each year. In comparison to other springs, this decrease is very high. Since 2007 the discharge has dropped to less than 300 m<sup>3</sup>/hr, although it appears that since 2014 the discharge has increased up to





### Springs

450 m<sup>3</sup>/hr. The amount of yearly measurements however has decreased, so a full analysis is not possible. The dispersion varies between 150 m³/hr 750 to m<sup>3</sup>/hr, with the highest discharge at the



second half of the rainy season from February and April. The measured discharge in March and July is typical for that time.



The Tannur spring is dewatering the A4 aquifer and is located near Ajloun. It shows a negative trend of -3.2 m³/hr/yr with а wide dispersion of discharge values between less than 50 m<sup>3</sup>/hr and up to 550 m<sup>3</sup>/hr. The seasonal variations can be identified, with а

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higher discharge from February until May. The overall discharge variations are very high. E.g.

in February the discharge is ranging between 75 m³/hr around 600 and m<sup>3</sup>/hr. This year's discharge is very low both as measurements are 10% the near quantile.



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The Wadi Es Sir spring is also dewatering the A4 aquifer and is located West of Amman. Differently to most other springs in the same aquifer, this spring has an increase in discharge by +6.7 m<sup>3</sup>/hr/yr. The reason for this reverse trend is most probably the

water losses in the leaking water supply network of Amman city area. The dispersion varied between 200 m<sup>3</sup>/hr and 600 m<sup>3</sup>/hr, with an increase now to min. 500 m<sup>3</sup>/hr. The seasonal

variations show higher discharge rates in February, March and April. The monthly variation is relatively even. This years measured values are clearly above the average discharge.





EI Qantara The spring in Ajloun is dewatering the A1/2 aquifer and shows a decreasing trend of 3 m<sup>3</sup>/hr/yr. The average dispersion is between 25 m<sup>3</sup>/hr and 200 m<sup>3</sup>/hr with some high outliners especially in 1996 reaching up to 420 m<sup>3</sup>/hr. The average





discharge currently is less than 80 m<sup>3</sup>/hr. The time series has clear seasonal а variation with the highest discharge from January until April. The two discharge measurements of this year's rainy season are within the usual range, the other two values are

#### below average.

The Mbeirdeh spring near Madaba is also dewatering the A1/2 aquifer but hardly shows a trend unlike the El Qantara spring near Ajloun. The measured average discharge varies between 50 m<sup>3</sup>/hr and 250 m3/hr with a few higher outliners 2014. Smaller in



outliners are more common; in 2006 it even appears that the spring had no discharge and was



seasonally dry.

The seasonal variation is not very accentuated with higher discharge from January until April. The four measurement in the hydrological vear 2016/2017 were all at the lower end of the usual range.





The Mugheisel Kabeira spring North Tafilah of is dewatering the Kurnub aquifer and has a general small discharge in comparison to other springs with а 68 maximum of m³/hr. Also here, a negative long-term trend of -0.5 m<sup>3</sup>/hr/yr can be found.

This spring has no clear seasonal discharge variation, probably because Kurnub is a relatively deep aquifer. The measurements at the end of 2016 and beginning 2017 were in the upper historical range, while in July relatively low.



### 4.3 Springs for drinking water supply

Some springs are used for the drinking water supply if the water quality and the quantity are appropriate for drinking purposes. Frequently, the quality of spring water does not reach the required standards although the discharge quantity is very good. In general, the main reason for not using a spring discharge for drinking water supply is bacterial contamination. In a few cases, the use was interrupted due to this kind of problems. In other important springs, treatment plants are installed to remove the bacterial contamination from the water. The following figure 4-3 shows the distribution of the springs currently used for drinking water supply in Jordan.





Figure 4-3. Springs used for drinking water supply

As shown above, most springs used for drinking water supply are located in the northern highlands around Amman, Zarqa and Balqa, further north in Ajlun, Jarash and Irbid, as well as a few springs in Karak. The following charts give an overview of the yearly discharge amount in m<sup>3</sup>/yr since 2014 for the springs grouped according to the region they are located in.

The total amount of water from all springs used for drinking water in 2017 is around 20 MCM.



#### **Springs**



The discharge of the springs in the Irbid, Ajlun and Jarash governorate show a general decrease, particularily from 2015 until 2016. although it slightly recovered in 2017. The Tannur spring has the highest yearly discharge,

varying between 0.8 and 1.0 MCM/yr. Other springs like Zugaig and El Qairawan had a similar discharge as the Tannur spring in 2014, however, their discharge has decreased significantly since then. The overall development of the other springs in this area was relatively stable.



Most of the springs in the Amman, Balqa and Zarga governorates, have only slight variations apart from the Ras Ein Spring and the Shore'Ai spring, which show an increase in discharge. The Ras Ein Spring is since

2015 the spring with the highest discharge being well above 5 MCM/yr. The reason for the unusual increase are probably the recharge of the aquifer with water leaking from the water supply network, since the concerned springs are located within or at the limit of urban areas.

The springs in the Karak Governorate have а relatively small quantity (less than 0.1 MCM/yr and above 0.6 MCM/yr) in discharge but an overall similar trend. increase An in discharge in 2015 is noticed. which is probably due to



slightly higher precipitation in this year.





## Chapter 5 - Groundwater

Groundwater is the principal source of drinking water for the majority of the Jordanian's population. In addition, groundwater is an important resource for irrigation in several agricultural areas within the country.

Long-term, systematic measurements of groundwater levels provide essential data needed to evaluate changes in the resource over time, forecast trends, and to design, implement, and monitor the effectiveness of groundwater management and protection programs. Thus, the Ministry of Water and Irrigation is performing groundwater monitoring programs that include the regular measurement of the groundwater level in the different aquifers. This measurement is done either manually or automatically (or both) in special monitoring wells that are distributed all over Jordan. The depths of these wells vary according to the target aquifer. Map 2 gives an overview on the water resources monitoring network and the groundwater monitoring wells.



## 5.1 Introduction

Limited surface water resources in Jordan add pressure on aroundwater the to cover the continuously resources increasing demands of the different sectors. Currently, around 3000 active governmental and private wells exist mainly in the highly populated northern and governorates. central In term of sustainability, the state of groundwater in Jordan can be described as critical since most of the groundwater resources are overexploited. Many wells have dried up in the past few years due to the falling groundwater levels in the central and northern parts of Jordan especially in the A7/B2 aguifer. Many other wells were deepened in order to either fully penetrate the target aquifer to enhance the productivity or to reach the deeper aquifer. This, however results in increasing abstraction costs and a loss in economic efficiency, as well as in some cases the need of treatment of the water because of declining water quality.

In light of these challenges, MWI is enforcing the law against illegal drilling by closing illegal private wells. Additionally, further investments groundwater in abstraction from the deep aquifer system continues. Furthermore, the water supply relays more and more on the unconventional water resources such as desalination, water reuse and water conveyance.

