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Assessment of Brackish Groundwater in Jordan

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The maps included in this report were digitized and drawn on AutoCad by *Issa Al Obra*, Senior MWI draftsman I am grateful to him for his patience Also, thanks are extended to *Fadia Abu Zeid* and *Rania Shahin* who typed the draft and final text, respectively

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Executive Summary

This report contains an updated assessment of brackish groundwater in Jordan, together with an assessment of brackish water flowing from springs The assessment is based on present knowledge of the hydrogeology of the country and the available data

The stored volumes of brackish groundwater in each aquifer and one aquitard were calculated for each basin With the exception of the basalt aquifer, brackish water occurs in all other aquifers The volumes stored are summarized in Table 9 on page 41 The total quantity of brackish groundwater stored in all aquifers exceeds three trillion cubic meters About 80% of this estimated quantity is stored in the Ram aquifer The estimate has been based on assumed hydraulic parameters and should only be considered as pure scientific evaluation

The quantities of exploitable brackish groundwater exceed 4,000 MCM or approximately 0 12 percent of total brackish groundwater resources Estimates of the exploitable reserves have been based on assumed economic, technical and environmental parameters such as drilling depths, pumping lifts, productivity of wells and brine disposal A summary of the exploitable quantities from the different aquifers in each basin is shown in Table 14 on page 63 In addition to the above estimate, there are eight areas which require additional investigations, including drilling and testing, before the exploitable quantities can be estimated These additional areas are the Kurnub and Khreim aquifers in the southern desert, the B4/B5 and B2/A7 aquifers in the Hamad and Sirhan basins and the Kurnub aquifer in the northeastern part of the Hamad Basin (Ar-Rukban area) The B2/A7 and the Kurnub aquifers in the eastern part of the Hamad basin do not meet the economic criteria for exploitation as the pumping lifts exceed 300 meters However, brackish groundwater of these two aquifers are the only known source of water in that remote area where fresh water is needed at any cost

One area, among the exploitation areas listed in Table 14, has been studied in detail It is the southern part of the Jordan Valley, in particular the Hisban, Kufrein and Sweima areas The Japanese International Cooperation Agency (JICA) (1995) study is considered sufficient to justify the construction of a desalinating plant The feed to the plant in the short term will be from the Zerqa aquifer and on the long term from both, the Zerqa and the underlying Ram aquifers

In various parts of the Kingdom, brackish water is being used to a limited extent from springs and wells for industrial, touristic and agricultural purposes It appears that meeting the increasing demand for fresh water can be partially achieved in many areas by desalinating brackish groundwater The cost of desalination has decreased over the past few years from US$ 3/m^3 to as low as US$ 0 5/m^3 as a result of both advancements in technology and market processes [1]

[1] Based on a recent cost assessment study by the Office of Technology Assessment for the US Congress (Ref 10)

1.0 Introduction

The present study has been undertaken within the framework of the " **WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT (WQIC)**" which is funded by the USAID with technical assistance being provided by Development Alternatives, Inc (DAI)

The purpose of this study is the assessment of the quantities and qualities of brackish groundwater resources in Jordan as a non-conventional source of water supply Projections of demand for water by all users indicate the necessity for development of non-conventional sources of water, among which brackish groundwater can be utilized directly, by mixing with fresh water, or by desalination The country at present has a serious shortage of fresh water Even if all the currently planned water resources development projects are implemented, the water shortage will still continue to exist Brackish groundwater occurs in nearly all areas of the country However, with the development of desalination technology in a competitive cost range, utilization of this technique can be considered in Jordan's on-going water development plans

Previous studies of brackish groundwater resources of Jordan are limited to a report by Hydrogeological Services International (HSI) 1991 and a comprehensive study of brackish groundwater for desalination potential for the southern part of the Jordan Valley by Japan International Cooperation Agency (JICA) (1995) JICA contracted the study to Yachio Engineering Co Ltd and Mitsui Mineral Development Engineering Co Ltd of Tokyo - Japan

Sources of data contained in this report are in part from published reports listed in the references The isopach maps are based on interpretation of various geophysical surveys including airborne geophysical survey of Jordan, several reflection and refraction seismic surveys for oil exploration, geoelectrical surveys, and deep drilling for petroleum exploration (NRA openfile reports) Updated flow data and chemical analyses of brackish water from springs and boreholes have been obtained from the Water Authority of Jordan (WAJ) archives

2.0 Hydrogeological Setting

The stratigraphic classification of the sedimentary sequence of rock has been recently modified according to new surface and subsurface data obtained from detailed geological mapping of the country conducted by the Natural Resources Authority (NRA) as well as from geophysical surveys conducted for oil and mineral exploration, including airborne magnetic and radiometry, deep reflection seismic and deep drilling for oil and gas exploration and to a limited extent for geothermal resources

Although there are differences in the nomenclature of rock units as well as the basis on which boundaries between units are determined among petroleum geologists, surface mapping geologists, and hydrogeologists, the hydrogeological classification presented in Table 1 is a result of detailed study of all available data

The sedimentary series above the Precambrian basement complex vary in thickness from zero in the south, where the crystalline basement rocks are outcropping, to more than 8 5 kilometers in the northeastern part of the country near the borders with Iraq In the deepest parts of the Jafr and Azraq basins, the sediments thickness exceeds 4 kilometers A contour map showing depths to the basement complex is shown on Figure 1

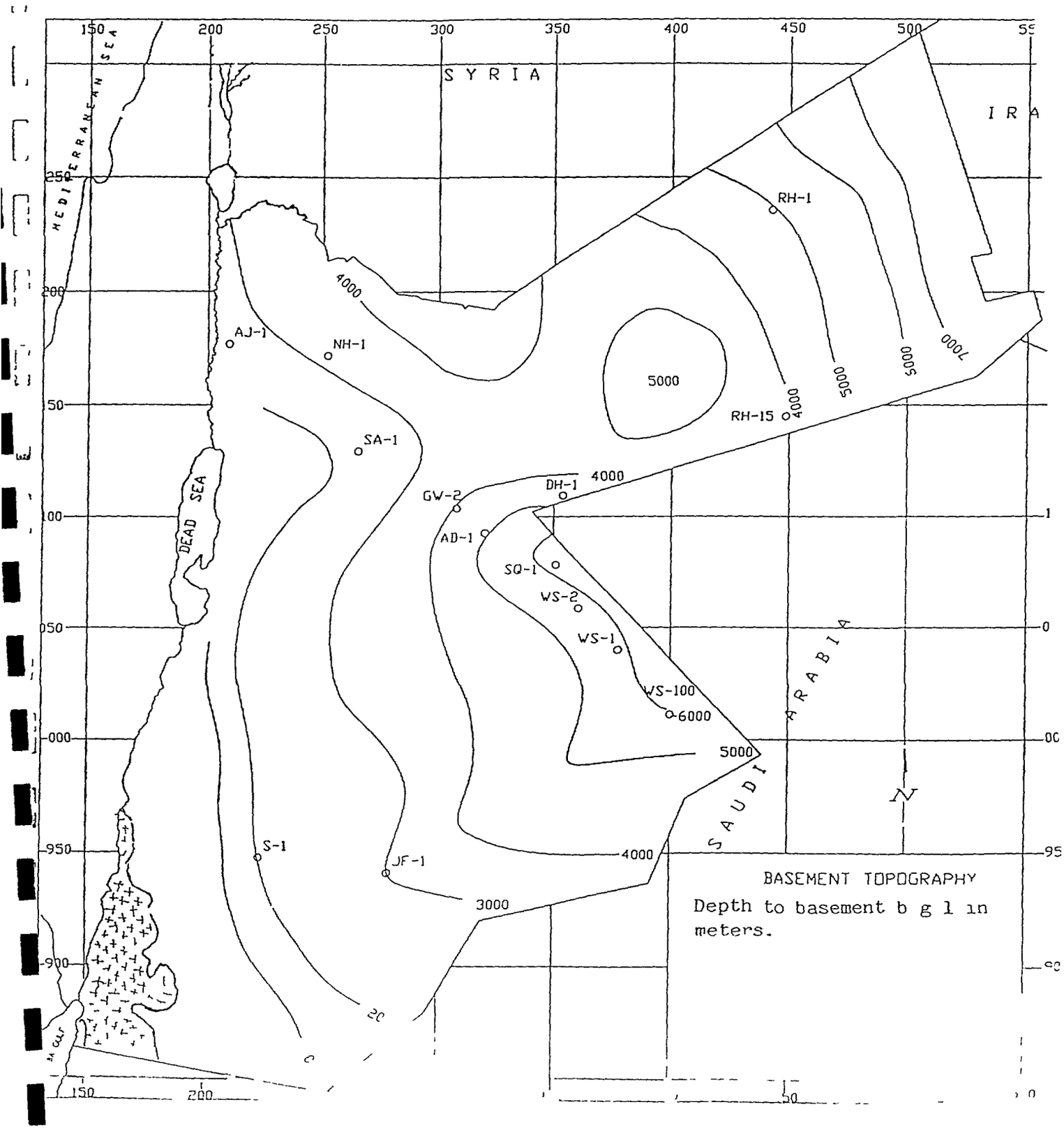
Nine aquifer systems are recognized Four of them have regional importance, another four are of importance in limited areas, and the ninth yields water to small springs and a few wells in a limited area

