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Reclaimed Water Project
Ministry of Water and Irrigation (MoWI)
Jordan Valley Authority (JVA)Deutsche Gesellschaft für Technische Zusammen-arbeit (GTZ) GmbH
Email: rwp@go.com.jo

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III. List of Abbreviations

BOD_5	Biological Oxygen Demand
BWP	Brackish Water Project
COD	Chemical Oxygen Demand
DA	Development Area
DO	Dissolved Oxygen
du	dunum (1 dunum = 0.1 ha or 0.001 km^2)
EC	Electrical Conductivity
FOG	Fat, Oil and Grease
NO_3-N	Nitrate-Nitrogen
GMC	Groundwater Monitoring Concept
MIN-VO	Deutsche Mineral- und Tafelwasserverordnung (German Mineral and Table Water Standard)
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
GW	Groundwater
JDWS	Jordan Drinking Water Standard
JVA	Jordan Valley Authority
KAC	King Abdullah Canal
KTR	King Talal Reservoir
l/c/d	liter per citizen and day
MBAS	Chemical Detergents
MCM	Million Cubic Meter
mg/l	milligram per liter (= ppm)
MoWI	Ministry of Water and Irrigation
MSL	Mean Sea Level
NO_3-N	Nitrate nitrogen
RW	Reclaimed Water
RWP	Reclaimed Water Project
SAR	Sodium Adsorption Ratio
sp	sampling point
TDS	Total Dissolved Solids
T-N	Total Nitrogen
T-P	Total Phosphorus
T-PO_4	Total Phosphate
TSS	Total Suspended Solids
WAJ	Water Authority of Jordan
WWTP	Wastewater Treatment Plant

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1. Summary

The Jordan Valley Authority (JVA), along with other Jordanian organizations and the German Technical Cooperation (GTZ), is currently implementing the *Reclaimed Water Project (RWP)*. One important activity of the RWP is the establishment of a groundwater monitoring system focusing on the impact of reclaimed water (RW), which is used for agricultural irrigation, on the groundwater (GW) in the middle and southern Jordan Valley.

Based on available studies, data interpretation, interpretation of geological maps and intensive reconnaissance walks in the Southern Jordan Valley and the eastern escarpments (foothills) the groundwater monitoring concept (GMC) has been developed. Essential for the GMC is a hydrogeological model for the relevant close-to-the-surface aquifer in the area.

The main idea for the GMC is that groundwater in the Jordan Valley generally flows from east to west. Therefore, it should not be affected by the use of RW when it reaches the irrigation areas from the east. However, along the flowpath to the west the groundwater quality could be affected below arable land impacted by agricultural activities. Hence, the groundwater quality should be monitored before and within the irrigated areas in the Jordan Valley.

Three different sampling sites for the GMC have been selected, depending on various local hydrogeological conditions and different use of RW for irrigation. Some areas are supplied with KTR-water and others get water from KAC-south, a mixture of KAC-north and KTR water. The main areas for the GMC are DA 22, DA 23 (northern part) and DA 28.

Detailed recommendations are given about suitable sampling points – already existing ones as well as new observations wells which still have to be established – and relevant parameters (first of all: EC, Na, Cl, TDS, NO_3, PO_4, K, B, and heavy metals [Cr, Pb, Cd, Co, Ni]). The choice of hydrochemical parameters for the GMC is based on assessments of the occurrence of critical substances in RW and their possible change on the surface and within the soil after irrigation (especially nutrients). Within the GMC, measured concentrations should be referred to permissible levels mentioned in the Jordanian Drinking Water Standard and in the German Source and Table Water Standard. Additionally, an assessment about potential adsorption of critical substances in the soil was conducted.

The GMC should start as soon as possible, accompanied by qualified personnel. The GMC and the database established so far should be evaluated after a 12-months-measuring-period in 2005. The GMC should be adjusted according to the results of this evaluation.

2. Introduction, Task

The Jordan Valley Authority (JVA), along with other Jordanian organizations and the German Technical Cooperation (GTZ), is currently implementing the *Reclaimed Water Project (RWP)*. One important activity of the RWP is the **establishment of a groundwater monitoring system** focusing on the impact of reclaimed water (RW), which is used for agricultural irrigation, on the groundwater (GW) in the middle and southern Jordan Valley.

Consequently, an appropriate and applicable concept for **groundwater monitoring in the middle and southern Jordan Valley** is necessary. The following **questions** and **topics** have to be elaborated:

- relevant parameters to be monitored
- representative sampling sites for GW monitoring and / or comparison of uncontaminated and contaminated GW locations (foothills, Jordan Valley)
- assessment of GW flow direction(s)
- assessment of trends in parameters' concentrations
- adsorption of substances (heavy metals, nutrients) in the soils
- recommendations for thresholds regarding critical substances/parameters
- recommendations for measuring locations and measuring dates, frequencies, and periods
- recommendations for evaluation procedures and interpretation of monitored data.

The highest amount of reclaimed water (RW) used for irrigation comes from the wastewater treatment plant (WWTP) Khirbet As-Samra, where the wastewater from Amman is treated. This WWTP is overloaded, but the reclaimed water (RW) is discharged into the Zarqa River and the King Talal Reservoir (KTR) respectively. Therefore, a measurable impact of reclaimed water (RW) in groundwater might be primarily expected in areas where RW from the KTR is used for **irrigation**. Hence, the investigations focus on areas which are irrigated with **KTR-water** and with water from **KAC-south**.

According to these questions and topics the available data and reports had to be studied and interpreted. In addition, intensive reconnaissance walks were conducted. Based on this knowledge, the groundwater monitoring concept (GMC) was developed and is documented in this report.

3. Available Data and Reports, Activities

The information used for this report is listed in chapter IV. Additionally, the following activities were conducted in Jordan from February 16th to 20th 2004:

- studies, evaluations, and interpretations of available documents (reports and maps)
- interpretations of current soil analyses
- interviews with experts and project personnel
- intensive reconnaissance walks in the Southern Jordan Valley and the eastern escarpments (foothills).