Several aquifers from different geological ages are existing in Jordan. These aquifers vary in their geological and hydrogeological characteristics so they vary in groundwater potential accordingly. Figure 5-1 shows a simplified map of the outcrops of the hydrogeological units in Jordan. In the Mountains Heights Plateau the limestone aquifer, commonly known as "A7/B2", is the most exploited aquifer since the depth to the groundwater table is relatively low and the water quality is good. Many wells are also drilled in the overlaying Basalt aguifer in the northeastern part of Jordan and the so-called "B4/B5" limestone aguifer in the eastern desert. Beneath the A7/B2 aquifer, other aquifers in older geologic formations exist such as the A1/A6 limestone aquifer. Although in some places this aguifer is used for the extraction of drinking or irrigation water, the permeability is often much lower than in the overlaying aguifers, due to the occurrence of layers of marl. Additionally, the water has а higher salinity. The sedimentary sandstone formations of Kurnub, Zarqa and Ram, which underlay the A1/A6 comprising another sequence, are important aquifer system, commonly summarized under the term "deep aquifer". As part of the Ram sandstone aguifer, the Disi aquifer in the south of Jordan is a main water source in Jordan. Its water is a nonrenewable resource, since it infiltrated several thousands of years ago and currently there is no significant recharge.

The Alluvium of Jordan Valley is also one of the important aquifers in Jordan. The thickness and the permeability of these alluvial deposits allow the storage of a big volume of water, which is mainly recharged by the numerous seasonal watercourses that collect the runoff from the surrounding highlands. This aquifer is exploited by a big number of shallow wells mostly for irrigation purposes.





Figure 5-1. Simplified hydrogeological units of Jordan

The Ministry of Water and irrigation maintains a network of around 200 monitoring wells, from which currently 187 are active, i.e. allow the measurement of current groundwater level data.

This Year Book shows the development of the groundwater levels by presenting the monitoring data of a few selected monitoring wells of each aquifer. The data is represented graphically in so called hydrographs that show all available measurements in these wells at different times, so a long-term analysis can be carried out.



## 5.2 Alluvial Aquifer

This aquifer mainly consists of recent unconsolidated (loose) sediments accumulated in the depression of the Jordan Valley. The soil-covered sediments of the alluvial aquifer are consisting of sand and gravel, which have been deposited along the Jordan River and as alluvial fans along both sides of the escarpment. Groundwater level is relatively shallow in this aquifer; it ranges between 5-150 m below ground level, which make this aquifer highly used. Several monitoring wells were drilled in this aquifer to monitor groundwater levels in different places. Some of these monitoring wells were selected to show the changes in water levels in different places in the aquifer. The figure presents the distribution of the alluvial aquifer in Jordan and the location of the selected monitoring wells. The graphs below show the groundwater level time series in the selected wells.



Figure 5-2. Location of selected representative wells in Alluvium

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Groundwater levels in the monitoring well AB1341 located in Jordan Valley show a continuous decline between 1995 and 2015 reaching а maximum decline of 5 m/yr. Since 2015 the groundwater level appears to be stable.

In the well CA1095 northern in Wadi Araba, the water level has been relatively stable, showing only a very slight negative trend with less than 2.5 m for the entire measured period.





The well EA3009 in southern Wadi Araba is very similar to the above well with no significant changes in groundwater level since 1995.



### 5.3 Basalt Aquifer

The basalts of the North Arabian Volcanic Province (which is also known as Harrat Ash Sham) extend from southwestern Syria through eastern Jordan into Saudi Arabia over a total length of around 460 km and with a width of 50-150 km. They cover an area of approximately 48,000 km<sup>2</sup>, of which 11,000 km<sup>2</sup> are located in Jordan, 23,000 km<sup>2</sup> in Saudi Arabia and 14,000 km<sup>2</sup> in Syria. The basalts generally overlie sedimentary formations of Tertiary and Cretaceous ages and are hydraulically connected with them to form a complex aquifer system<sup>4</sup>.

The figure below presents the distribution of the basalts in Jordan and the locations of the selected monitoring wells in this aquifer. The following charts present the groundwater level time series in the selected wells in the Basalt aquifer.



Figure 5-3. Extension of the Basalt and location of selected monitoring wells

4 UN-ESCWA and BGR (United Nations Economic and Social Commission for Western Asia; Bundesanstalt für Geowissenschaften und Rohstoffe). 2013. Inventory of Shared Water Resources in Western Asia. Beirut.





The declining of groundwater level in this well is obvious since the start of measuring (1996) till now. The water level declined about 30 m in 22 years with an average of 1.36 m/yr. The frequency of measurements aets less after the 2001 which year made the seasonal

fluctuations less clear.

The general trend for water level in this well is also negative. smooth Α time series with declining levels can be observed between 1995 and 2009, but after that, the behavior went more irregular and the water level values scattered. The average drawdown



in this well is about 1.3 m/yr.

Due to the high rates of abstraction, which exceed the recharge rates, groundwater levels show quite sharp declining rates in most of the monitoring wells in the Basalt aquifer. Furthermore, groundwater temperature and salinity are increasing<sup>5</sup>. Because of this decline in groundwater level, Azraq wetland was dried up through the last few decades which caused serious social, economic and environmental problems in the area.

<sup>5</sup> UN-ESCWA and BGR (United Nations Economic and Social Commission for Western Asia; Bundesanstalt für Geowissenschaften und Rohstoffe). 2013. Inventory of Shared Water Resources in Western Asia. Beirut.





## 5.4 B4/B5 Aquifer

The rocks of this aquifer are mainly consisting of carbonates (Limestone) from the Tertiary period. The rocks of this aquifer are cropping out within a wide area in the eastern part of Jordan in addition to some places next to Yarmouk River in the most northern part of the country (see figure below). In most parts of Jordan, this aquifer is not used as a source of groundwater, mainly because of the high salinity of the water, but also due to the low population density and the lack of agriculture and industrial activities in these areas.

An exception are the areas of Azraq and Jafer, where this aquifer is highly used for groundwater abstraction especially for agricultural uses. This caused declining in water level and decreasing water quality these areas.



Figure 5-4. Location of selected representative wells in B4/B5 Unit

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#### Groundwater

The groundwater level registered in the monitoring "H2017 station IRAQI ARMY M2" near Ar Rweyshid shows almost stable conditions over the last 20 years. In this area. almost no groundwater is abstracted because of its high salinity and the recharge is



nearly zero because of the very low precipitation.



The Mahmiyyet Esh Shomary 1 observation well (F 1126) locates a few kilometers south of Azraq where groundwater is highly exploited. This well is slightly affected by groundwater level decline in the surrounding areas

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showing a continuous drop of around 7 m since 1996 till 2011. Since then, water level seems to be stable.

The groundwater level at F1286. further 50 km to the south has a minor negative trend with less than 2.5 m for the entire measured period. This well is located in a remote area with no activities.



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At Jafer 4 observation well (G3149) at about 50 km east of Ma'an, the effect of the over abstraction of groundwater in Jafer is area clearly observable. The water level declined by 9 m since 2009 till now with an average of 1 m/yr. The decline during

the overall measuring period of 20 years was around 13 m.

### 5.5 A7/B2 Aquifer

A7/B2 is the most exploited aquifer in Jordan. It is a highly fractured-rock aquifer, consisting of sedimentary rocks (primarily carbonates and chert) from the late Cretaceous epoch. The fractures and other discontinuities such as joints, fissures and faults, which occur in the rocks of this unit, are providing the voids that hold huge amounts of groundwater. Therefore, the A7/B2 can be considered a highly productive aquifer.

A7/B2 rocks are cropping out in wide areas in the western and southern parts of Jordan, while they underlie B4/B5 and Basalt units in the central and eastern parts of the country. Many governmental private and groundwater pumping wells were drilled penetrating this aquifer, mostly for domestic and agricultural uses. A7/B2 is preferable for aroundwater hiahlv abstraction since it is highly productive, extensive and not very deep. Furthermore, the water quality in this aquifer is good.