An updated map of the surface distribution of the hydrogeological units, including major faults affecting groundwater movements, is shown on Figure 2

The following is a brief description of the hydrogeological units overlying the basement complex which is considered an aquifuge

2.1 The Ram Aquifer·

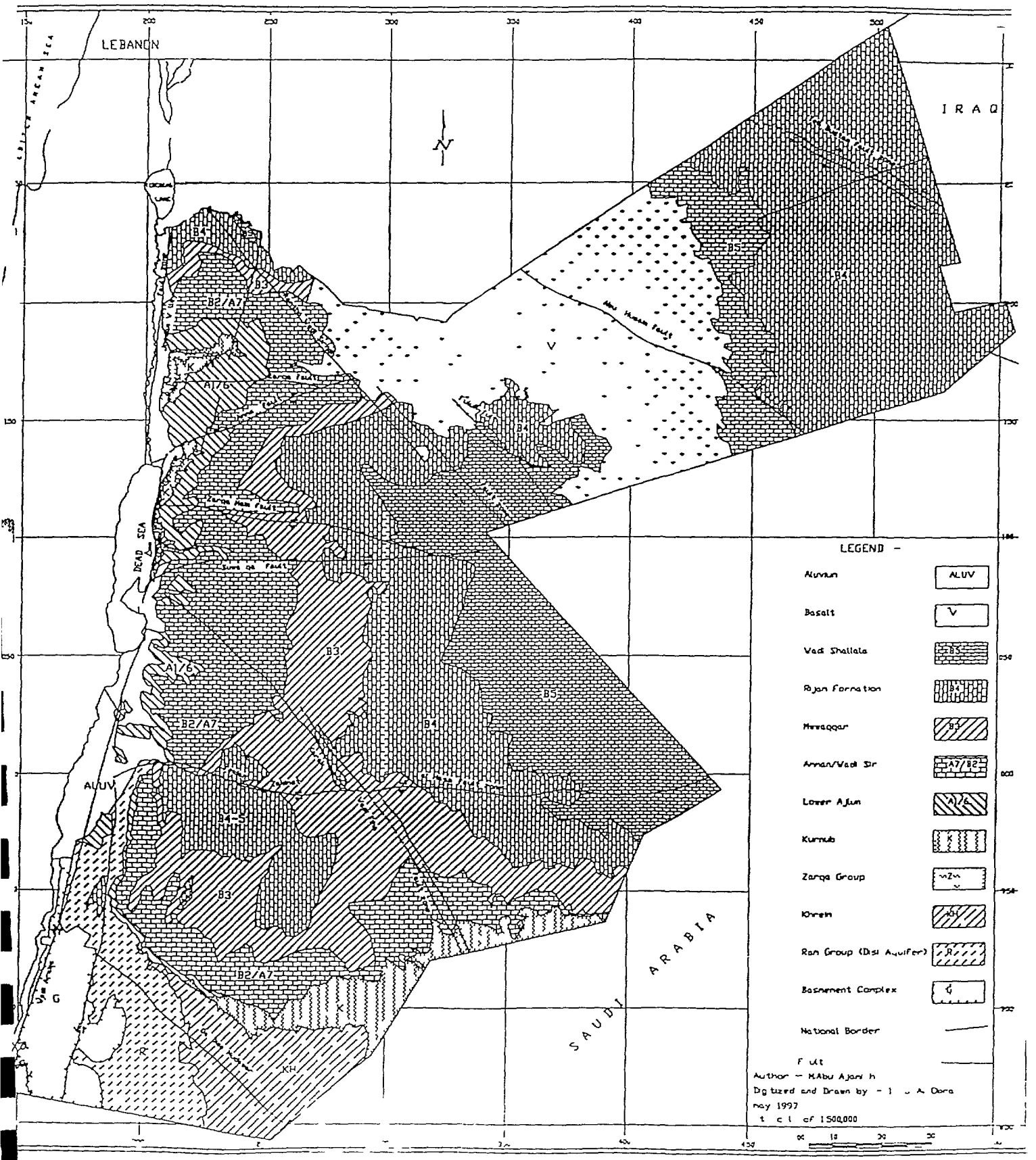
Formerly, the Ram aquifer was known as the "Disi Aquifer" But, recently acquired data mainly from NRA's detailed geological mapping and deep exploration drilling for oil and gas, the more precise name "Ram" has been adopted


SYRIA
MEDITERRANEAN SEA
DEAD SEA
SAUDI ARABIA
RH-1
RH-15
AJ-1
NH-1
SA-1
GW-2
DH-1
AD-1
SQ-1
WS-2
WS-1
WS-100
S-1
JF-1
4000
5000
6000
7000
3000
N
BASEMENT TOPOGRAPHY
Depth to basement b g l in meters.

GEOLOGICAL SCALE			HYDROGEOLOGICAL CHARACTER		
ERA	PERIOD	EPOCH	GROUP	FORMATION	SYMBOL
CENOZOIC	Quaternary	Holocene	Rift Valley	Alluvium Aquifer	Q21
		Pleistocene		Lisan	RV3
	Tertiary	Pliocene Miocene	Smara	Basalt Aquifer Garma	V G
		Oligocene	Neogene	Alluvium Aquifer	RV1-2
		Eocene	Belqa	Wadi Shallala (Aquitard)	B5
				Rijam Aquifer	B4
		Paleocene		Muwaqqar (Aquitard)	B3
MESOZOIC	Upper Cretaceous	Meastrichtian Campanian		Amman (Aquifer)	B2
		Santonian Coniacian		Umm Ghudran (Aquitard)	B1
		Turonian	Ajlun	Wadi Sir (Aquifer)	A7
		Cenomanian		Shuaib Hummar (Aquifer) Fuheis Naur	A5/6 Aquifer A4 Aquifer A3 Aquifer A1/2
	Lower Cretaceous	Albian	Kurnub Aquifer	Subeihi A'rda	K2
		Aptian			K1
		Neocomian			
	Jurassic Triassic Permian		Zerqa Aquifer	Azab Ramtha Hudayib	Z2 Z1
PALEOZOIC	HERCYNIAN UNCONFORMITY				
	Silurian Ordovician		Khreim Aquitard	Kishsha Mudawwara Dubeidib Hiswa	Kh
	Cambrian		Ram Aquifer	Umm Sahm Disi Umm Ishrin Burj Salib	R
PROTEROZIC	LIPALIAN INTERVAL (PLANTAIN)				
	Late Precambrian		Araba Complex	Saramuj Congl (Safi Group)	
	Early Precambrian		Aqaba Complex		

Table 1 Hydrogeological Classification

SU AC DISTRIBUTION O YDROGEOLOGICAL UNITS



The Ram aquifer covers the entire country excluding the limited outcrops of the basement complex in the southwest of Jordan It also is widely extensive in Saudi Arabia where it is known as the Saq aquifer It is developed in the Tabuk area of Saudi Arabia for irrigated agriculture In Iraq and Syria, it is very deep and contains brackish and even saline water The thickness of the Ram aquifer is shown on the isopach map (Figure 3)

The Ram aquifer consists of sandstones of Paleozoic age (Cambrian-Ordovician) According to recent data, the Ram Group is composed of five lithological units which are distinguishable at outcrops and in the subsurface