The first conclusions for the groundwater monitoring concept have already been drawn in Jordan, presented in a short summary report, and discussed with RWP personnel.
This report provides the final result/concept.

4. Project Area, Use of Reclaimed Water and Possible Risks for Groundwater Quality

4.1 General Information on Project Area

The project area of the Reclaimed Water Project (RWP) is located in the middle and southern part of the Jordan Valley between the Wadi Kufrinja in the north and the Dead Sea in the south. It covers a 45 km long and 3 to 10 km wide area (about 222,000 du) on the recent flood plains of the Jordan River in the west and the escarpment of the eastern highlands in the east.

Four topographical units characterize the Jordan Valley and the adjacent highland areas:

- Jordan Rift Valley Floor (from 390 to 200 m below MSL)
- Foothills (from 200 to 0 m below MSL)
- Escarpment (between 0 and 800 m above MSL)
- Eastern highlands or Side Wadis Basin (800 m above MSL).

The recent flood plains of the Jordan River are generally referred to as “Zhor”. The “Zhor” is flanked by the “Katar”, which was formed by erosion of soft marls and is not suitable for agriculture. The terrace between the “Katar” and the escarpment of the eastern highlands is the “Ghor”, an old alluvial plain of the Jordan River.

The eastern escarpment of the Jordan Valley is formed by the “eastern highlands” (lime- and sandstone plateaus), bordering the valley all along its course. Since the escarpment and the eastern highlands are deeply divided by east-west orientated streams (“side wadis”), this area is also called the Side Wadi Basin. East of the RWP area, these streams include (from north to south): Wadi Kufrinja, Zarqa River, Wadi Shueib, and Wadi Kafrein. These wadis gather the water from the eastern highlands.

4.2 Use of Reclaimed Water for Agricultural Irrigation

In more than 90 percent of the Jordan Valley, soil moisture from rainfall and shallow groundwater is inadequate to sustain non-irrigated agriculture. This creates a demand for irrigation water from other sources, including groundwater from deeper aquifers, springs and reclaimed water from wastewater treatment plants. In the project area reclaimed water is used for agricultural irrigation as follows:

Irrigation areas

About 145,000 du of the entire RWP area is cultivated. Cultivation is carried out mostly on open fields (84 %), or in tunnels and greenhouses (each about 8 %). Irrigation is commonly performed by drip irrigation (nearly 70 %) and to a lesser degree by furrow/basin irrigation (30 %). Overhead sprinkler irrigation is rarely used.

Rainfall periods

The rainy season in the Jordan Valley extends from October to April with maximum precipitation in January and February.

Irrigation water sources

Five principal water sources for irrigation water in the RWP area can be distinguished:

1. **River water:** Yarmouk river water is delivered by KAC-north to the project area. Important side wadis east of the project area are Wadi Zarqa (with King Talal Reservoir), Wadi Kufrinja, Wadi Shueib (with reservoir), and Wadi Kafrein (with reservoir). In KTR in Wadi Zarqa, the surface run-off water and RW (see below) is stored and blended.
2. **Effluents of municipal wastewater treatment plants (WWTP).** The 8 WWTPs are located in Kufrinja, Khirbet As-Samrah, Baqa'a, Jerash, Abu Nuseir, As-Salt, Fuheis, and Wadi Essir /3/. The WWTPs dicharge their effluents into the side wadis and reservoirs as outlined below. Note, however, that the major RW receiving wadis have very low flow with wastewater comprising a significant portion of stream flow.
   - **WWTP Kufrinja**: Discharge directly to Wadi Kufrinja.
   - **WWTP Jerash, WWTP Baqa'a, WWTP Abu Nuseir, and WWTP Khirbit As-Samra** (**overloaded**): These WWTPS discharge directly into several small Wadis that are tributary to Wadi Zarqa/**King Talal Reservoir (KTR)**. The water of Wadi Zarqa is discharged into the **King Abdallah Canal (KAC)** via Abu Ezzehan Canal or is directly used for irrigation via Zarqa Carrier I and II.
   - **WWTP Fuheis** and **WWTP As-Salt:** Discharge directly to Wadi Shueib and finally downstream into the Wadi Shueib Reservoir.
   - **WWTP Wadi Essir:** Discharge directly to Wadi Essir, Wadi Bukath, and finally downstream into the Wadi Kafrein Reservoir.

3. **Groundwater:** Groundwater of highly variable quality is pumped from a large number of governmental and private irrigation wells /7/.

4. **Springs:** Spring water is frequently used for irrigation (even mineral-rich spring water) and a large number of springs with very different water quality (though mostly saline) occur in the side wadis. However, many springs have ceased due to overuse of the aquifers.

5. **Rainfall:** Rainfall is a very limited source for irrigation water since the average annual rainfall in the Jordan Valley is between 70 mm in the south, near to the Dead Sea, and 380 mm in the north. This is a tenth of the potential evaporation (from 2.000 to 2.500 mm per year) at mean annual temperatures between 20° (January) to 35 - 40 °C (June-

September). However, rainwater runoff occurs in the eastern highlands and in the urbanized Amman area during winter and flows into the wadis/reservoirs.

Water quantity

The quantity of irrigation water in the RWP area supplied by JVA averages about 59 MCM per year. The main part of the water comes from the Zarqa River/KTR (about 54.3 and 58.11 MCM per year in 2002 and 2003, respectively) whereas the other side wadis (Kufrinja, Shueib, and Kafrein) contribute only minor amounts of water (between 0.5 and 7.8 MCM per year in 2002 and 2003, respectively).