Four monitoring wells were selected to represent the water level situation in this aquifer: the wells AE1003 and AL1521 in the northern part, CD1212 in central Jordan and CF1078 in the South. In the following, the hydrographs of the groundwater level time series of the selected wells are shown.



Figure 5-5. Location of selected representative wells in A7/B2 Unit

In well AE1003, located 10 km northeast of Irbid, an obvious long-term decline in groundwater level can be found. The average of groundwater level drawdown for the period 1995-2017 is more than 3.5 m/yr, which reflects the



high over-exploitation of the groundwater in the area of this well.



#### Groundwater



Also, further East near to Mafraq, significant declining rates were From registered. 1995 until 2005, groundwater levels m/yr. fall with 1 Since 2013. the declining rate increased significantly to reach around 12 m/yr due the huge to

abstraction volume of groundwater in the area, which reach about a quarter of all exploited

groundwater in Jordan<sup>6</sup>. In central Jordan, groundwater the in A7/B2 aquifer is also declining continuously. The time series of the CD1212 monitoring well shows that the groundwater level decline in the period 1995- 2017 was about 37 m with an average of around 1.7 m/yr.





The groundwater levels in the well CF1078 in the South of Jordan are also showing a continuous drawdown. From 1995 to 2017, groundwater level dropped by about 20 m with an average of about 0.9 m/yr.

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<sup>&</sup>lt;sup>6</sup> Margane et al, 2013. Updating the Groundwater Contour Map of the A7/B2 Aquifer in North Jordan, Amman.

# 5.6 A1/A6 Unit

The A1/A6 hydrological unit refers to the late Cretaceous. The rocks of this unit are carbonates (limestone and marl). They are exposed along the escarpment of the Jordan Valley and extend beneath other geological units throughout wide areas of Jordan (see figure below). A1/A6 unit is composed of several geological formations. Some of these formations can be considered as aquifers whereas others are aquitards. Groundwater potential in this unit is highly depending on the location.

Thus, A1/A6 can be identified as a local and discontinuous productive aquifer in some places or as a minor aquifer with local and limited groundwater resources elsewhere.

Groundwater abstraction from the A1/A6 unit is common in the western and northern parts of Jordan where it is exposed or not very deep. In the other areas, A7/B2 is more favorable for abstraction since it is less deep and a more productive aquifer.



Figure 5-6. Extension of the A1/A6 hydrogeological unit and location of selected monitoring wells

In order to evaluate the development of the groundwater levels in the A1/A6 hydrogeological unit, seven monitoring wells were selected and their water level data is shown in the following hydrographs.

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#### Groundwater



The water level in Club N°13 Race observation well shows an irregular behavior for groundwater level. There was a decline from 1995 to 2002. water then level increased between 2002 and 2005. Afterwards a strong drawdown occured between 2005 and 2012, followed by the complete

recovery of the water level between 2012 and 2017. In order to understand the unusual recovery of the water levels, the location of the well in the urban area of Marka district has to be considered. The most probable explanation is an increased recharge of the groundwater after 2012 because of rising losses in the water supply network and possibly from the sewage, too. The water losses from the distribution network in Jordan are estimated to be above 50 % of the total distributed drinking water.

The water level in Ruseifa Monitoring 1 Well verv is irregular, possibly because of a high correlation of the groundwater levels with precipitation. Besides the high variability a clear negative trend in the periods 1995-2002 and 2005-2012 can be identified, as well as a slight recovery from 2002 until 2005



and a sharp increase from 2012 until now. The reasons for this behavior is surely the same as mentioned above.





The well AL3520 is located in Balga, in a distance of about 20 km to the northwest of the above indicated wells. The groundwater level trendline shows а clear variation seasonal with an increase in rainy season the and a drop in the dry season. In the long term, no significant changes of the

water level since 2004 happened. In general, the water level in this well is stable, which is an indicator of sustainable exploitation of the aquifer.

Further northeast, near Mafrag, the groundwater level in well the Za'tari Monitoring shows a continuous decline and no seasonal variation. From 2001 to 2017. groundwater level dropped about 10 m with an average of more than 0.6 m/yr. This indicates that



there is an over exploitation from A1/A6 aquifer in the northern part of Jordan.

### 5.7 Kurnub & Zarqa Aquifers

Kurnub and Zarqa are two separated hydrogeological units. They are different in age and they also have some differences in lithology. However, these two units have similar hydrological characteristics and they are hydraulically connected, what allows groundwater to move freely within these units, as it was one unit. The Kurnub unit (lower Cretaceous) is exposed in many areas along the escarpment of the Jordan Valley and in a wide area of the southern part of Jordan. It is extending beneath some other geological units throughout wide areas of Jordan (see the figure below). Kurnub is an aquifer consisting of sandstone and the flow of groundwater is mainly intergranular.



The Zarqa unit (Jurrasic) is cropping out in some areas along the escarpment of the Jordan Valley. Zarqa unit consists of sandstone, siltstone, limestone and dolomite and it is classified as an aquifer with an intergranular flow mainly. Groundwater in the Kurnub/Zarqa system varies from fresh to brackish and it has a high temperature in many places, which requires treatment in many cases before the water can be used.



Figure 5-7. Location of selected representative wells in Kurnub and Zarqa Units

Two monitoring wells were selected in each unit to represent the changes in groundwater levels. The wells AL1430 and AL3379 were selected to represent water levels in the Kurnub aquifer. The wells AL3530 and AL3785 were selected to represent water levels in Zarqa.



### Groundwater



In Balqa, a long term decline in groundwater level can be found in the time series of the well AL1430. The decline total of groundwater level for the period 1995-2017 is around 20 m or 0.9 m/yr.

The second selected monitoring well of the Kurnub aquifer located in Jarash, has а relatively stable water level since 2002. slight with seasonal fluctuations. Between 2014 and

2017 there was a minor decline in water level.





#### Groundwater



The Baq'a Deep Well N°13A monitors the Zarqa aquifer in Balqa. It is very close to the well AL1430 but 280 meters deeper. In difference to the former, in the Zarga aquifer is no significant change in water level for the measuring period 2001 and 2015. The

two measurement in 2017 show that there is an increase of about 5 meters.

In the other selected observation well of the Zarqa unit, the water level has been relatively stable since 2007, with slight seasonal fluctuations.





## 5.8 Ram Aquifer



Figure 5-8. Extension of the Ram hydrogeological unit and location of selected monitoring wells

Ram is a sandstone aquifer cropping out in the southern part of Jordan and along Wadi Araba-Dead Sea Rift Valley. It underlies the majority of Jordan's area (see figure above). The water of this aquifer is mainly considered as nonrenewable because of limited groundwater recharge through small outcrop areas in the arid southern part of Jordan.

The Ram fine grained sandstone aquifer has fairly good yields. As a part of this aquifer, the Disi Group is the main used part of this aquifer in southern Jordan where many extraction wells were drilled to be the water source of the Disi Conveyer project, which supplies Amman with drinking water.



#### Groundwater



In observation well ED1203 the level groundwater was declining since mid of 1996 at a fixed rate of around 1.2 m/yr. The continuous drawdown the and seasonal missing variation is typical the for constant exploitation of an aquifer without any

recharge.

In ED1328 further southeast, the declining rate was about 0.55 m/yr between 1995 and the end of 2013 but it was highly increased to reach about 5 m/yr between 2013 and 2017. The significant increase in the negative trend happened shortly



after starting the abstraction from the wells of the Disi conveyer project.