The Ram Group units are briefly described from base to top as follows

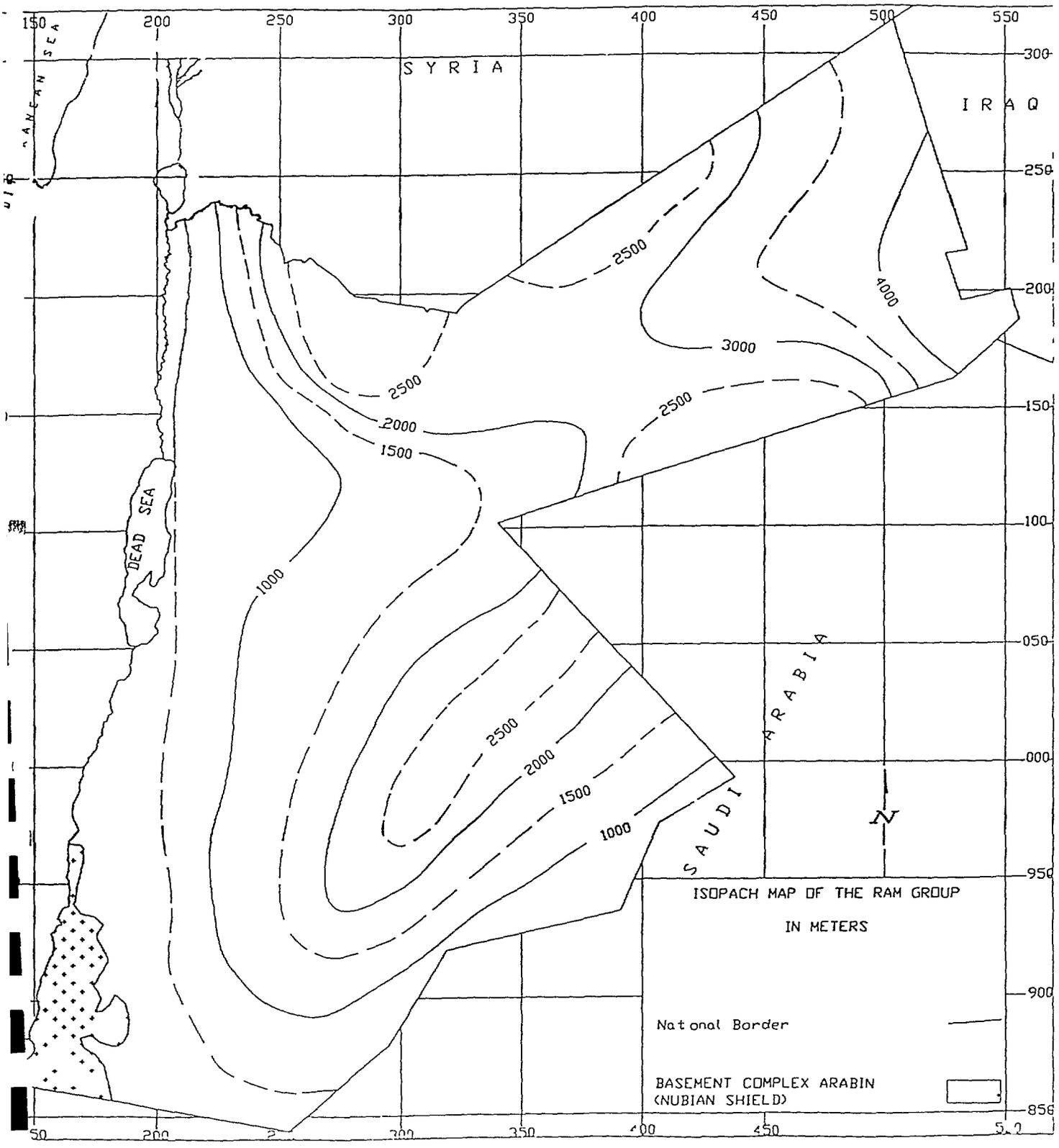
2 1 1 Salib

The Salib is the basal unit and consists of very coarse-grained arkosic sandstone with pebbles and conglomerates Where it is outcropping, its thickness varies between zero and 100 meters But the thickness increases to the east and northeast of Mudawwara where it reaches 200 meters and 700 meters in Jafr and Azraq and about 1000 meters in the eastern part of the Hamad basin In the northwestern highlands (north of Irbid), it is 600 meters thick and 450 meters thick in the Ajlun dome

2 1 2 The Burj Formation

The Burj Formation is exposed in the eastern rift escarpment in Feinan, Wadi Dana Wadi Isal and Wadi Fifa It is known in these outcrops as the dolomite-limestone- shale unit The Burj is missing south of the edge of the Jafr basin while south of Feinan in Wadi Araba it is replaced by the stratigraphic equivalent 'Abu Khusheiba sandstone"

Where it is outcroping, in the south and in the Wadi Araba escarpment, the thickness ranges from 15 to 80 meters But the thickness increases to the north where it is about 250 meters in Amman and 350 meters in Mafraq This formation has been used as a good marker in seismic reflection surveys, being a good reflector


SYRIA
IRAQ
SAUDI ARABIA
DEAD SEA
N
2500
3000
4000
2000
1500
1000
ISOPACH MAP OF THE RAM GROUP
IN METERS
National Border
BASEMENT COMPLEX ARABIN
(NUBIAN SHIELD)

2 1 3 Umm Ishrin

Umm Ishrin consists of massive, medium to coarse-grained quartzose sandstone including micaceous, ferruginous and manganiferous sandstone It is named from its outcrops (230-320 meters) in Jebal Umm Ishrin, the second highest peak in Wadi Ram

Outcrops of this formation occur in south Jordan, in the southeastern desert and along Wadi Araba and the southern part of the eastern shore of the Dead Sea There, the thickness ranges from 80 to 350 meters

The following thicknesses were recorded in deep wells Jafr basin (288 meters), Azraq basin (158-200 meters), Sirhan basin (319-342 meters), north western highlands (110-215 meters), and 110 meters north of Irbid In Ain El Basha it is 215 meters The unit is missing in the Ajlun dome But in the Hamad and the deepest part of the Azraq basin, it occurs at considerable depths and has not penetrated by drilling

2 1.4 Disi Sandstone Formation

The Disi Sandstone Formation consists of medium to coarse grained quartzose sandstone with intercalations of fine-grained, micaceous bedded sandstone and scattered quartz pebbles Outcrops of the formation occur in the southwestern desert and along the Wadi Araba escarpment

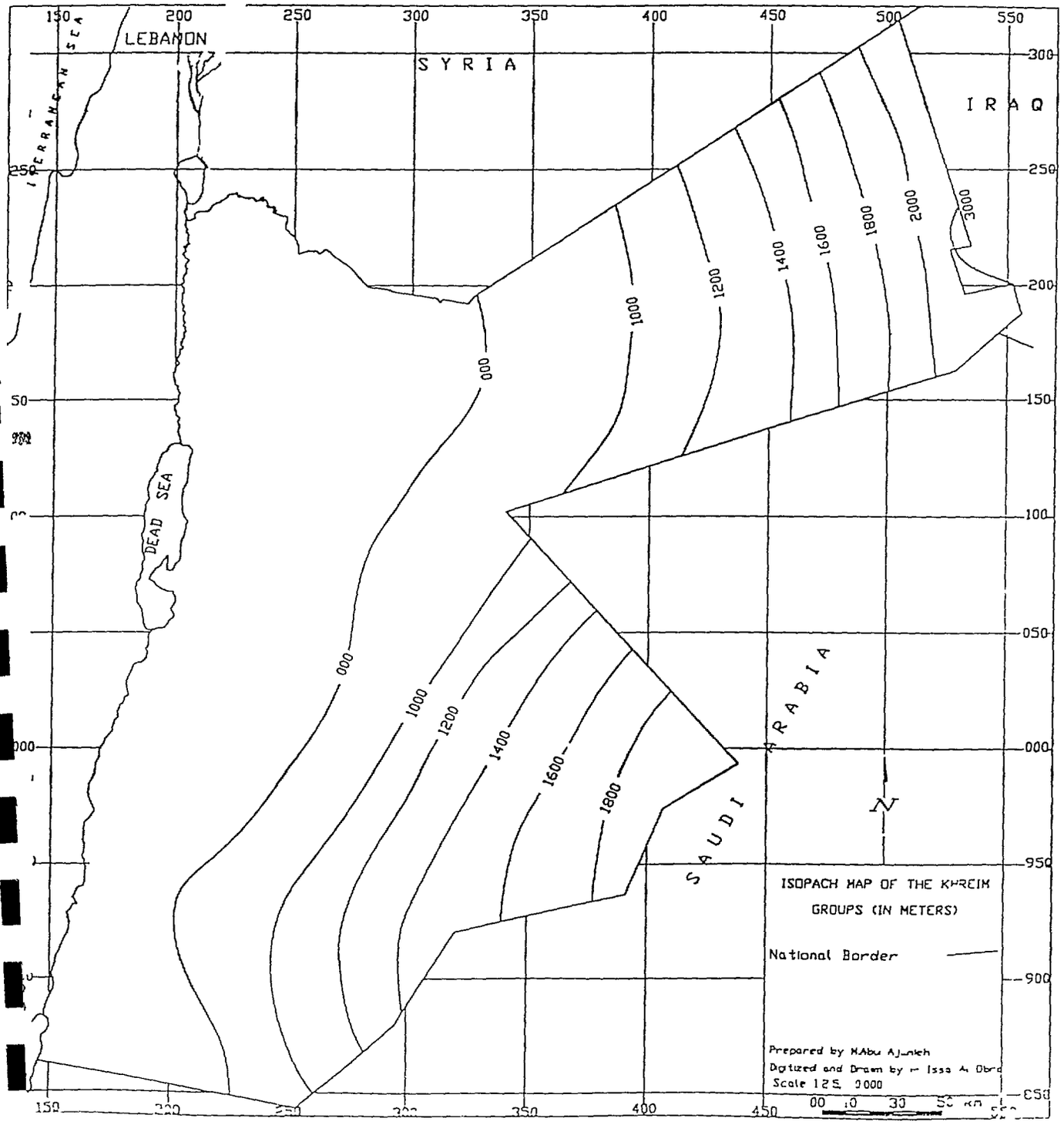
The thickness in exposed sections varies between 80 meters in Wadi Rahma to 350 meters in the Ayn Al Hashim area in the southern desert But, it is missing in the Dana-Petra area Further north it occurs at considerable depths In the Azraq basin, the thickness exceeds 1127 meters (oil exploration well DH1), and it is encountered at a depth of 3306-4433 meters