Quantity of RW for irrigation

The quantity of RW may be estimated from the designed (planned) and operating capacities of the WWTPs as outlined below:

- **WWTP Kufrinja:** **0.657** (designed) and **0.803** (operating) MCM/year
- **WWTP Jerash:** **1.277** and **1.058** MCM/year
- **WWTP Baqa'a:** **5.475** and **4.380** MCM/year
- **WWTP Abu Nuseir:** **1.460** and **0.730** MCM/year
- **WWTP Khirbit As-Samra:** **24.820** and **65.700** MCM/year (overloaded)
- **WWTP Fuhis:** **0.876** and **0.547** MCM/year
- **WWTP As-Salt:** **2.81** and **1.387** MCM/year
- **WWTP Wadi Essir:** **1.460** and **0.693** MCM/year

Therefore, more than 80 % of the wastewater is actually treated at WWTP Khirbit As-Samra. I.e., if all the treated (reclaimed) wastewater is used for irrigation, the quality of the **outlet of WWTP Khirbit As-Samra is the most essential for the possible impact of irrigation water to soil and groundwater** (see also tables 4-1 and 4-2 and page 10).

4.3 Quality of Reclaimed Water for Agricultural Irrigation

The specific characteristics of wastewater in Jordan result from:

- the low average domestic water consumption (around 70 l/c/d country-wide),
- the high salinity of municipal water supply (in average 580 ppm of TDS[1]),
- the wastewater treatment in waste stabilization ponds (85% of the total generated wastewater) with high evaporation rates,
- the low level of industrial discharges to sewage treatment plants.

The specific characteristics of wastewater in Jordan are documented in the analysis of effluents from eight WWTPs provided in annex 1 of /3/. According to these lists, the concentrations of the following **parameters**[2] are **typically increased in RW**, i.e. the permissible levels fixed in JS 893:2002 were generally (g), mostly (m) or sometimes (s) exceeded in the effluent of WWTPs Kufrinja, Jerash, Baqa`a, Abu Nuseir, Khirbet As-Samra, Fuhis, As-Salt, Wadi Essir in 2002:

- organic parameters (BOD_5, COD) (m)
- total suspended solids (TSS) (g)
- fat, oil and grease (FOG) (m)
- bacteriological load represented by E. coli (g)
- heavy metals: lead (Pb) (s), chrome (Cr) (g)
- boron (B) (g).

The measured **nitrate concentrations** were lower than 10 mg/l at 6 out of 8 WWTPs in 2002. The exceptions are the WWTP Baqa`a with a nitrate concentration of 15.6 mg/l (2002) and the WWTP Abu Nuseir with nitrate concentrations up to 41.9 mg/l (2002). The permissible level with regard to the "Reclaimed Domestic Wastewater Standard No 893/200" (JS 893:2002) is 45 mg/l, which is not exceeded in any case.

The measured **TDS-values** (2002) were also **generally below the permissible level in JS 893:2002** which is 1,500 mg/l. The only exception is the single value of 1,645 mg/l measured at WWTP Khirbet As-Samra (mentioned in /3/).

The following permissible levels for the use of irrigation water without restrictions are listed in the FAO Guideline, 1985 (mentioned in /3/):

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[1] Only water with TDS-concentrations up to 450 mg/l may be used for irrigation without restrictions (see below).

[2] Please note: Not all parameters listed in JS 893:2002 were measured at the above mentioned WWTPs. Additionally, the list of measured parameters is slightly different between the several WWTPs /3/.

- nitrate-nitrogen (NO_3-N): < 5 mg/l; i.e. NO_3: < 22.5 mg/l
- boron (B): 0,7 mg/l
- TDS: 450 mg/l

These permissible levels were exceeded by boron and TDS in all WWTPs (2002), but - with one exception (WWTP Abu Nuseir) - not for nitrate.
With regard to the **Jordanian Drinking Water Standard** (JDWS; Jordanian Technical Regulation No. 286/2001), the concentrations of most chemical parameters measured at the WWTPs (2002; listed in annex 1 of /3/) were lower than the **permissible (pl) or maximum**[1] **levels (ml)**, outlined in the following (see also chapter 6.5):

- pH-value: 6.5 – 8.5
- **TDS: 500 mg/l (pl); 1,500 mg/l (ml)**
- **Nitrate (NO_3): 50 mg/l (pl); 70 mg/l (ml)**
- Copper (Cu): 1.0 mg/l (pl); 1.5 mg/l (ml)
- Iron (Fe): 0.3 mg/l (pl); 1.0 mg/l (ml)
- Manganese (Mn): 0.1 mg/l (pl); 0.2 mg/l (ml)
- Nickel (Ni): 0.07 mg/l (pl)
- **Lead (Pb): 0.01 mg/l (pl)**
- Cadmium (Cd): 0.03 mg/l (pl)
- Zinc (Zn): 3.0 mg/l (pl); 5.0 mg/l (ml)
- **Chrome (Cr): 0.05 mg/l (pl)**
- **Boron (B): 2.0 mg/l (pl)**

The concentration of **chrome** in the RW was **mostly above the permissible level in the Jordanian Drinking Water Standard**, which is 0.05 mg/l. In addition, the concentrations of **lead and boron frequently** exceeded the regarding permissible levels, which are 0.01 mg/l and 2.0 mg/l, respectively.
It has to be considered that only some of the parameters listed in the Drinking Water Standard were actually measured at the WWTPs (2002) and that a distinct change (dilution-effect) of wastewater composition takes place by blending with river/wadi water and during storage in reservoirs.

The bacteriological load of the RW is generally increased with regard to Drinking Water Standards. The concentration of components (e.g. BOD_5, COD) is also high in RW.
The following **comprehensive analysis of the water quality of Khirbet As-Samra effluent** (Zarqa River at KTR-inlet) is given in /14/. These results are further considered as relevant for the use of KTR-water for irrigation (e.g. in DA 22 and DA 23).