Well K1000 some 40 km east of Disi, shows a continuous declining rate of about 0.6 m/yr until 2013 with a total drop of 11 m. After 2013 the water level seams to have stabilized.

Interesting is also, that the trendline until 2012 shows a seasonal variation,

which is typical for aquifers that receive recharge during the rainy season. But the rainfall in this area is almost zero. A possible explanation for the seasonal variation and the stop of the drawdown may be agricultural activities south of the well. The seasonal variable groundwater withdrawal for irrigation purposes can explain the variations. Further, the stop of the agricultural activities at beginning of 2013 may be the reason of the stabilization of the groundwater level in the same year.



#### **Hydrochemistry**



# Chapter 6 - Hydrochemistry

The Laboratories and Quality Affairs of the Water Authority of Jordan monitors the quality of the water resources. The monitoring program comprehends the collection of water samples from surface water, springs, groundwater wells, water infrastructure and wastewater treatment plants. The Laboratories analyzes different water quality parameters depending on the origin and intended use of the water and stores the analysis results.

This chapter evaluates selected parameters of concerning groundwater pollutants like nitrate, electrical conductivity, nickel and molybdenum.



### 6.1 Introduction

Water is considered to be the vital element to guarantee the sustainability of life and the main cornerstone in all the major areas of development. The water situation in Jordan faces the challenge that the available water resources do not meet the growing needs.

The management of water resources and maintaining its quality is considered one of the strategic goals of the Water Authority of Jordan (WAJ), especially the Laboratories and Quality Affairs plays a pivotal role in monitoring of water quality according to the set standards for drinking water and reclaimed water. Protecting water resources from pollution sources is considered a priority for WAJ through implementing the instructions of protection of water resources and adopting the up to date approaches such as water safety to guarantee safety and integrity of drinking

water from the source to the customer faucet.

The quality of drinking water is a universal health concern and access to safe water is a fundamental human right. Drinking water quality in Jordan is governed by the Jordanian Standard 286 / 2015, which is based on the World Health Organization drinking water guidelines This standard is applied for the supplied water for drinking purposes whereas some sources need treatment in order to comply with this standard.

Hydrochemical data from the wells and springs was analyzed and checked for indications of threats to the water quality. All samples were taken and analyzed by the Water Authority of Jordan, Laboratories and Water Quality Affairs.



#### 6.2 Nitrate



Figure 6-1. Nitrate median level time series (2002-2017) for Aquifers A1-A6, ALL, A7/B2, B4, BA, K, Ram-Z

The trend shows that Nitrate median levels for all Aquifers have a slight decrease except for Kurnub aquifer due to the influence of the B'aqa wellfield where higher levels were reported. The highest median values calculated are in A7/B2 with long term median values between 15-30 mg/L. The lowest nitrate median values calculated are found in the Ram-Zarqa hydrogeological unit between 0.2-6.8 mg/L.



Figure 6-2. Nitrate level time series (2002-2017) for springs and wells in aquifer A1-A6

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In the A1/A6 aquifer, the highest nitrate concentrations where found in the Ajloun Springs and the lowest readings are recorded in the Ezqeiq well field. The long-term average trend for all wellfields where minor with  $\pm 0.15$  mg/L per year. The highest decrease in nitrate levels in the long term are observed in Yazidiyya well field.



Figure 6-3. Nitrate level time series (2002-2017) for well fields in aquifer A7/B2

The A7/B2 aquifer is the most exploited and used aquifer in Jordan. It shows very small negative trend in nitrate levels for all well fields. The highest nitrate concentrations in the A7/B2 aquifer are measured in Znayya well field and the lowest readings are recorded in Jabir well field.



Figure 6-4. Nitrate level seasonal variation in 2017 for Aquifer A7/B2



Identifying a seasonal variation is very difficult because of the wide distribution of the nitrate levels in 2016/2017 for the A7/B2 aquifer. Nevertheless, an increase of the concentration in October and November can be found.



Figure 6-5. Nitrate level time series (2002-2017) for B4 aquifer

In the hydraulically connected Basalt and B4 aquifer, the highest nitrate concentrations were measured in the AWSA well field, as well as the highest increase in the long term. The lowest readings are recorded in the Rweished well field.



Figure 6-6. Nitrate level time series (2002-2017) for the AWSA wellfield, Basalt and B4 aquifer



Within the AWSA well field, the highest  $NO_3$  concentrations were registered in the most southern wells; it seems that there is a clear south-north gradient in the nitrate levels.



Figure 6-7. Nitrate level time series (2002-2017) for Ram-Zarqa aquifer

In the Ram-Zarqa aquifer, usually no considerable levels of Nitrate were recorded. The values were below 7 mg/L for Allan and Mdawwarah well fields, although Mdawwarah well field recorded higher values.



Figure 6-8. Nitrate level time series (2002-2017) for Kurnub aquifer

In the Kurnub aquifer, considerable levels of nitrate are observed especially for the Baq'a well field, which may originate from the agricultural activities in that area.



#### Checking normality of the data:

A wide variety of commonly used statistical procedures, including the mean, standard deviation and median require the data to be normally distributed for the statistics to be fully valid.

The cumulative frequency distribution (CFD) of the nitrate data in the Ram-Zarga aquifer was plotted, in order to determine if the NO<sub>3</sub> data through 2002-2017 is normally distributed. The CFD approximates a straight line (particularly between 20 and 80



Figure 6-9. CFD % for Balqa well field for Ram-Z

per cent), which implies that the nitrate data of the period 2002-2017 was normally distributed. Consequently, it can be stated that the statistical procedures used for the analysis of the  $NO_3$  data are valid.

The following regression plot shows the relationship of Electrical Conductivity to chloride, hardness, nitrate, sulphate, carbonate, bicarbonate, calcium, magnesium, sodium and potassium in all the aquifers.



Figure 6-10. Hydrochemistry for Aquifers A1-A6, ALL, A7/B2, B4, BA, K, Ram-Zarqa

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#### 6.3 Electrical Conductivity

The Electrical Conductivity (EC) is the measure of a materials ability to transport an electric charge. Salts or other chemicals dissolve in water into positively and negatively ions. These free ions in the water conduct electricity, so the electrical conductivity of water depends on the concentration of ions. Consequently, EC is an indicator of the salinity of water or its content of total dissolved solids (TDS). Therefore, EC is a useful parameter to

evaluate the water's quality: the lower the EC, the better the water quality.

The figure below shows the long-term evaluation of EC in A7/B2 aquifer well fields. Some well fields have only small fluctuations like A'bur between 450  $\mu$ S/cm - 550  $\mu$ S/cm , others show high fluctuations within the well field as Wadi Arab between 700  $\mu$ S/cm and 1500  $\mu$ S/cm, and Znayya from 650  $\mu$ S/cm to 2500  $\mu$ S/cm.



Figure 6-11. EC level time series (2001-2017) for A7/B2 aquifer

The following figure shows the long-term evaluation of EC in different well fields, representing different aquifers. In Ezqeiq well field of the A1/A6 aquifer, the longterm EC concentration is decreasing from 1500  $\mu$ S/cm in 2005 to 750  $\mu$ S/cm in 2017. Some well fields have high fluctuations: Um Mithla well field in the alluvium aquifer between 875  $\mu$ S/cm and up to 3000  $\mu$ S/cm; AWSA well field in the B4 aquifer between  $360 \ \mu$ S/cm and  $3500 \ \mu$ S/cm; Jafer well field in the B4 aquifer between  $680 \ \mu$ S/cm and  $4450 \ \mu$ S/cm, Baq'a well field in the Kurnub aquifer from  $440 \ \mu$ S/cm up to  $1700 \ \mu$ S/cm. Despite the high fluctuations within the single well fields, in almost all a significant increase in electrical conductivity can be noticed. This positive trend in salinity may be caused by the increasing water abstraction compared with less recharge.