2.1.5 Salib Sandstone

The Salib Sandstone consists of hard brown, thick bedded quartzose sandstone medium to coarse-grained with thin interbeds of fine-grained micaceous sandstone and siltstone The thickness in boreholes ranges from 180 meters in Sirhan to 190 meters in Hamad basin, the unit has not been reached in the Azraq basin and is missing in the western and northwestern highlands

2 2 The Khreim Aquitard (Kh)

The Khreim aquitard consists of fine-grained micaceous sandstone, siltstone and shale The Khreim Group occurs in the eastern half of the country and is missing in the western part Figure 4 is an isopach map of the Khreim Group


LEBANON
SYRIA
IRAQ
SAUDI ARABIA
DEAD SEA
MEDITERRANEAN SEA
ISOPACH MAP OF THE KHREIM GROUPS (IN METERS)
National Border
Prepared by M.Abu Ajameh
Digitized and Drawn by Issa A. Obed
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N

Surface mapping geologists have subdivided the Khreim Group into five formations namely from base to top Sahl Es Suwwan, Umm Tarifa, Trebeel, and Alna Hydrogeologists have adopted a different subdivision of the Khreim Group as follows from base to top

2.2.1 Hiswa

The Hiswa consists of black to dark gray shale, siltstone, and claystone Its thickness varies from 29 meters in Jafr, 115-130 meters in Sirhan, 152-177 meters in the Hamad, and the formation is missing in the western highlands

2.2 2 The Dubeidib Formation

The Dubeidib Formation is sandwiched between the Hiswa shale from below and the Mudawwara shale on top It consists of several cycles of sands, silts and sandy shale The top 120 meters of sand are porous Figure 5 is an isopach map of the Dubeideb Formation Porosity ranges between 3 and 9% In the eastern part of the Hamad basin, commercial gas is produced (Rish Gas Field) from the formation But elsewhere, the formation is saturated either fully or in part with water The quality of water in the Dubeidib is brackish to even saline In the southeast (Mudawwara-Halet Ammar on the borders with Saudi Arabia), the salinity ranges between 700 and 760 mg/l The salinity increases northwards to 1200 mg/l in the southern part of Wadi Sirhan and reaches 9200 mg/l in the northern part of the basin (well WS-2) The salinity is expected to be much higher in the Hamad basin

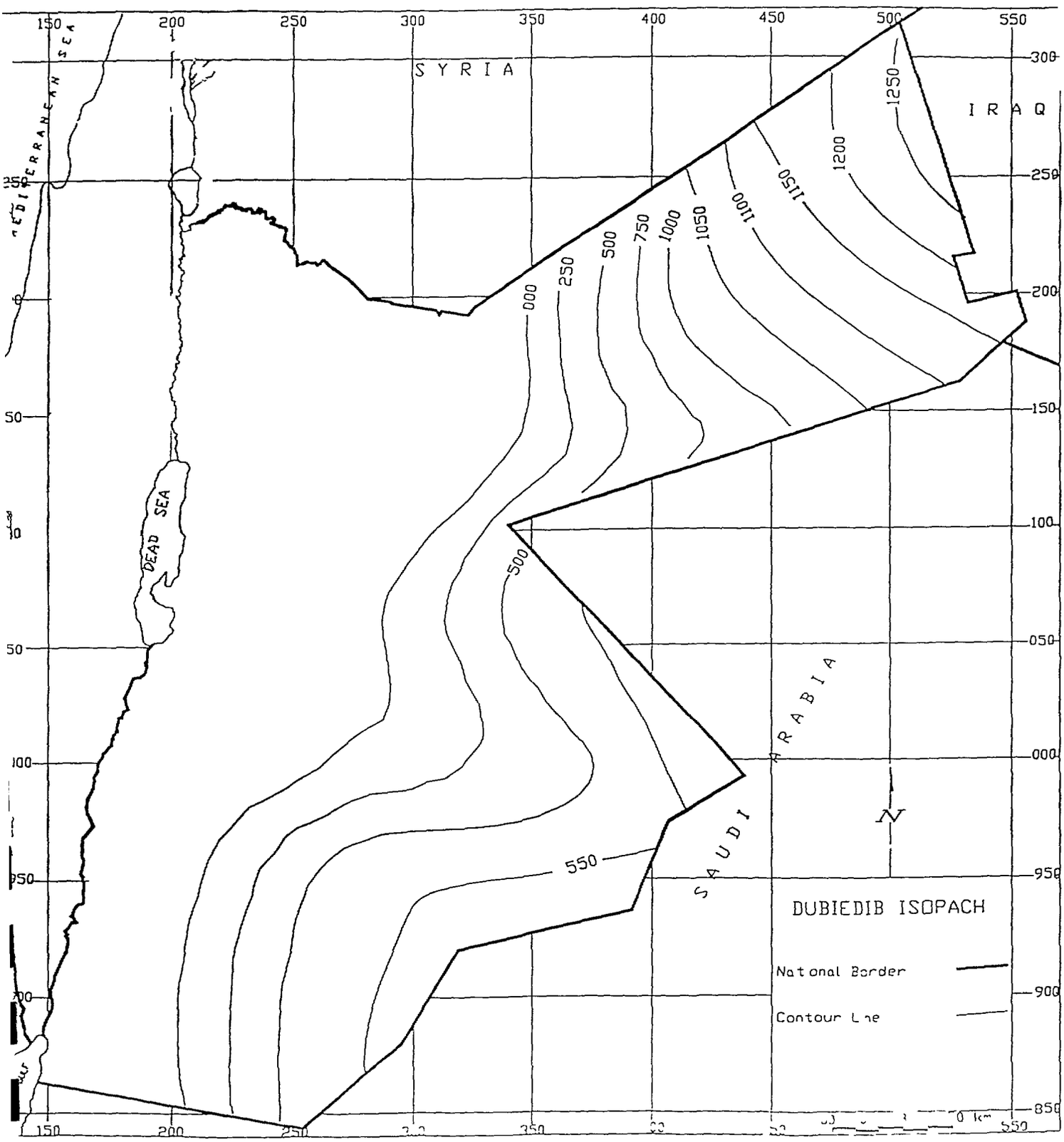
2 2.3 The Mudawwara Formation

The Mudawwara Formation consists of thick shale which reaches 1200 meters in thickness in the eastern part of the Hamad basin

2 2.4 The Kishsha Formation

The Kishsha Formation consists of shale intercalated with fine-grained sandstone

Although these formations are distinguishable in drilling and electric logs as well as in surface outcrops, the entire Khreim Group is hydrogeologically considered as an aquitard Consequently, the Khreim Group confines the underlying Ram Aquifer It also is considered as a leaky aquifer, especially the Dubeidib Formation, which forms the second subdivision from its base The thickness distribution of the Dubeidib aquitard is shown on Figure 5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1200
1250
500
550

2 3 The Zerqa Aquifer

The Zerqa Group stratigraphically occurs between two unconformities, the Hercynian at the base and the Lower Cretaceous unconformity at the top The Group is limited to the northern half of Jordan and is missing south of 100 North (Palestine Grid) It attains its maximum thickness in the northwestern part of the country (Yarmouk River area) as shown on the isopach map (Figure 6) It is completely missing in the Sirhan basin

Three main formations are clearly distinguished in the Zerqa Group They are from the base to top as follows

2 3 1 The Hudeib Formation

The Hudeib Formation recently has been added to the Zerqa Group It belongs agewise to the Permian strata which has been penetrated by seven oil exploration wells But the Formation is limited to the northwestern highlands, the basalt plateau, and the Hamad basin The Hudeib consists of sandstone, shale and limestone Its thickness varies from 20 meters in the eastern Hamad to 250 meters north of Irbid