[1] In absence of a public water source of better quality

Table 4-1: Average quality of As-Samra outlet, measured at Zarqa River, KTR-inlet (from /14/; arithmetic mean of measurements taken between April 1999 – February 2000)

Parameter	Unit	Concentration
TSS	mg/l	118
BOD_5	**mg/l**	**47**
COD	mg/l	183
SO_4	mg/l	129
NH_4-N	**mg/l**	**43**
NO_3-N	**mg/l**	**8.34**
T-N	**mg/l**	**65.12**
T-P	mg/l	13.0
B	mg/l	0.66
TDS	mg/l	1,426
EC	µS/cm	2,703
DO	mg/l	6.45
pH		8.12
Na	mg/l	276
Al	**mg/l**	**0.3**
As	mg/l	<0.005
Cd	mg/l	<0.003
Cr	mg/l	<0.025
Cu	mg/l	<0.025
Fe	mg/l	0.17
Li	mg/l	<0.025
Mn	mg/l	0.06
Ni	mg/l	<0.02
Pb	mg/l	<0.01
Zn	mg/l	0.03
Hg	mg/l	<0.001

With regard to the **Jordanian Drinking Water Standard** (JDWS), except of **aluminium** (Al), which is slightly concentrated **above the permissible level** (0.2 mg/l), all of the above mentioned parameters have concentrations below the permissible and/or maximum levels, even the nitrate (37 mg/l, estimated from NO_3-N). However, it has to be emphasized, that the **load with nitrogen-compounds is increased** in RW. The possible impact of nitrogen-compounds and BOD_5 to groundwater is elaborated in chapter 6.3.
Phosphorus and phosphate are not listed in the JDWS.

The concentrations of **nitrate-nitrogen (NO_3-N) and TDS** mentioned in table 4-1 are above permissible levels for the use of **irrigation water** without restrictions fixed in the FAO Guideline, 1985 (see above).

The following comprehensive analysis of the **water quality of KTR-outlet** (Zarqa River) is also given in /14/.

Table 4-2: Average quality of KTR-outlet, measured at Zarqa River downstream KTR (from /14/; arithmetic mean of measurements taken between April 1999 – February 2000)

Parameter	Unit	Concentration
TSS	mg/l	14
BOD_5	**mg/l**	**6**
COD	mg/l	45
SO_4	mg/l	175
NH_4-N	**mg/l**	**21**
NO_3-N	**mg/l**	**2.9**
T-N	**mg/l**	**28.37**
T-P	mg/l	6.8
B	mg/l	0.6
TDS	mg/l	1,379
EC	µS/cm	2,483
DO	mg/l	3.8
pH		7.84
Na	mg/l	254
Al	**mg/l**	<**0.01**
As	mg/l	<0.005
Cd	mg/l	<0.003
Cr	mg/l	<0.025
Cu	mg/l	<0.025
Fe	mg/l	0.2
Li	mg/l	0.038
Mn	mg/l	0.22
Ni	mg/l	<0.02
Pb	mg/l	<0.01
Zn	mg/l	<0.01-0.03
Hg	mg/l	<0.001

The results in table 4-2 should not to be considered as relevant for the use of KTR-water for irrigation, because RW is diluted by other sources within the KTR and the measuring period was quite short. Therefore, the figures in table 4-2 possibly show a better RWP-quality in reality, but TDS is still above permissible levels for the use of irrigation water without restrictions fixed in the FAO Guideline, 1985 (see above).
Otherwise, the concentrations in **table 4-1** might represent a **worst-case-scenario** which should be taken for further considerations.

5. Hydrogeology

5.1 Geological Setup (Overview)

The Jordan Rift Valley resulted from rifting along a vertical line going from the Dead Sea to the Red Sea. During the last ten million years, this rifting event led to a strong subsidence (vertical displacement max. 3,000 m) of the Jordan Rift Valley relative to the highlands on both sides along faults, and to a horizontal displacement of about 100 km with the eastern side offset northwards relative to the western side.
The Jordan Rift Valley floor consists mainly of non-consolidated alluvial sediments (gravel, sand) of Holocene age, that overly marls, clays and evaporites of Pleistocene age.
The mountains forming the eastern highlands (Side Wadi Basin) are mainly formed of sedimentary rocks (sand- and limestone) of Upper Triassic to lower Paleogene age.

5.2 Aquifers, General Groundwater Flow

Groundwater resources and relevant aquifers in the RWP area and its catchment area belong to the **Jordan Rift Valley Floor** and the **eastern highlands (Side Wadi Basin)**. The aquifers of the Jordan Valley and the Side Wadi Basin can be grouped into three major units (from base to top, see also annex 1 for details):

1. **Lower Aquifer Complex**: This sandstone-dominated hydraulic system includes the aquifers of the Zarqa Group (Triassic-Jurassic, Code Z1/2) and the Kurnub Group (Lower Cretaceous, Code K1/K2). Both aquifer systems are hydraulically connected. The entire thickness of this group is about 600 m and increases from south to north.
2. **Upper Aquifer Complex**: This limestone-dominated hydraulic system includes the aquifers of the Ajlun Group (Cenomanian-Turonian) and the Balqa Group (Coniacian-Eocene). The latter contains the important aquifer system of the Amman and Wadi Essir Formations.
3. **Jordan Valley Alluvial Aquifer System**.

Along the Jordan Valley escarpment and the western part of the highlands, the aquifers dip to the west towards the Jordan Valley. The north-south graben fault in the Jordan Valley is the contact between the aquifer east of the fault and the Jordan Valley alluvial system to the west. The main direct recharge of the aquifers takes place in the high rainfall regions of the eastern highlands, where the strata of the Upper (limestone-dominated) Aquifer Complex of the Amman-Wadi Sir Groups comes to the surface. Along the mountain ridge a water divide exists, separating the water flow in an eastern and western direction.

The Lower (sandstone-dominated) Aquifer Complex of the Kurnub and Zarqa Groups receives its replenishments indirectly by vertical recharge from the overlying aquifer systems. In the foothills area of the escarpment, wells are established in the confined sandstone aquifers. The Jordan Valley Alluvial Aquifer System is recharged by lateral and vertical influx from adjacent older aquifer systems.

5.3 Assessment of Groundwater Flow Direction, Hydrogeological Model

With regard to the groundwater monitoring concept (GMC), a hydrogeological model for the RWP-area can be developed as follows (see annexes 1, 3 and 4):

- The Jordan Valley Alluvial Aquifer System is the relevant groundwater bearing layer (aquifer), because it is (normally) close to the surface. Hence, it can be influenced by activities on the surface, e.g. use of RW for irrigation.