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Figure 6-12. EC level time series (2002-2017) for different well fields

The following figure shows the long-term EC evaluation for different springs located in Wadi Shoeib, North of Amman.



Figure 6-13. EC level time series (2002-2017) for Wadi Shueib springs group

Same as in the wellfields, also in the springs a clear positive trend in the EC can be identified.

### 6.4 Nickel

Nickel is one of many trace metals widely distribute in the environment. It is present in the soil, water and air. Nickel in low concentration is an essential element for plant growth.

The following graph shows the registered Nickel concentration from 2002 until 2019, classified by aquifer. This graphical evaluation indicates that the nickel values in most aquifers are stable at a very low level. The only exception is the A7/B2 aquifer, which clearly shows variations of the Nickel concentrations.



Figure 6-14. Nickel level time series (2002-2017) for aquifers

Since the good data availability allows for a long-term analysis, the Wadi Al Arab well field was selected as an example of the Nickel level trend from 2002 until 2017.



Figure 6-15. Nickel level time series (2002-2017)



### 6.5 Molybdenum

Molybdenum (Mo) is a metallic element that is naturally present, usually at low levels, in the earth's crust. Trace amounts of molybdenum are necessary for human health, and are obtained from common foods in the diet such as leafy vegetables, legumes, grains and organ meats.

The concentration time series (2008-2017) for the different aquifers indicates that Molybdenum has a similar behavior to Nickel. It is stable in most aquifers except for A7/B2 that shows a variation in nickel and molybdenum values.



Figure 6-16.Molybdenum level time series (2008-2017) for different aquifers

Again, Wadi Al-Arab was used due to the availability of data as a representative station for the A7/B2 aquifer. The concentration time series (2008-2017) show temporal variations in the groundwater chemistry for Molybdenum (Mo) for Wadi Al Arab well field.



Figure 6-17. Molybdenum level time series (2008-2017) at Wadi Al Arab well field

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## Chapter 7 - Water Infrastructure

This chapter presents the different types of water infrastructure in Jordan, including dams, well fields, wastewater treatment plants, desalination plants and other treatment plants. The complete overview of the water infrastructure of Jordan can be found in map n°3 annexed to this Yearbook.

Further, the water volumes abstracted, transported or stored in this infrastructure, as well as its development over the last years is shown in tables and graphs.

On the contrary to the climate and surface water data that is presented for the hydrological year, the figures and tables in the water infrastructure chapter refer to the calendar year.





## 7.1 Dams, desert dams and ponds

The Jordan Valley Authority, founded in 1977, was given the responsibility to carry out all work related to the development and establishment of dams, ponds and excavations, including study, design, operation and maintenance.



Figure 7-1: Major dams in Jordan.

- All major dams are located in the valleys and wadis draining to the Jordan Valley / Death Sea basin.
- > There are 11 major dams in Jordan with a total capacity of around 332 MCM.
- > 3 additional Dams are being finalized, Lajjun, Karak and Zarqa Ma'in.
- > Additionally, there are 63 desert dams with a total capacity of 96.5 MCM.
- > 65 ponds are registered with a total capacity of around 0.3 MCM.
- There are 245 excavation ponds with a total capacity of 22.8 MCM. 23 additional excavation ponds are under construction with another 2.3 MCM capacity.



The following table shows the development of the total yearly amount of water leaving (effluent) the major dams since 2012. Note, that the calendar year and not the hydrological year has been used for the calculations. In all cases, the yearly influent into the dam is higher than the effluent. Due to evaporation, a considerable amount of water is lost. The water entering the dam is a combination of surface water runoff and precipitation. In some cases, treated water from waste water treatment plants will also enter the dam, being part of the surface runoff. In this case, the effluent of the dam is used for irrigation only. In most cases, the effluent is used for irrigation and artificial recharge. Only the water from the Mujib dam is used for the drinking water supply of Amman and Karak area. The effluent from the Wehdeh dam enters the King Abdulla Canal.

Dam	Capacity (MCM)	Effluent (2012)	Effluent (2013)	Effluent (2014)	Effluent (2015)	Effluent (2016)	Influent (2017)	Effluent (2017)
Wehdeh	110	23	67.5	39.2	60.2	72.1	93.6	73
Wadi Arab	16.8	12.4	16.9	16.9	13.2	12.4	11.3	9
Zeqlab	3.9	1.8	3.8	1.8	1.6	1.1	0.5	0.5
Kufranja	5.6	0	0	0	0	0	1.2	1.2
King Talal	75	117	132.5	123	133.6	140	141.8	115.8
Karameh	55	1.8	5.8	3.6	2.4	3.8	6.2	1.7
Wadi Shueib	1.43	6.2	7.6	6.2	9	7	7.3	6.4
Kafrain	8.5	9.9	11.9	10.1	15.4	12.2	10.9	10.1
Wala	7.1	4.7	29.8	14	13.7	9.5	6.3	1.4
Mujeb	29.8	8.5	30.6	21.8	24	17.4	20.7	7
Tanour	1.68	2.1	10.7	9.5	7.9	2.1	5.8	1.6
Karak	2							
Lajjun	1							
Zarqa Ma'in	2							
Total	320	187	317	246	281	278	228	306

Table 7-1: Major Dams of Jordan, including capacity, yearly influent and yearly effluent in MCM.

In the following chart, all dams with a continues effluent are presented, what implies that the two new dams, as well as Kufranja dam are not shown.



Figure 7-2. The development of yearly dams effluent since 2012

In comparison, the Kind Talal Dam has the highest yearly discharge, and Wehdeh dam the highest capacity with 110 MCM and the second highest yearly discharge. The other dams are all in the range up to 30 MCM capacity.

The King Talal Dam shows a relatively stable discharge volume, mostly because it has a constant inflow of treated wastewater. The Wehdeh dam has, after a low discharge volume in 2014, recovered the same effluent amount as in 2013. Some dams have decreasing effluent volumes since 2013, because the amounts of rainfall in the years 2012-2017 reached only average volumes, which are not sufficient to fill these dams. In order to fill these dams, a year with particularly high rainfall would be needed. Especially the Mujeb dam, that is used for drinking water supply of Amman and Karak, is experiencing a strong decrease in the yearly effluent. Considering the increasing demand especially in this area the trend is highly alarming.



### 7.2 Groundwater abstraction

#### 7.2.1 Water abstraction in the main wellfields

Jordan is heavily relying on groundwater abstraction in order to meet the increasing water demand. Groundwater is the most important source for water supply. It contributes around 60% to all uses and 79% to the municipal water supply in 2014. The safe yield for groundwater abstraction is estimated to be about 275 million cubic meters, while the quantities that were pumped in the year 2014 exceeded the safe yield by about 160 million cubic meters<sup>7</sup>.

Several well fields were constructed in different places around the kingdom (see figure below and map n°3 in the annex) by the Jordanian government to extract groundwater. These well fields vary in productivity, number of wells and target aquifer.