2 3 2 The Ramtha Formation

The Ramtha Formation overlies unconfomably the Hudeib and older formations such as the Khreim and the Ram Group It consists of a succession of gypsum, anhydrite and halite interbedded with shale, limestone, and dolomite overlain by pelitic limestone followed upwards by shale interbedded with siltstone and minor marl intercalations The Ramtha Formation is one source of salt for groundwater In one of the deep wells in the Hamad basin, 57 meters of halite were encountered in the formation

2 3 3 The Azab Formation

The Azab Formation unconformably overlies the Ramtha Formation The Azab Formation recently has been named and replaced two previously used formation names (Huni or Muadi and A'rda) It consists of five successions of limestone and sandstone with a limestone layer on the bottom The Formation is limited in extent to northern Jordan where it reaches a thickness of 598 meters in the Ajlun Dome (Aj-1 oil, exp well) It is missing in the Jordan Valley escarpment

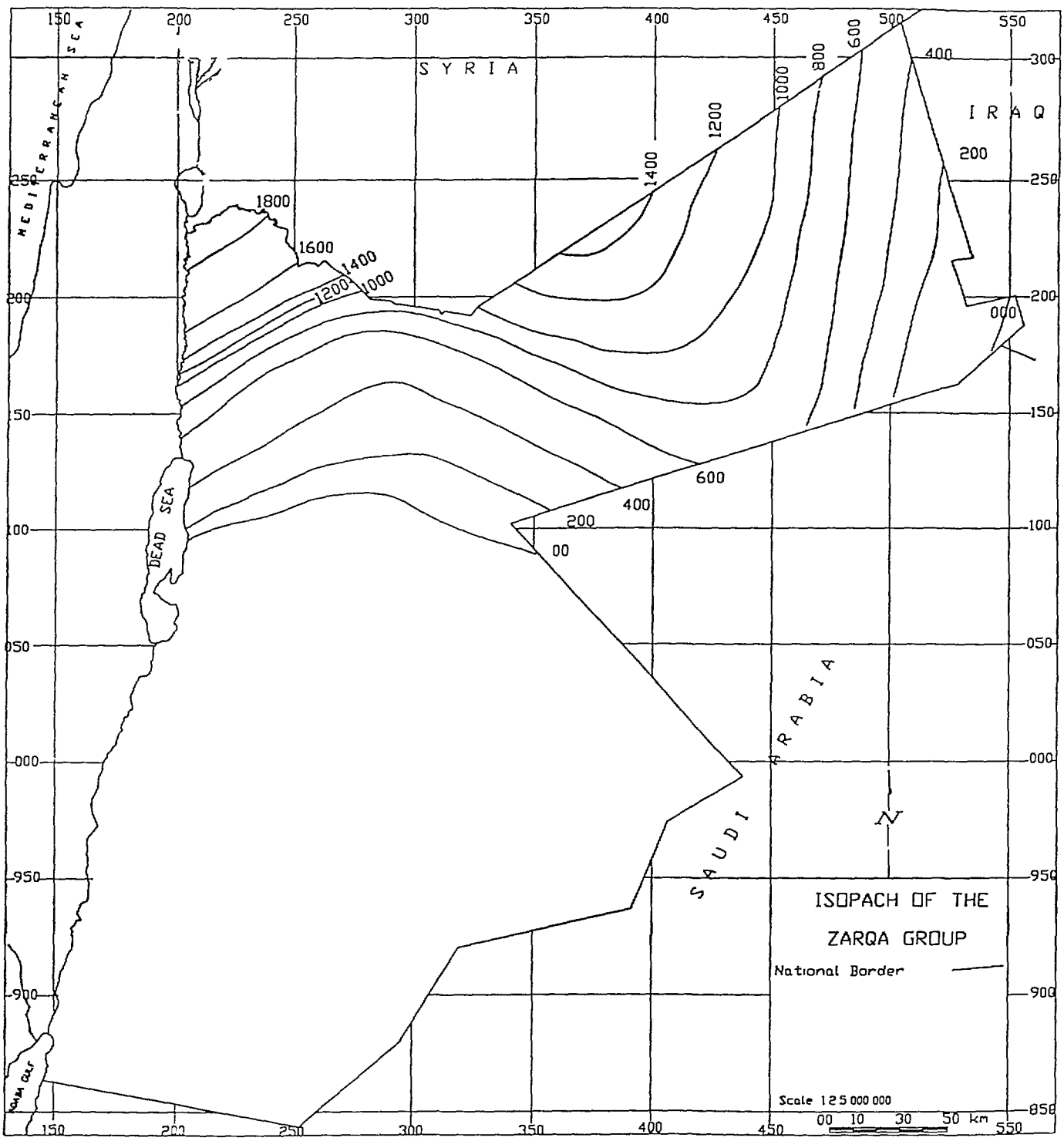

SYRIA
IRAQ
SAUDI ARABIA
DEAD SEA
MEDITERRANEAN SEA
AQABA GULF
ISOPACH OF THE
ZARQA GROUP
National Border
Scale 1:5 000 000
00 10 30 50 km
N
1800
1600
1400
1200
1000
800
600
400
200
00

Fig 6

The Zerqa Group as a whole forms one aquifer system in the northern and northeastern parts of Jordan Its areal extent is about 32,000 km^2 It reaches a maximum thickness of about 1,800 meters along the northwestern borders with Syria The aquifer was penetrated by 22 deep wells drilled for oil exploration and by two other wells drilled for geothermal exploration Recharge to the aquifer occurs in areas of its outcrops such as the eastern escarpment of the Jordan Valley, the northern part of the Dead Sea, Jerash, Baqa' and along the Zerqa River

In the Western Highlands, the aquifer is recharged by infiltration through the Upper Cretaceous aquifers where groundwater infiltrates down through fractures and faults and also by direct infiltration through the exposed parts of the aquifer in the core of eroded anticlines and indirectly by runoff along wadis

In the eastern parts of the country such as the Azraq and the Hamad basins, the aquifer occurs at considerable depths with several interlayered aquitards In these areas, the water in storage is very old and non-renewable Leakage from other aquifers is possible but not substantial

In the highlands west of Amman, the piezometric head of the aquifer at well AL 1430 has been monitored since the early 1980's A decline of 11 meters (from 484 to 473 meters above sea level) has been recorded over eight (8) years

2.3 4 Hydraulic properties

The aquifer contains permeable layers of sand and fractured limestone and dolomite which are separated by tight layers of very low porosity and permeability Porosity values of 10% to 18% were determined in the Hamad basin for the Azab and the Ramtha Formations, respectively

In the area between Deir Alla and Hisban in the Jordan Valley, the following parameters have been reported for the Zerqa aquifer (JICA, 1995)

Permeability	0 3 - 0 8 m/d
Transmisivity	60-160 m^2/d
Storage coefficient	10^{-3} - 10^{-2}

In this area, the aquifer is artesian Its piezometric head is higher than that of the overlying Kurnub aquifer, but much lower than that of the underlying Ram aquifer

2 3 5 Flow Pattern

A groundwater divide oriented in a north-south direction along the western highlands, directs the flow west of the divide towards the Jordan Valley and the Dead Sea East of the divide, the flow direction is eastwards toward the Azraq basin

In the western half of the country, the Zerqa aquifer directly overlies the Ram aquifer due to absence of the Khreim aquitard

The Zerqa aquifer in general is brackish Wells in the Hamad basin encountered brackish water with a TDS range of 1,500-2,700 mg/l In the Jordan Valley, the TDS varies between 5,422 -11,033 mg/l (JICA, 1995)

Only in limited areas where the aquifer receives modern recharge as in Ain El Basha, Baq'a and limited localities along the Zerqa River, is the groundwater fresh