- It is not possible for RW to have an impact on groundwater occurring in aquifers below the alluvial system. The artesian character prevents a vertical seepage from the surface to the deep groundwater bearing layers. However, the overlying alluvial system can partially be influenced by intrusion of salty groundwater from deeper aquifers.

- Within the alluvial sediments in the Jordan Valley the following hydrogeological units can be distinguished:
  - **Alluvial and Wadi Sediments** (alluvial fans) which occur along the foothills where wadis come into the Jordan Valley. These sand and gravel deposits are highly permeable and constitute the **relevant aquifer**. Such alluvial fans occur at Wadi Kafrein and Wadi Shueib in the south, and at Zarqa River and Wadi Rajeb in the north.
  - Between the area where the Zarqa River flows into the Jordan Valley and the area around the village of Karama, **marls and siltstones** dominate within the quaternary sediments. These less-permeable sediments contain only **poor amounts of groundwater**.

- The vulnerability[1] of the alluvial aquifer depends on the coverage by soil. Overlying clay rich soils reduce the vulnerability of the close-to-the-surface aquifer, especially if these soils are thicker. Clay rich soils occur mainly in the area around Deir Alla, e.g. in

[1] Vulnerability describes the potential risks for groundwater quality and groundwater bearing layers respectively, depending on the coverage by overlying strata and soil. Negative impacts on groundwater caused by human activities are more likely in case of high vulnerability. Vice versa, good coverage will protect groundwater effectively and causes low vulnerability.

the irrigation areas DA 22 and DA 23. Less clayey soils occur south of the Zarqa River and sand rich soils mainly predominate along the foothills.

- The **groundwater flow** in the alluvial system is generally orientated to the Jordan River, i.e. **from (north-) east to (south-) west**, and is also influenced by the following boundary conditions:
  - intrusion of salty groundwater from deeper aquifers, e.g. along tectonic fractures and in the surrounding of the Karameh Dam
  - lateral groundwater influx along the foothills (from the aquifers in the eastern mountainous area)
  - the possible influx of infiltrated water from the Zarqa River and other wadis.

- Renewal of groundwater by precipitation is insignificantly low in the Jordan Valley.

This hydrogeological model is considered as the theoretical foundation for the groundwater monitoring concept (GMC) described in the following chapter.

6. Concept of Groundwater Monitoring

6.1 General Ideas

The following statements refer exclusively to groundwater monitoring in the middle and southern Jordan Valley within the RWP. Other hydrogeological aspects are neglected.

The questions and topics mentioned in chapter 2 are elaborated in the following order:
1. assessment of groundwater flow directions based on a hydrogeological model for the relevant area
2. assessment of trends in concentrations with regard to groundwater monitoring in the future (relevant substances to be monitored)
3. representative sampling sites for groundwater monitoring considering (potentially) contaminated and uncontaminated locations (foothills, Jordan Valley)
4. adsorption of substances (heavy metals, nutrients) in the ground (soil and unsaturated zone)
5. recommendations for thresholds regarding critical substances/parameters
6. recommendations for measuring locations and measuring dates, frequencies, and periods
7. recommendations for evaluation procedures and interpretation of monitored data.

The **use of RW for irrigation** differs in the Jordan Valley as follows[1] (from north to south):
- **DA 29, 22, 23, 53, 24 + 25 (northern part): almost totally supplied by KTR**. Therefore, the maximum impact of RW on plants, soil and groundwater might be expected there. Other sources for irrigation water are not important, because of insignificant quantity.
- **DA 25 (southern part), 30, 54, 26, 27 + 28: almost totally supplied by KAC-south** (including KTR-water). Therefore, a measurable impact of RW on plants, soil and groundwater seems to be possible in these areas. Other sources for irrigation water are not significant.

The **distribution** of irrigation water and the distribution of **RW** has to be considered for **groundwater monitoring** respectively.

The following mentioned development areas are not suitable for groundwater monitoring within the RWP area, because RW is hardly used:
- DA 20 + 21: supplied by KAC-north (without KTR-water)
- DA 49 + 50: predominantly non-irrigated farm units

[1] The numbers for development areas of JVA (e.g. DA 22) are used in this report.

- DA 31: supplied by Kafrein Dam and local wells
- DA 32: predominantly supplied by Kafrein Dam, local wells and wadi
- DA 51 + 52: predominantly non-irrigated farm units, partly supplied by local wells.

If an impact on groundwater caused **by RW** is considered, the **change of groundwater quality can be expected as follows**:

- Normally, groundwater east of the agricultural areas in the Jordan Valley should not be impacted by irrigation water. However, around Deir Alla, east of the irrigated areas groundwater could already be infiltrated by water from the Zarqa River (including RW from KTR).
- If an impact of RW on groundwater takes place, it should cause higher concentration of significant hydrochemical substances along probable groundwater flowpaths (from east [foothills/wadis] to west).

Therefore, the goal of **the groundwater monitoring concept (GMC) is to prove this possible impact** of RW on groundwater quality. If concentrations of hydrochemical substances which are significant for RW do not increase along the likely flowpath ([nearly] east-west), groundwater might not be impacted by agricultural activities.

The monitoring of groundwater quality **needs a chain of suitable sampling points along the probable flowpaths**. Wells, drains etc. which already exist are helpful and should be used for monitoring. If appropriate sampling points are not available, additional and/or alternative sampling points have to be established.

6.2 Representative Sampling Sites for Groundwater Monitoring

Considering the hydrogeological situation in the Middle and Southern Jordan Valley and the above mentioned distribution of irrigation water/RW within the RWP-area, the sampling sites listed in following table 6-1 are recommended for groundwater monitoring.