As a result of the water supply shortage and the continuously increasing demands, especially in the highly populated areas (mainly Amman, Zarqa, Irbid and Mafraq), the Jordanian government was obliged to construct well fields far from the high demand areas and transfer the abstracted water to it. This water reallocation is an economically costly approach due to the high costs of well drilling and construction, required infrastructure to transfer water to the target areas in addition to the high operational, energy and maintenance costs.

Along the western borders of the country, in the Jordan Valley and Wadi Araba areas, some well fields were drilled in the alluvial aguifer. In the western highlands, most of the well fields exploit the A7/B2 aquifer. Additionally, some well fields are extracting groundwater from the Zarqa, Kurnub and A1/A6 aguifers. In the eastern part, well fields were drilled to extract groundwater from the Basalt and B4/B5 aquifers. In southern Jordan, the fossil groundwater of the Disi aguifer is abstracted to provide drinking water by implementing the Disi Water Conveyance Project which started operating in 2013. The water from this well field is pumped to the capital Amman and other cities through a network of pipelines, pumping and boosting stations. Groundwater of the Disi aquifer cannot be considered as a sustainable water resource since it is nonrenewable (i.e. the recharge amounts of the aquifer is negligible) in opposite to the other aquifers in Jordan.



<sup>&</sup>lt;sup>7</sup> Ministry of Water and Irrigation. 2016. Groundwater Sustainability Policy. Amman



Figure 7-3: Main well fields in Jordan.

There are 21 main well fields located in Jordan used for drinking water located in different places of the Kingdom as shown above. There are many further smaller well fields in Jordan not shown in the map.

Following table lists the main well fields and the total amount of abstraction for each well field in MCM for the period from 2009 until 2017.

Well Field	2009	2010	2011	2012	2013	2014	2015	2016	2017
Disi					30.9	99.7	100.0	100.5	100.0
Mukheiba	21.8	27.7	22.0	23.3	21.6	23.2		23.8	23.9
Wadi Alarab	13.0	17.1	17.9	16.6	16.6	17.1	18.6	18.0	18.0
AWSA	15.3	16.2	17.1	14.8	14.0	14.5	14.3	16.3	14.2
KM	12.2	14.7	13.5	12.1	11.8	13.9	13.9	13.2	13.4
Heedan	9.9	10.4	9.8	9.0	7.3	8.2	7.9	7.9	10.3
Qattraneh	6.0	7.0	6.5	5.7	2.7	6.4	7.2	5.7	5.5
Lajjoun	6.5	6.8	5.7	5.4	4.7	5.1	5.6	5.9	5.3
Corodor	7.9	8.7	8.1	7.4	6.7	6.9	7.0	5.4	5.1
Swaqa	5.8	5.4	5.0	4.6	4.7	3.3	4.0	4.1	4.2
Hallabat	5.7	5.4	5.4	5.7	5.5	4.9	4.9	4.4	3.8
Abu Elzeeghan	10.5	8.9	13.2	13.6	12.8	9.9	8.7	7.7	3.6
Sultaneh	4.6	4.6	4.3	3.8		5.3	4.8	4.1	3.5
Tahouneh	2.4	2.6	2.8	2.4	1.6	3.0	3.0	2.4	2.5
Supply	2.5	2.8	2.0	1.6	1.6	1.6	2.0	1.4	1.9
Walla	2.0	2.0	2.4	2.3	1.7	1.9	1.9	2.0	1.8
Safi	1.4	1.3	1.3	1.2	0.2	2.0	2.0	1.9	1.7
Baq'a	1.7	1.7	1.8	1.9	1.9	1.5	1.4	1.7	1.6
Samna	1.0	1.2	1.4	1.2	1.0	1.4	1.7	1.8	1.5
Muhay	1.1	1.1	1.0	1.0		2.2	2.1	1.6	1.4
Sama El Sarhan	2.3	2.0	2.3	2.3	1.4	1.5	1.8	1.5	1.3
Yaziddiah	0.8	0.9	1.1	1.6	1.2	0.9	1.0	1.0	1.1
Shobak	1.0	1.1	1.0	1.1	1.1	1.4	1.4	1.5	1.0
Ghuwair	0.6	0.8	1.0	1.1		1.1	1.1	1.1	1.0
Muwaqqar	1.3	1.4	1.2	1.1	0.9	0.9	0.9	0.8	0.8
Q'a Assaidiyin	0.1	0.3	0.4	0.5	0.6	0.0	0.2	0.3	0.4
Sleikhat	0.2	0.9	0.9	0.1	0.6	0.6	0.9	0.7	0.4
Wadi El Qattar	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Qastal	1.4	1.0	0.9	0.8	0.5	0.2	0.2	0.2	
Total	139	154	150	142	154	239	218	237	229

Table 7-2: Total abstraction volume in MCM for the main well fields in the period from 2009 until 2017



In 2013 the Disi well field started to operate and the total abstraction of the major well fields in Jordan increased drastically (see figure below) from 2013 with 154 MCM to 239 MCM in 2014 to satisfy the increasing demand. However, the demand will continue to increase due to further growth in population as well as rising needs for irrigation and industrial use. Additional water resources need to be allocated to fulfill the increasing demand.



Figure 7-4. Development of the total yearly abstraction of groundwater in major wellfields in Jordan since 2009

Many of the major well fields have a relative stable yearly abstraction rate with minor decreases. However, some well fields as Abu Elzeeghan, Corodor or Hallabat, suffer a significant decrease of the abstraction rate as shown in the following figure. With a continuous increasing demand, the aquifers are overexploited and the groundwater levels drop. That means that some wells fall dry and need to be deepened. In other cases, the water quality decreases and the wells have to be closed. If this trend continuous, it will affect other well fields, too. A close observation is needed and the allocation of further water resources has to be investigated and prompted.



Figure 7-5. Development of yearly abstraction rates in the main well fields (without Disi Well field that since 2014 has a constant production of around 100 MCM)

### 7.2.2 Total groundwater abstraction 2017

Besides the above described main wellfields, many further individual wells or smaller wellfields exist all over Jordan. They have a major impact on the overall groundwater abstraction. The following figure shows the percentage of water used for each sector.



Figure 7-6: Percentage of water use for the different sectors in 2017



According to the information in the Ministries database, the majority of the abstracted water is used for domestic supply with 52%. 38% of the registered volumes are used for irrigation but this share may be higher due to illegal abstraction.

In the following map, the abstraction hot spots can be identified to be in Disi in the southern part of Jordan and in northern Jordan especially around Amman, Azraq, Mafraq and Wadi Al Arab.



Figure 7-7. Spatial distribution of groundwater abstraction in Jordan for 2017



### 7.2.3 Drilled wells 2017

The continuous increasing water demand results in the drilling of new wells. In the year 2017, 61 newly drilled wells were registered. The following figure shows the use of the new wells. Most of the wells are used for domestic water supply. Donor funded projects have drilled 21 monitoring wells. Five were constructed for industrial use and only one well for irrigation.



Figure 7-8. Drilled wells in 2017 separated according to use

#### 7.3 King Abdulla Canal

The KAC is the main water conveyer for irrigation in the Jordan Valley. At present, it conveys good quality water from the Yarmouk River, Mukheiba well field, Dajania diversion canal in the north and from the base flows of side wadis that dewater the eastern escarpment of Jordan Valley. These wadis are Al Arab, Ziglab, Yabis, Kufranja, Rajib and other small wadies. The water is used for irrigation and

industrial purposes in the Jordan Valley as well as for the domestic supply of Greater Amman area via Deir Alla intake to the Zai Water Treatment Plant for the Greater Amman area.