2 4 The Kurnub Aquifer

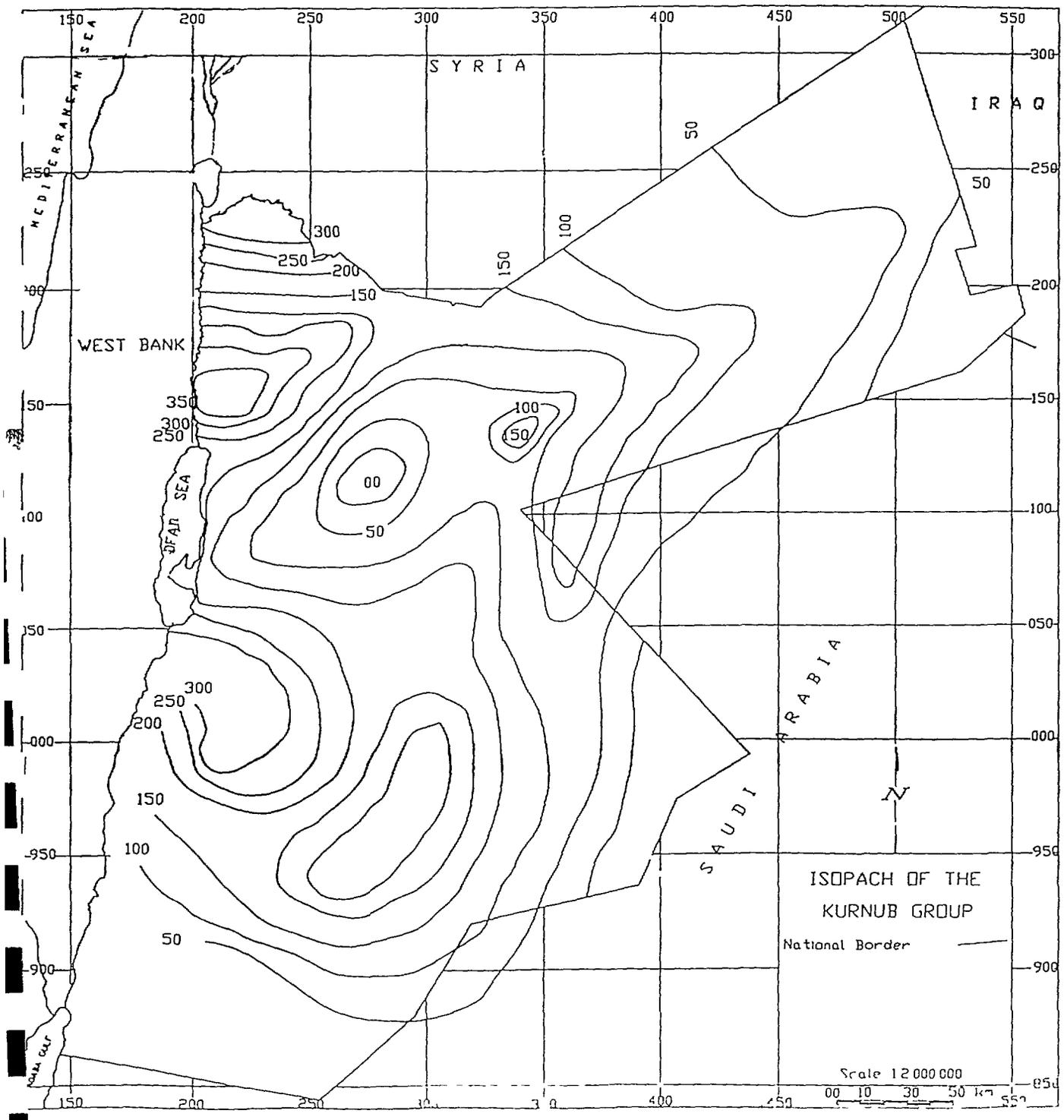
The Kurnub aquifer consists of medium to coarse-grained sandstone Two units are recognized in its exposed sections in Ain El-Basha, Arda, and Subeihi The Arda Formation forms the lower part where the sandstone is massive and white in colour The Subeihi Formation overlies the Arda Formation and is varicoloured sandstone

The Kurnub sandstone occurs almost everywhere in Jordan with the exception of basement complex outcrops, the sandy desert area in the southeast, and the border area of Wadi Sirhan in the east It reaches its maximum thickness of 371 meters in the Jafr basin and its minimum of 50 meters on the north eastern borders with Iraq The distribution of the thickness of the Kurnub aquifer is shown on the isopach of Figure 7

2 4 1 Hydraulic Properties

The Kurnub is separated from the underlying Zerqa aquifer in the central, northern and northwestern part of the country by the upper Azab shale and marl (bluish green in colour) And is confined in these areas by the overlying-lower Naur Formation In the southeastern part of the Jafr basin the Kurnub is hydraulically connected with the B2/A7 through the Lower Ajlun group which becomes arenaceous (The Fassua Formation)

In the south, both the Zerqa and the Khreim Groups are missing and the Kurnub is hydraulically connected with the Ram aquifer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The aquifer parameters obtained from tested wells are as follows

Permeability	2-5 m/d
Transmissivity	23 2-84 0 m^2/d
Storage Coefficient (S)	10^{-4}
Effective Porosity	1 5%

2.4.2 Water Quality

The greater part of the Kurnub water is brackish TDS values range from 1,350 in Azraq to 2,800 mg/l in the Jafr basin In the Hamad basin TDS values range from 1,500-2,700 mg/l Only in the limited areas of its outcrops is the water fresh

In the northwestern highlands, TDS values of 614 and 700 mg/l have been obtained from tested wells north of Sweileh and in the Majdal area near Jerash Also, fresh Kurnub water has been developed in the Jordan Valley escarpment in Kafrein

2.5 Lower Ajlun Group (A1-6)

The lower Ajlun is a multi-layered system of aquifers and aquitards It is characterized by facies changes from one area to another The A1-6 is missing in Wadi Sirhan Only in central and northern Jordan are the formations forming the system distinguishable In this area, the Group consists of limestone marl and dominate Four hydrogeological units are recognized in this area They are from base to top as follows

2.5 1 The Na'ur Formation (A1/2)

The Na'ur Formation consists of marl at the base which confines the underlying Kurnub aquifer The marly base is overlain by the Na'ur limestone aquifer This is a limited aquifer in the central, northern and northwestern parts of the country The Na'ur limestone varies in thickness from 30 to 40 meters The Naur limestone is recharged from rainfall and runoff in the areas of its outcrops which are relatively high rainfall areas The estimated amount of recharge is 4 5 million cubic meters a year

2 5 2 Fuheis Aquitard (A3)

The Fuheis Formation consists of olive green marl intercalated with marly limestone It extends over a wide area from the Ajlun mountains in the north to the escarpment of Ras en Naqab in the south

2 5 3 The Hummar Aquifer (A4)

The Hummar Formation consists of limestone Its thickness in the Amman-Zerqa basin averages 45 meters It is a good local aquifer in the greater Amman area, Zerqa, and Sukhna The recharge area is about 20 km^2 It extends from Biadir Wadi Sir to Sukhna through Sweileh and the southwestern part of Amman

The permeability of the Hummar aquifer ranges from 0 8 to 65 m/d in the Amman-Zerqa basin Elsewhere it is much lower The estimated amount of water in storage is about 1,500 million cubic meters Water quality of the aquifer is fresh and is suitable for all uses But pollution, both organic and industrial, is becoming a threat to this valuable source which also is overexploited TDS values range from 230 to 770 mg/l

Groundwater flow within the Hummar aquifer in the Amman-Zerqa basin is controlled by a divide extending between Amman and Wadi Sir northwards to Sweileh East of the divide, water flows to the southeast towards Amman and then to the east and northeast West of the divide, the flow direction is southwestwards to Wadi Sir The flexure of south Amman which strikes NE-SW forms the southeastern limit of groundwater flow

2 5.4 Shueib Aquitard (A5/6)

The Shueib Formation consists of thick bedded fossiliferous limestone, crystalline in part and thinly bedded porcelaineous limestone Its thickness ranges from 33 to 127 meters In central and northwestern Jordan, the Formation is tight and of very low porosity and is considered an aquitard In the Hamza Graben within the Azraq basin, both the Shueib and Hummar Formations are fractured, porous and saturated with oil

The lithology of the lower Ajlun Group together with the upper Ajlun (A7) changes gradually in the south and southeast of Jordan into a sandy facies and forms one formation (Fassu'a Formation) in the Jafr basin

2 6 The Upper Ajlun (A7)

The Upper Ajlun Formation consists of thick bedded limestone forming distinct ledges in outcrops It outcrops in the western highlands where it occasionally contains chert nodules and chert bands The formation changes facies in the south and southeast (south of El Hasa) into a sandy facies as mentioned earlier Another facies change has been found in the Hamad basin where the whole Ajlun series (A1-7) are composed mainly dolomite, chert and chalky limestone and occasionally sandy There the whole series A1-7 are considered one group named "The Ajlun Group" A third change in lithology of the A7 and the

underlying A1-6 occurs in northwestern Jordan (The Yarmouk Sub-basin, El Shajara and El Turrah) There the whole series (A1-A7) consists of limestone, marls, dolomite and dolomitic and marly limestone undifferentiated The formation is missing in Wadi Sirhan

2 7 Umm Ghudran Formation (B1)

In its outcrop in the northwestern part of the country, the Umm Ghudran Formation consists of a sequence of chalk and marl, about 52 meters thick, forming the basal unit of the Belqa series It thins southward where hydrogeologically it is included in the overlying Amman Formation (B2) In the southeastern part of the Azraq basin in the Hamza Graben and in its northeastern extension in north Sirhan and further east into Saudi Arabia, the B1 thickens into a multilayered formation There, four hydrogeological units are identified in the subsurface They are listed from base to top as follows