Tabelle 6-1: Recommended sampling sites for groundwater monitoring

Sampling sites (DA)	Hydrogeological conditions and soil coverage	Possible and/or necessary sampling points	RW normally used for irrigation
22, 23 (north)	alluvial fans (most likely highly permeable and groundwater rich), covered by clay rich soils; possible influence of infiltration water from the Zarqa River (including KTR-water [RW])	wadis, springs, drains; new observation wells are necessary	**KTR-water**
23 (south), 53, 24, 25, 26, 27	predominantly marls and siltstones (less permeable and groundwater poor); most likely low groundwater movement close to the surface; mostly covered by less clayey soils	drains, wells	**KTR-water (23 – 25north)** **and** **KAC south-water (25south – 27)**
28	alluvial fans (most likely highly permeable and groundwater rich), mostly covered by less clayey soils	wells; new observation wells are necessary	**KAC south-water**

The chosen sampling sites are characterized by **different local hydrogeological and soil conditions and different supply of irrigation water/ RW** for irrigation.

Details about the suggested sampling sites are described in the following table 6-2 also including the reasons why the listed sampling points are recommended for the groundwater monitoring concept (GMC).

Tabelle 6-2: Details regarding recommended sampling sites [1] /13/)

Sampling Site	Recommended sampling point (sp) upstream[2]	Recommended sampling point (sp) downstream[3]	Reasons for Recommendation
DA 22	➢ Wd002 ➢ new observation well near Wd002 ➢ new observation well near FU 236	➢ Sp026 ➢ Sp027 ➢ Dr004 ➢ Dr003	2 new sps are necessary to monitor groundwater coming from the east, most likely loaded by RW-infiltration along the Zarqa River. Possible impact of agricultural activities (including irrigation and fertilization) can probably be measured at the mentioned downstream sps
DA 23north	➢ Wd004 ➢ new observation well near FU 196	➢ Sp012 ➢ Dr032 ➢ Dr010 ➢ chain of 3 – 4 sp along drainage Dr007/Dr027/Dr008	1 new sp is necessary to monitor groundwater which comes from the east, most likely loaded by RW-infiltration along the Zarqa River. Possible impact of agricultural activities (including irrigation) can probably be measured at the mentioned downstream sps

[1] Sampling points from north to south

[2] upstream: refering to groundwater flow direction: sampling/measure point along GW flowpath before irrigation area

[3] downstream: refering to groundwater flow direction: sampling/measure point along GW flowpath within or after irrigation area

Sampling Site	Recommended sampling point (sp) upstream[2]	Recommended sampling point (sp) downstream[3]	Reasons for Recommendation
DA 23south	none	none	Most likely groundwater poor areas, because of local hydrogeological conditions (predominantly marls and siltstones). Therefore, the establishment of observation wells is not recommended. However, soil/ groundwater quality can probably be measured at the mentioned downstream sps (behind or within irrigated areas)
DA 53		➢ We003	
DA 24		➢ Dr026	
DA 25		➢ Dr028 ➢ Dr018 ➢ Dr030 ➢ Dr031 ➢ Dr021 ➢ Dr023	
DA 26		➢ Dr024	
DA 27		➢ We004 ➢ We006	
DA 28	north: ➢ We AB1210 (?; restoration is necessary) south: ➢ We925 ➢ We906 (in deleted area of DA 49)	north: ➢ We173 ➢ We174 ➢ We175 south: ➢ We010 ➢ We172 ➢ new observation near FU 146	1 sp is necessary for groundwater monitoring to complete "the observation chain" along the likely GW flowpath from sp We906 [+We925] to west of We172

Not all sampling points mentioned above could be found during the reconnaissance walks in February 2004. Therefore, some of them might be not available and suitable alternatives are necessary. In this case, new sampling points have to be found or established by project personnel.

6.3 Relevant Parameters – Concentrations and Trends

Referring to annex 1 in /3/ the most critical **substances and parameters** which **occur in RW** are the organic components, the bacteriological load, the salinity represented by TDS, nitrate (NO_3), boron (B), and the heavy metals chrome (Cr) and lead (Pb). These parameters should be addressed by the groundwater monitoring concept (GMC): Additionally, the **results of current soil analyses** /18/ have to be considered.

- Organic components and bacteriological loads need not be measured within groundwater monitoring, because they are diminished by the reduction processes in the soil and in the unsaturated zone above groundwater (see chapter below). However, high concentration of organic components in RW might lead to an increased nitrate-concentration in soil water and in seepage water respectively (**nitrate-origin by mineralization of organic components**). Therefore, the measurement of **nitrate** in groundwater is necessary. Additionally, the possible oxidation of **other nitrogen-compounds occuring in RW** (NH_4, T-N) will also elevate the nitrate concentration in soil water / seepage water, if enough oxygen is available.

  The risk for groundwater quality due to the load of organic and nitrogen compounds in RW will be emphasized by the following **worst-case-estimation of potential nitrate concentration** (conc.) in soil water and/or seepage water. Total mineralization of organic components and total change of nitrogen compounds can only take place if enough oxygen is in the soil. This is assumed for the following calculations (rough estimates) based on quality data from the Zarqa River (KTR-inlet) mentioned in /14/ (see table 4-1).

  - NH_4-N = 43 mg/l; estimated possible NO_3-conc.: $NO_3 \approx NH_4\text{-N} \times 4{,}5 \approx 195$ mg/l
  - NO_3-N ≈ 9 mg/l; estimated possible NO_3-conc: $NO_3 \approx NO_3\text{-N} \times 4{,}5 \approx 40$ mg/l
  - **T-N » 65 mg/l; estimated possible NO_3-conc: NO_3 » T-N x 4,5 » 290 mg/l**

  Additionally, the load of organic components, e.g. represented by BOD_5, will further elevate nitrate-concentration (nitrate-origin by mineralization of organic components), but cannot be quantified exactly.

  These assessments lead to the conclusion that the load of BOD_5 and the load of the above mentioned nitrogen-compounds might cause strongly increased nitrate concentrations in soil water / seepage water if nutrients and/or nitrogen-compounds are not used by plants in irrigated areas. In this case, nitrate-concentrations in groundwater far above 100 mg/l seem to be possible, induced by irrigation with RW. Additionally, nitrate-input into groundwater can be increased by over-fertilization.