The total effluent for the year 2017 was 228 MCM from which 73 MCM were used for drinking water and the rest for industrial and irrigation purposes.



### 7.4 Treatment plants

#### 7.4.1 Wastewater treatment plants

Due to the overall water shortage in Jordan, the use of unconventional water sources with constant renewal has become increasingly in focus. One of the sources is reclaimed wastewater. The amount of reclaimed wastewater in 2017 was around 165 million cubic meters, from which 90% are reused directly (direct agreements with farmers) or indirectly (mixing with rainwater and surface water in dams). The sewage network reaches more than 65% of the households. The collected wastewater is clarified in 31 public wastewater treatment plants. In order to obtain optimal and quick treatment of wastewater, in most of the WWTP the mechanical treatment system is used (24 out of 31). It is very important to treat all, domestic and industrial waste water, to protect surface and groundwater from pollution, to preserve the environment and public health and to provide a renewable water source for irrigation. The Wastewater Management Policy in the Kingdom of Jordan regulates the development, management, collection, treatment and reuse of waste water in accordance with the standards and legislation governing this vital sector



Figure 7-9. Waste Water Treatment Plants in Jordan

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	Final R	euse	BOD DESIGN	BOD IN	BOD OUT	Effici- ency	Design capacity
WWTP	Type of crops	Residual	(mg/l)	(mg/l)	(mg/l)	%	(m³/day)
Al-Samra	Fodder, Olive	King Talal Dam	650	550	5.3	0.99	364 000
Aqaba	Irrigation, Industry	Irrigation	420	415	3.2	0.99	12 000
Aqaba	Irrigation, Palm Trees, windbreakers	Irrigation	900	840	36.7	0.96	9 000
Ramtha	Fodder	Irrigation	1000	730	28.8	0.96	7 400
Mafraq	Fodder	Irrigation	825	1090	17.8	0.98	6 050
Madaba	Fodder, Olive	Irrigation	950	920	14.6	0.98	76 000
Ma'an	Fodder, Olive	Valley	700	515	8.1	0.98	5 770
Irbid	-	Jordan River	800	1240	50	0.96	11 023
Wadi Al Shallala	-	Jordan River	760	600	30	0.95	13 700
Kufranja	Fodder, Olive, Forest	Irrigation	850	770	16	0.98	9 000
Abu- Nusair	Jordan Street (plants)	Berain Valley	1100	620	33	0.95	4 000
Salt	Olive, Fruit Trees	Wadi Shu'eeb Dam	1090	750	19	0.97	7 700
Baq'a	Plantation, Olive, Polo Playground	King Talal Dam	800	580	32	0.94	14 900
Karak	Fodder, Olive, Forest	Irrigation, Valley	800	1850	414	0.78	5 500
Tafieleh	-	Fifa Ghour	1050	730	303	0.58	7 500
Wadi Alseer	Olive	Kafrain Dam	780	420	56	0.87	4 000
Fuhais	Fodder, Olive	Wadi Shu'eeb Dam	995	500	16.5	0.97	2 400
Wadi Arab	-	Jordan River	995	430	40	0.91	21 000
Wadi Hassan	Olive, Fruit Trees, plantation	Irrigation	800	680	23	0.97	1 600
Wadi Musa	Fodder, Olive	Irrigation	800	350	4.4	0.99	3 400
Tal Al Imantah	-	Drying + Jordan River	2000	1160	246	0.79	400
Akaider	Olive, Fruit Trees	Irrigation around the plants	1500	2050	218	0.89	4 000
Lajjoun	Fodder	Lajjoun Valley	1500	590	17	0.97	1 200
Talbieh	Fodder, Forest, Decoration plants	Irrigation	800	720	60.7	0.92	4 500
Me'rad	Olive, Fruit Trees	King Talal Dam	800	850	47	0.94	9 000
Mu'ta,Mazar Adnanieh	Fodder	Valley	600	550	24	0.96	7 600

Table 7-3. Overview of design	parameters and final reuse for	<sup>.</sup> WWT Plants in Jordan



	Final R	BOD DESIGN	BOD IN	BOD OUT	Effici- ency	Design capacity	
WWTP	Type of crops	Residual	(mg/l)	(mg/l)	(mg/l)	%	(m³/day)
Fujaij Shubak	-	No discharge in lagoons till now	1850	600	11.3	0.98	
North Shuna	-	Jordan River		520	47	0.91	1 200
South Amman	Fodder, Olive	Special pools near the plants	750	740	26.3	0.96	52 000
Za'taree camp (TF)	Fodder	-	1150	1550	29.5	0.98	
Za'taree camp (MBR)	Fodder		1150	1550	460	0.70	

Table 7-4. Development of Influent, Effluent and Operation Capacity for WWT plants in Jordan

WWTP	2015/2016 Influent (m <sup>3</sup> /day)	2015/2016 Effluent (m³/day)	2015/2016 Operation Ratio %	2016/2017 Influent (m³/day)	2016/2017 Effluent (m³/day)	2016/2017 Operation Ratio %
Al-Samra	294862	269802	81.01	343802	316832	94.5
Aqaba	12475	10062.5	103.96	12719	12337	106
Aqaba	6699	4995.5	74.43	7066	6854	78.5
Ramtha	4743	4227.4	64.09	4268	3957	57.7
Mafraq	3556	2932.5	58.78	3731	3694	61.7
Madaba	6549	5381.3	86.17	7388	6408	97
Ma'an	2288	2209	39.64	2324	2254	40.3
Irbid	8350	8041.5	75.75	8272	7817	75
Wadi Al Shallala	5912	5655.5	43.15	8421	8015	61.5
Kufranja	2506	2453.5	27.84	3497	3263	38.9
Abu- Nusair	3201	3096.9	80.03	3385	3317	84.6
Salt	7289	7289.4	94.66	8086	7703	105
Baq'a	11862	11277.5	79.61	14563	13889	97.7
Karak	1408	1384	25.60	1321	1308	24
Tafieleh	1450	1335.6	19.33	1945	1925	25.9
Wadi Alseer	5040	4473	126.00	4976	4973	124.4
Fuhais	2719	2655.3	113.29	2928	2861	122
Wadi Arab	12851	12414.4	61.20	12683	12306	60.4
Wadi Hassan	1594	1435.3	99.63	1262	1181	78.9
Wadi Musa	2628	2524.3	77.29	2832	2794	83.3
Tal Al Imantah	363.2	355.8	90.80	383	377	95.8
Akaider	3400	3060	85.00	2087	2024	52.2
Lajjoun	595	512.5	49.58	712	691	59.3
Talbieh	773	700	17.18	895	868	19.9
Me'rad	6268	5954.2	69.64	4397	4265	48.9
Mu'ta,Mazar Adnanieh	1203	1164.4	15.83	1369	1059	18



WWTP	2015/2016 Influent (m <sup>3</sup> /day)	2015/2016 Effluent (m³/day)	2015/2016 Operation Ratio %	2016/2017 Influent (m³/day)	2016/2017 Effluent (m³/day)	2016/2017 Operation Ratio %
Fujaij Shubak	95	85.5	27.14			
North Shuna	777	660.7	64.75	655	635	54.6
South Amman	5000	4500	9.62	16219	15732	31.2
Za'taree camp	600	560	34.09			
Za'taree camp	840	780	47.73			
TOTAL	418 000	382 000	62.6%	482 177	449 339	64.64%

In most of the waste water treatment stations the amount of daily influent increased from 2015/2016 to 2016/2017. The same applies for the effluent. This means that the total operation ratio is as well increasing from 62% to 64%. Some of the waste water treatment stations are near their design capacity. Others however, still have the capacity for further increasing the influent, which is needed as with a rising population also the amount of sewage in increases.