B1/A Rajil sandstone aquifer, 350-500 meters thick
B1/B Rajil Claystone aquiclude 100-260 meters thick
B1/C Hamza domomite-chert aquifer, 200-700 meters thick
B1/D Hazeem limestone aquitard, 200-600 meters thick

In this area, the A7 aquifer is separated from the overlying B2 aquifer by about 1,600 to 1,700 meters of B1 which acts as an aquitard

2.8 The Amman-Wadi Sir Aquifer System (B2/A7)

The Amman Formation (B2) consists of limestone, chalk, marl, phosphate and thick bedded chert In boreholes, it is very easily recognized on gamma-ray logs due to the higher content of secondary uranium minerals especially in the upper part In the Azraq basin, east of the Fulouq fault (Tel Qarma fault) a new formation has been identified and introduced by NRA to mark the top of the B2 which is the Usaykhim sandy limestone

The Amman Formation (B2) outcrops are extensive in the western highlands and towards the southern edge of the Jafr basin In the area between Al Hasa and Madaba, three units are recognized in the formation They are from base to top as follows (1) chert limestone unit, (2) phosphate unit, and (3) chalk-marl unit on top

In the western highlands and the plateau, the thickness of the B2 ranges from 151 meters to 375 meters It is much thicker in the Azraq basin where it reaches 630 meters The formation thins out in the southeastern part of the Jafr basin where it is 56 meters thick In Wadi Sirhan it is 62 meters thick

On a regional scale the A7 B1, and B2 form one aquifer system which is the most important aquifer in Jordan It has a very large and continuous extent and

a relatively high permeability It receives the largest amount of modern recharge and is a principal source of fresh water for domestic as well as for irrigated agriculture in the plateau province But it is overexploited and the quality of its water is deteriorating in the northern Badia and in the area of Wadi Dhuleil

Recharge to the aquifer occurs in the western highlands The estimated amount of recharge both direct and indirect is 337 million cubic meters a year The aquifer also receives a substantial amount of groundwater from the basalt aquifer in the Wadi Dhuleil - Mafraq area

In the central and western parts of the Sirhan basin, the B2 is hydraulically connected with the underlying Kurnub Its average saturated thickness in the western part is 70 meters increasing northwards to 150 meters in the northern part

In the northern part of the Sirhan basin, the A1-6 acts as an aquitard between the B2 and the underlying Kurnub

2 8 1 Flow Pattern

Five main recharge mounds are developed in the recharge zone which extends from the Yarmouk River in the northwest to the Ras en Naqab escarpment in the south These mountainous blocks are separated by the Zerqa, Mujib, and Hasa wadis and the Dana fault Groundwater flows from these blocks in all directions The western flow components give rise to important springs such as Wadi Sir spring, Ayoun Musa northwest of Madaba, and Ain Sara west of Karak The northern and southern components contribute to the base flow of Wadi Zerqa, Wadi Mujib, and Wadi Hasa The eastern components saturate the aquifer in the plateau and in the Azraq and Jafr basins

Flow in the Hamad basin is distributed into three directions from an apparent divide lying to the northeast of Tulul El Ashaighaf close to the borders with Syria From there, an eastwards component is directed towards Tell El Bustan area The second component is directed southwards to the borders with Saudi Arabia through Abu Hafna and Dumeitha The third component is directed southwestwards to the Hamza Graben in the Azraq basin

In the central part of the Sirhan basin, flow is directed to the southeast towards Saudi Arabia While in the northern part of the Sirhan basin, the flow direction is to the southwest towards the Hamza Graben

In the Azraq basin, flow is directed towards an elongated sink whose axis extends from Qa Khanna southeastwards to the southeastern closure of the Hamza Graben near the borders with Saudi Arabia

2 8 2 Aquifer Parameters

For the unconfined part of the B2/A7 aquifer, the effective porosity ranges between 1% and 3% For the confined part, the storage coefficient is about $5x10^{-5}$ (El-Nasser, 1991) In the Amman-Zerqa basin, tests results of several wells gave an effective porosity of 2 to 3% and transmissivity (T) ranges from 9 to 900 m^2/d In the Azraq basin, T as calculated by Salzgitter and Arab Tech (1994) is 1,600 m^2/d

2.8 3 Water Quality

In the western highlands and the plateau, groundwater of the B2/A7 is fresh and suitable for all uses Further east and southeast it becomes brackish with a high content of H_2S gas Similar brackish water has been encountered in the Hamad basin

2.9 The Muwaqqar Aquitard (B3)

The Muwaqqar Formation consists of chalk and chalky marl with thick bands of dark brown and black chert with intercalation of marly limestone It is characterized by boulder size limestone with rounded and elliptical concretions In the central part of the plateau as well as in the Azraq and Jafr basins, the lower part consists of bituminous limestone, bituminous shale and bituminous marl (oilshale) In the area between Siwaqa and Jurf Ed Daraweesh, 40 billion tons of rich oilshale have been identified In the Azraq basin two units have been identified in the subsurface They are separated by an unconformity surface The boundary between the two units is characterized by the occurrence of radioactive phosphatic beds which are easily identified on gamma logs Petroleum geologists have renamed the Muwaqqar Formation with the above two mentioned units and have given them the names of Gharib for the lower unit and Taqiyeh for the upper one

The maximum recorded thickness has been found in the northwestern part of the country where it exceeds 910 meters in Waqqas In the area between Amman and Azraq, the thickness ranges from 100 to 300 meters In the plateau south of Siwaqa, it ranges in thickness from 120 to 434 meters north of Ma'an In Jafr, 235 meters were identified in boreholes In the area between Jafr and Shaubak, 413 meters were recorded The formation thickness decreases southeastwards It is only 20 meters thick, east and southeast of Bayir In the Sirhan basin (well W5-3) it is 42 meters In the Hamad basin, the thickness decreases eastwards from 300 meters in the west to 70 meters near the borders with Iraq in the east

The B3 acts as a confining layer to the underlying B2/A7 aquifer In one of the Azraq wells (AZ-1), water from the B2/A7 flows from a depth of 450 meters below ground level to 7 5 meters above the ground

2 10 The Rijam Aquifer (B4)

The Rijam Formation consists of limestone, chert, chalky limestone and cherty limestone The aquifer is limited to the Jafr, Azraq, Sirhan and the Hamad basins It also outcrops north of Irbid The thickness of the B4 in outcrops ranges from 40 to 75 meters It attains a maximum thickness in the subsurface in the Hamza Graben and near the borders with Saudi Arabia where it is about 300 meters The thickness is 50 meters in Jafr and 100 to 150 meters in Sirhan More than 100-200 meters were recorded north of Azraq beneath the basalt

2 10.1 Groundwater Recharge

In the Azraq basin, the Rijam Formation is saturated from approximately 23 km from the west, 40 km from the northeast and 40 km from the south of Azraq esh Shishan (Al Azraq Al Janoubi) From the north, the B4 is overlain by the basalt aquifer and is hydraulically connected with it In the central part of the Azraq basin, the Rijam Formation together with the overlying lacustrine and alluvial deposits (Azraq Formation) and the basalts form a closed composite aquifer, which naturally, before excessive abstraction started, discharged at the springs and swamps of the Azraq oasis Direct recharge is negligible but indirect recharge from ponded runoff in wadi courses and over the outcrops of the aquifer is important This is because the area is characterized by localized, high intensity short-duration storms forming flash-floods in various parts of the basin This indirect recharge amounts to about six (6) million cubic meters a year Total recharge was calculated using two methods one used the combined energy balance and aerodynamic concept (Penmanns, 1948), and the other used flow-net analysis The first method gave 20 5 million cubic meters a year and the second gave a recharge of 18 2 million cubic meters a year The estimates are close Of the total recharge, about 4 2 million cubic meters a year are contributed from the basalt aquifer

In the Hamad basin, the Rijam Formation is saturated from approximately 50 to 60 km west of the border with Iraq In the western part of the basin, the B4 is overlain by the B5 aquitard and by basalt where it is confined Only the western part of the Hamad basin receives modern recharge from ponded runoff where wadi sediments are permeable and the basalts below are fractured In the east and center of the basin, the geology does not favor recharge

The saturated part of the Rijam Formation lies in the eastern part of the Sirhan basin It is an elongated strip oriented in a northwest-southeast direction Its width is 42 km in the south, 40 km in the north and 55 km in the center The eastern limit of the zone is parallel to the borders with Saudi Arabia The only source of recharge in the southern part of the Sirhan basin is indirect from floods and flash floods The latest estimate is about 10 million cubic meters a

year, the greater part of which saturates the alluvium (Sirhan formation) which overlies the aquifer A small portion of that infiltrates to the B4