- Heavy metals should primarily be measured within soil monitoring, because these parameters are normally adsorbed on clay minerals. Therefore, it is unlikely that the heavy metal concentrations in RW will influence groundwater significantly. Nevertheless, the measurement of **chrome (Cr) and lead (Pb)** within the GMC is recommended, because the concentrations of these substances are **significantly increased in RW** (regarding to annex 1 in /3/; see chapter below). Chrome and lead are also listed in the current soil analyses /18/ besides cadmium (Cd), cobalt (Co), and nickel (Ni).

  Other heavy metals are not significant for groundwater monitoring, because of concentrations below permissible levels with regard to JS 893:2002 (e.g. zinc [Zn], copper

[Cu]) or occurring generally with completely harmless concentrations (iron [Fe], manganese [Mn]).

Aluminium (Al) can also be ignored, because the concentration mentioned in /14/ (0.3 mg/l) is only slightly above the permissible level in JDWS (0.2 mg/l). Additonally, Al-mobility is low, if pH-values in soil are above 7, as documented in current soil analyses /14/.

Hg is insignificant, because of concentrations in KTR-inlet and –outlet below measurable level /14/; Hg is also not listed in annex 1 in /3/.

- **Boron (B)** is a **typical parameter in domestic wastewater**. Boron-concentration is significantly increased in wastewater from the WWTPs, also from WWTP Khirbet As-Samra, documented by analyses in annex in /3/. With regard to these results, at the following WWTPs the boron-concentration (2002) is always or at least sometimes **above the permissible level in JDWS** (2.0 mg/l):
  - WWTP Jerash
  - WWTP Abu Nuseir
  - WWTP Khirbet As-Samra
  - WWTP Fuheis
  - WWTP Wadi Essir

  With regard to /14/, boron-concentration in the Zarqa River (KTR-inlet) is below the permissible level in JDWS. Nevertheless, it is a relevant parameter, because **significantly increased values** are documented **in current soil analyses** (/18/; boron-values frequently above 2.0 mg/l and sometimes above 4.0 mg/l).

- The T-PO_4-values measured at the WWTPs are generally below the permissible level in JS 893:2002 (see annex 1 in /3/); a T-P-value of 13.0 mg/l from the Zarqa River (KTR-inlet) is mentioned in /14/. Although, phosphorus or phosphate are not listed in the JDWS, **phosphorus-compounds** are relevant for soil and groundwater monitoring, because their concentrations are **increased in soil** below arable land (see P-Olsen-values in current soil analyses /18/).

- **Potassium (K) is** not listed in JDWS and is also not measured at the WWTPs. Nevertheless, this parameter is relevant for soil and groundwater monitoring, because the soluble potassium-concentrations are **remarkably high in current soil samples**. K-values (available K) of some hundred mg/l and sometimes above 1,000 mg/l are documented in current soil analyses /18/.

- In some areas close-to-the-surface groundwater (shallow groundwater) is saline caused by **vertical intrusion of salty groundwater** from deeper aquifers. This has to be considered for the interpretation of soil and groundwater monitoring data. Therefore, the measurement of typical "saline parameters" is necessary and **sodium (Na), chloride (Cl), and TDS** are recommended for that.

According to these assessments and available soil and water analyses (see annex 1 of /3/, /14/, and /18/), the following **parameters** are **recommended for groundwater monitoring**:

Tabelle 6-3: Recommended parameters for groundwater Monitoring

Characteristics	**Parameters**
basic parameters	pH-value, temperature, EC
parameters to record influence of salty groundwater	Na, Cl, TDS
typical parameters due to agricultural activities (incl: use of RW)	NO_3, PO_4, K
typical parameters due to use of RW	B, heavy metals (especially Cr, Pb, Cd, Co, Ni)

6.4 Adsorption of Substances in Soil

Heavy metals are typically adsorbed on clay minerals, thus being accumulated in soil and in the unsaturated zone above groundwater and therefore, not affecting the groundwater quality. This conclusion might be drawn if shrinkage cracks are not effective. Otherwise, if irrigation is practised on dried out areas, the adsorption of heavy metals might be weakened by shrinkage cracks. Under this condition, potentially, contaminated seepage water can reach the groundwater level much faster and easier and adverse impact on the groundwater is more likely. However, with regard to interviews with project personnel shrinkage cracks rarely occur. Hence, heavy metals **might be significantly adsorpted**, especially in the north (e.g. in DA 22 + DA 23 [north]) where clay rich soils predominate. Nevertheless, heavy metals should be measured within **soil and groundwater monitoring**.

It is very likely that the bacteriological load of RW and its contents of **organic components** will be diminished effectively at or near the surface after irrigation. However, the diminishing of organic components is inevitably accompanied by the **mineralization processes** which can lead to **increased nitrate-concentrations** in seepage water beneath irrigated areas and – affected by this – in groundwater (see chapter 6.3).

The risk of negative impact on groundwater quality by strong seepage through **shrinkage cracks** is low, because they rarely occur. However, RW can also seep through deeper soil zones under **intensive irrigation** which might affect groundwater. Therefore, if the following situations and/or actions can **be avoided**, percolating excess RW might be cleaned satisfactorily while seeping to groundwater:

- Shrinkage cracks increase the vertical permeability of soil and create higher risk of vertical transport of contaminants to groundwater.
- Intense irrigation, which leads to strongly water-saturated soil and therefore significant seepage to groundwater.

Additionally, avoidance of shrinkage cracks and intense irrigation will maximize the adsorption of heavy metals on clay minerals and will support the reduction of the bacteriological load above groundwater.

Hence, if **minimization of seepage rates** from surface to groundwater can be achieved, negative impact to groundwater by agricultural activities (including use of RW) might significantly be reduced. In this case, **use of RW will most likely not affect groundwater quality**.

6.5 Recommendations for Thresholds Regarding Critical Substances and Parameters

The hydrochemical parameters recommended for groundwater monitoring are listed in chapter 6.3. The measured concentrations should be referred to the individual permissible or maximum levels in **JDWS** as far as possible.