#### 7.4.2 Desalination plants

In order to bridge the gap between water demand and supply in Jordan, MWI/WAJ have conducted several studies and researches to find appropriate ways to provide more water quantities and to exploit the available water resources in a manner that cope with the Jordanian and international standards for drinking water. One option is the desalination of well water with high salinity, using the latest techniques and technology. Since 1997, MWI/WAJ have created several desalination projects in different regions in the kingdom, using reverse osmosis in order to reduce the salinity of water mainly from wells. Additionally, to the listed treatment plants, three mobile desalination plants are available. For a long-term and sustainable solution to the Jordanian water shortage, desalination plants for seawater need to be set up as well. The treated water was around 8 851 m<sup>3</sup>/hr in 2017.



Figure 7-10: Treatment plants for desalination.

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Station	Governorate	Treated Water m³/hr	Туре	Source	Date of est.
Ruwaished	Mafraq	90	reverse osmosis	Well	2000
Deir Alla	Balqaa'	50	reverse osmosis	Well	2001
Zarqa	Zarka	600	reverse osmosis	Well	2002
Wadi Araba	Aqaba	35	reverse osmosis	Well	2002
Abu Al- Zegan	Balqaa'	1800	reverse osmosis	Well	2003
Safawi	Mafraq	55	reverse osmosis	Well	2003
Al-Omari	Aqaba	30	reverse osmosis	Well	2003
Qatar	Aqaba	3.5	reverse osmosis	Well	2003
Ghor Safi	Karak	75	reverse osmosis	Well	2005
Ain Sara	Karak	55	reverse osmosis	Spring	2005
Jafr	Ma'an	35	reverse osmosis	Well	2007
Al-Gweibeh	Karak	15	reverse osmosis	Well	2007
Al-Karama Border	Mafraq	18	reverse osmosis	Well	2007
Ghor Fifa	Karak	30	reverse osmosis	Well	2008
Al-Kraymeh	Balqaa'	100		Well	2008
Al-Rwaished 6&7	Mafraq	70	reverse osmosis	Well	2008
Zara Ma'in	Balqaa'	5300		Surface raw water	2006
Al-Omari	Zarka	5	reverse osmosis	Well	2008
Prince Faisal Gardens	Jarash	300	reverse osmosis	Well	2010
Dabaan	Mafraq	10	reverse osmosis	Well	2014
Tabaqet Fahel	Irbid	175	reverse osmosis	Well	2015

Table 7-5: Treatment plants for desalination in Jordan

#### 7.4.3 Other treatment plants for drinking water production

Additionally, to waste water treatment plants and desalination plants, many other treatment plants are working to treat well and surface water mainly from nitrate, sulfur, iron, turbidity and bacterial contamination.

Table 7-6: Treatment plants for nitrate, sulfur, iron, turbidity or bacterial contamination for individual wells, well fields or springs

Station	Governorate	Removed contaminant	Treated water (m <sup>3</sup> /hr)	Treatment method	Source	Date of est.
Mahasi	Ramtha	Nitrate	50		Well	1997
Shehan	Karak	Sulfur	45		Well	1998
Jabir	Ramtha	Sulfur	120		Well	1998
Mowagar	Amman	Sulfur	150			1998
Wadi Es-sir	Amman	Bacterial	400	UV, Microfiltration, Chlorination	Spring	1999



Station	Governorate	Removed contaminant	Treated water (m <sup>3</sup> /hr)	Treatment method	Source	Date of est.
Qairawan	Jarash	Bacterial	120	UV, Microfiltration, Chlorination	Spring	1999
Al-Deik	Jarash	Bacterial	120	UV, Microfiltration, Chlorination	Spring	1999
Qantara	Ajloun	Bacterial	120	UV, Microfiltration, Chlorination	Spring	1999
Kafren	Balqaa'	Turbidity/iron	250		Well	2001
Sharai'a	Balqaa'	Bacterial	700	Microfiltration		2001
Rusaifa	Amman	Bacterial	850	Coagulation, flocculation, settling, chlorination		2001
Souf West	Jarash	Turbidity	90	Coagulation, filtering	well	2003
Lajoun	Karak	Iron/Turbidity	1200	Oxidation, sedimentation	well	2003
Shawahid	Jarash	Bacterial	120	UV	well	2003
Tahoneh	Ma'an	Sulfur	40		well	2004
Ras El-Ein	Amman	Bacterial	900	Ultrafiltration	spring	2004
Manshia	Ma'an	Sulfur	50		well	2004
Uneza	Ma'an	Sulfur & Ammonia	50		well	2005
Baqa' well 2A	Amman	Iron	25	Adsorption mechanism	well	2005
Lajoun	Karak	Iron/Turbidity	100	Sand filtration	well	2006
Marhab	Zarka	Iron/Turbidity	50	Sand filtration	well	2006
Muhareb	Amman	Iron/ Temperature	20	Sand filtration	well	2006
Al-Qinya	Zarka	Bacterial	95	Ultrafiltration	spring	2007
Znayia	Mafraq	Nitrate	65	Chlorination, sand filters, desalination	well	2008
Al-Qinya exploratory well	Zarka	Iron/Turbidity	100	Aeration, sand filter	well	2008
Beerain	Zarka	Bacterial	110	Ultrafiltration, UV	well	2008
Kofr Khal	Irbid	Hardness/ Turbidity	15	Filtration, ion exchange filter	well	2014
Jaber	Mafraq	Iron/ Ammonia/ Arsenic	40	Aeration, sand filters, IOCS and GFH adsorption filters	well	2014
Sath Ma'an	Ma'an	Hardness	15	lon exchange filter	well	2015
Mujib dam	Karak	Bacterial	500	Filtration, oxidation with chlorine, ultrafiltration, UV, activated carbon filters	Surface water	2015

# Annexes

Map 1: Hydrogeological Units

Map 2: Monitoring Network

Map 3: Water Infrastructure





The Ministry of Water and Irrigation developed and is continuing to further improve the monitoring network of the different water resources in Jordan. The monitoring network collects quantitative and qualitative data in the country with the main objective to support the decision-making processes in the ministry. This Yearbook collects, represents and evaluates the hydrological data of selected stations, in order to inform decision makers and stakeholder in the water sector, as well as the interested public on the current situation of the water resources.

One very important parameter is the groundwater level in the different aquifers, since it is an indicator of the status of Jordan's main water resource. In addition, the quantification of the surface water resources is an essential part of the monitoring. Many runoff-measuring stations are installed in the watercourses in Jordan to record the runoff during the rainy season. The measurement of the discharge in important springs is also a part of the surface water monitoring. The Ministry of Water and Irrigation also collects meteorological data in several weather stations distributed over the entire country. Most of the stations are measuring the precipitation only; others furthermore register evaporation, air temperature, solar radiation, wind speed and direction.

The Laboratories and Quality Sector of the Water Authority of Jordan monitors the quality of the water resources. The monitoring program comprehends the collection of water samples from surface water, springs, groundwater wells, water infrastructure and wastewater treatment plants.

Other data collected by Water Authority of Jordan describes the annual abstraction in major well fields, as well as the capacity of wastewater treatment and desalination plants.