Potassium (K) and phosphate (PO_4) are not listed in JDWS. These parameters should be referred to the following permissible levels listed in MIN-VO (i.e. German Source and Table Water Standard):

- Permissible level of K in MIN-VO: 12 mg/l
- Permissible level of PO_4 in MIN-VO: 5 mg/l

If groundwater quality can fulfill the demands of quality standards like JDWS or MIN-VO, it can be considered as basically unaffected by human activities. Natural cleanness should be a main target of sustainable groundwater use.

The thresholds listed in the FAO Guideline, 1985 and JS 893:2002 are not suitable for the assessment of human affects on groundwater quality, because they refer to special use of RW (e.g. in agriculture) not considering natural groundwater.

6.6 Recommendations for Measuring

The groundwater monitoring should be closely connected to soil monitoring, to the management and distribution of RW for irrigation, and to the agricultural advisory services.

In the **first year** of applying the groundwater monitoring concept (GMC), the recommended **hydrochemical parameters should be measured at all proposed sampling points once a month**. Additionally, run-off (drains) and (ground-) water levels should be (roughly) estimated or measured while sampling; date, time, weather conditions, special incidents at sampling points, etc. have to be documented as well. Sampling should be conducted by experienced laboratory personnel.

It is possible and useful to start groundwater monitoring at already existing sampling points as soon as possible, even though the building of **new observation wells** might last a few months. The sampling program can be completed after new observation wells are available.
The establishment of new observation wells should be planned and accompanied by a hydrogeologist with knowledge about the local hydrogeological conditions. Therefore recommendations are given in chapter 6.8.

At least one of the **new observation wells** in DA 22 should be equipped with a **data logger system** which allows for a permanent recording of groundwater table (piezometric head) and EC and provides the best database for interpretation of monitoring results. This data will also be useful for further hydrogeological investigations, e.g. assessment of available groundwater for drinking water supply. Wells which are not equipped with data logger systems should be measured with electric contact water level gauge (groundwater level) within regular sampling procedures, but at least once a month.

The possible influence of **shrinkage cracks and/or intense irrigation** on seepage is described in chapter 6.4. It is recommended to **monitor such soil-/irrigation conditions** within soil monitoring and use this information with regard to groundwater quality. This might be helpful for data analysis within groundwater monitoring. For instance, it could possibly determined whether elevation of nitrate-concentration in groundwater in a particular area is caused by intense use of RW for irrigation or by over-fertilization.

6.7 Recommendations for Evaluation Procedures and Interpretation of Monitored Data

The groundwater monitoring program shall be tested for further suitability by **evaluation of data from at least 12 months of measurement**. The evaluation should be incorporated in RWP and conducted by hydrogeological educated personnel with regard to local agricultural activities.

Besides data from groundwater monitoring, the following **additional information** is **necessary** for evaluation of the GMC:

- results/analyses from soil monitoring
- hydrochemical analyses from KTR (outlet) and KAC-south (preferably monthly measurements)

- hydrogeological data from the recommended new observation wells and hydrogeological data from old wells, documented in the Geological Maps of As-Salt and Al Karama; wells around Deir Alla (near DA 22 and DA 23north) and southwest of Mukhayyam al Kashfi (near DA 28) as well.

The conclusions drawn from evaluation have to be discussed with RWP personnel and proposals for further groundwater monitoring should be submitted in a final report.

6.8 Recommendations for Establishment of New Observation Wells

Proposed places for building new observation wells are shown in annexes 3 and 4. The following technical details (recommendations) have to be considered for planning and building.

- depth: ≥ 20 m below local groundwater level
- borehole diameter: ≥ 300 mm; special drilling method not necessary
- well filter diameter: ≥ 150 mm; screens only below groundwater level
- annulus sealing/filling: clay (sealing: 0 – 5 m below surface) and gravel (below sealing up to well bottom)
- short pumping test (e.g. 12 h pumping period) for assessment of well capacity and aquifer parameters (geohydraulic analysis of pumping test data)
- first sampling within groundwater monitoring during the pumping test

The observation wells should only be used for groundwater monitoring and have to be secured against damage. Hence, suitable sites have to be found.
The drilling campaign should be accompanied by a local hydrogeologist. The results (drilling samples, well design plan, pumping test data etc.) have to be documented in a drilling report, including a hydrogeological interpretation with regard to other geological information (e.g. geological maps, hydrogeological reports etc.).

6.9 General Recommendations for Groundwater Protection

The recommended monitoring concept is in reference to the potential risk to groundwater quality by use of RW for irrigation. However, it should be considered that besides RW other factors can induce a negative impact on groundwater. For instance, over-fertilization and/or infiltration of RW along the Zarqa River can also endanger groundwater quality in the Jordan Valley. Therefore, a broader view on the necessities for groundwater protection is to be recommended. A purposeful long-term strategy for saving groundwater quality in the Jordan Valley should be developed, including the following tasks and objectives:

- Reduction of potential risks for soil and groundwater
    - by improving RW quality, i.e. better wastewater treatment and
    - by suitable use of fertilizers considering the concentration of nutrients in RW, i.e. agricultural advisory to local farmers
- Deliberate correlation of RW-, soil- and groundwater monitoring and comprehensive analysis of data from all these investigations
- Hydrogeological investigations in the middle and southern Jordan Valley providing following results:
    - assessment of vulnerability of the close-to-the-surface aquifer considering the available soil scientific studies (from the BWP); a map of vulnerability should be created and well documented
    - assessment of available groundwater in irrigation areas with similar hydrogeological conditions with regard to infiltration along the Zarqa River and to intrusion of salty groundwater from deeper aquifers

  Based on these results, a long-term risk assessment for the close-to-the-surface groundwater in the BWP- / RWP-area could be conducted.

With respect to the sustainable use of groundwater, the transport of nutrients, fertilizers, pesticides etc. into soil and groundwater should be reduced or at least limited significantly. If that can be achieved, the risk of negative impact on groundwater by agricultural activities in the Jordan Valley will also be limited, especially where the close-to-the-surface aquifer is not too vulnerable.

Dr. Bernd Hanauer
(Hydrogeologist)

HG Büro für Hydrogeologie und Umwelt GmbH
Europastrasse 11
35394 Giessen, Germany
www.buero-hg.de