In the Jafr basin, the saturated area of the Rijam Formation covers about 1,250 km^2 The B4 in the western part of the basin along the Desert Highway is dry Recharge to the B4 in the Jafr basin is limited to the indirect component Floods originating mainly from rainfall in the western highlands (Sharah Mountains) and occasional flash floods draining other parts of the basin are the only possible sources of modern recharge Vertical leakage from the deeper B2/A7 also is possible The estimated total recharge which is supported by monitoring data is 1 25 million cubic meters a year

2.10 2 Aquifer Parameters

Aquifer parameters for the Rijam aquifer is summarized in the following Table-2a

Parameters	Basin			
	Hamad	Sirhan	Azraq	Jafr
Permeability (m/d)	0 05-5	0 06-1 0	0 5-57 5	1 9-225
Storage coefficient	10^{-5}	10^{-5}	10^{-5}	10^{-5}
Effective porosity	1%	0 5%	1%	1%

2 10 3 Water Quality

Water quality for the Rijam aquifer is summarized in the following Table-2b

Basin	TDS (mg/l)
1 Hamad (central)	1660 - 2200
(Southeast)	2300
(North west)	960
2 Sirhan	1520
3 Azraq (north)	350-700
(South west)	700-1500
(South and south east)	> 2000
4 Azraq (playa)	170,000 - 200,000

2.11 Wadi Shallalah (B5) Aquitard /Aquifer

The B5 sections in outcrops consist mainly of chalk intercalated with chalky marl as is the case in northwest Jordan In Jebal eth Thulaythuwat north of Bayir in southeast Jordan, 64 meters of B5 are exposed There the B5 consists of limestone with layers of concretionary chart, marl with concretionary baryte and with interbedded clay bands It is well exposed in Dahkiyia, southeast of

Azraq as white chalk In the western parts of the Hamad and Sirhan basins, the chalk and chalky marls of this formation contain phosphate and glauconite The B5 is considered an aquitard on the basis of the lithology of its exposed sections But data recently acquired from deep drilling and from detailed geological mapping enables the identification of two units The lower one B5(a) is marly and acts as an aquitard while the upper one B5(b) consists of limestone and is an aquifer

The Wadi Shallalah Formation is 140 meters thick in the Yarmouk area north of Irbid, 230-250 meters thick in the Sirhan basin, 190-290 meters thick in the Hamad basin Near the borders with Saudi Arabia, in Qurayyat town, it attains its maximum thickness of 555 meters

The B5b forms a fresh water aquifer in the eastern part of south Sirhan, with a saturated thickness of 20-50 meters and a saturated area of 2,200 km^2 It is unconfined in this area In western Hamad it is hydraulically connected with the overlying basalt aquifer In eastern Hamad it is unsaturated

In south Sirhan, the flow in the Wadi Shallalah aquifer is eastwards to a sink along the Saudi borders In north Sirhan, the flow is southwards to Saudi Arabia also In the western part of the Hamad basin, from Tulul Ashaigaf, the flow is west-southwest towards the Hamza Graben

The permeability of the B5(b) generally ranges from 0 0055-0 025 m/d In the southeastern part of Azraq, the permeability ranges between 0 1 and 5m/d The transmissivity in the Sirhan basin ranges from 0 1-1 2 m^2/d

The B5(b) (limestone aquifer) is exploited in north Sirhan, Umari, El Hazeem and in the Hamza Graben, including the Husseida Police station well in Sirhan

Shallow fresh water aquifers, such as the upper part of Wadi Shallala (B5(b)) in the Sirhan, Hamad and Azraq basins and Garma in the Hamza Graben and Wadi Sirhan together with the basalt, are not discussed in this report

2 12 The Rift Zone

The Jordan Rift Zone forms the western part of the country It is about 350 km long extending from the confluence of the Yarmouk River with the Jordan River in the north to the Gulf of Aqaba in the south

It is subdivided from south to north into three physiographic areas

Wadi Araba which comprises the area from the Gulf of Aqaba to the southern shore of the Dead Sea (about 180 km long)

2 The Dead Sea which is the middle section of the Rift zone, the Dead Sea is about 70 km long
3 The Jordan Valley which is the area between the Dead Sea and the confluence of the Yarmouk and Jordan Rivers

2 12 1 Wadi Araba Alluvial Aquifer

Wadi Araba is defined as the area of the Rift between the southern end of the Dead Sea and the northern shore of the Gulf of Aqaba It is 174 km long The Jordanian side of Wadi Araba has an average width of 15 km It is subdivided into two sub-basin with a topographic divide (drainage divide) at 74 km north of Aqaba The divide is a 250 meters above sea level and occurs in Qa'es Sa'idyeen, in the area of Jebal er Risha

The alluvial aquifer in Wadi Araba consists from base to top of the following successions

1 The lower syntectionical conglomerate (L S C) which is the basal unit of the aquifer The L S C consists of conglomerates containing ill-sorted sub-rounded pebbles, and cobbles Its thickness ranges from 110 meters in Gharandal area to more than 800 meters in Wadi Ghuabe

2 The upper syntectonical conglomerate (U S C) consists of thick bedded, coarse conglomerate in a hard sandy calcareous matrix In Ghor Es Safi the U S C unit is 1800 meters thick (well no GS-1) and is 1100 meters thick in Wadi Ghuabe (well no WGh-1)

3 Quaternary sediments penetrated in deep boreholes consist of alternation of loose sand, gravel, conglomerate, calcareous claystone, marl, shale and mudstone The thickness of these sediments in the two deep wells, GS-1 and WGH-1, are 2 409 and 2,579 meters, respectively

2 12 2 The Dead Sea escarpment and shore zone

East of the Lisan Peninsula, the L C S outcrops in Ed Dhira' where it reaches 450 meters in thickness There it consists of a sequence of coarse clastics, grading into red sandstone, green shale and sandy marl The sequence unconformably overlies the B4 Equivalent stratigraphically to the L S C in Ed Dhira are over 4000 meters of evaporates in the Lisan peninsula beneath the Lisan Marl Formation (Phillips oil expl well no L-1)

2 12 3 The Jordan Valley Alluvial Group

The L S C is replaced by fresh-water lake deposits consisting of limestone, marl sand and conglomerate of about 315 meters thick (Oil expl well JV2) The upper syntectonical conglomerate U S C is 271 to 346 meters thick

2 12 4 Recharge

In Wadi Araba, possible sources of recharge are from runoff originating from the mountains in the east (indirect), and discharge into the aquifer from limestone and sandstone aquifers on the eastern escarpment (direct) A third recharge component is from upward leakage from underlying aquifers Results of mathematical modeling (Energoproject Co , 1990) gave a total recharge of 19 24 million cubic meters a year of which 10 8 million cubic meters a year occurs in the northern sub-basin and 8 44 million cubic meters a year occurs in the southern sub-basin

In the Dead Sea zone and the Jordan Valley, the alluvium receives direct and indirect recharge Most of this recharge, however, is transmitted to the underlying Kurnub or Zerqa aquifers in the Jordan Valley which are hydraulically connected to the alluvium

2.12 5 Groundwater Flow In the Rift Zone

Flow generally originates from the eastern escarpment and is directed westwards towards the axis of the Rift zone In the northern basin of Wadi Araba, groundwater eventually flows northwards to discharge into the Dead Sea, while in the southern sub-basin the flow is to the south towards the Gulf of Aqaba

In the Jordan Valley, groundwater flow is towards the Jordan River In the southern part, the flow is towards both the Jordan River and the Dead Sea

2 12 6 Aquifer Parameters

Permeability range	0 01 - 50 m/d
Transmissivity range	30-2,600 m^2/d
Storage coefficient	10^{-2} - 10^{-4}

2 12 7 Water Quality

In Wadi Araba, about 60% of the groundwater is brackish The TDS ranges from 500 to 5,000 mg/l Salinity increases from the eastern boundary towards the central part of the basin

3.0 Assessment of Brackish Groundwater

3.1 The Ram Aquifer System

The salinity of groundwater in the Ram aquifer increases from the outcrop area in the southeastern desert along the flow direction, (i e , to the north) Brackish groundwater occurs in the northern half of the Dead Sea basin, the eastern half of the Jafr basin and the southern part the Sirhan basin In these areas the salinity ranges from 1,000 to 3,000 mg/l In the Azraq basin, the northern part of the Sirhan basin, the entire Hamad basin, and the Jordan River basin, the salinity ranges from 3,000 to more than 6,000 mg/l

3.1 1 Flow Pattern

The regional flow direction is from the extension part of the aquifer located in Saudi Arabia (Tabouk Area) across the southeastern and eastern borders into Jordan The flow direction is southern Jordan is northwards to just north of latitude 1,000,020 (Palestine Grid) Then the flow direction changes to the northwest and eventually to the west towards the southern part of the Jordan Valley and the Dead Sea In the southeastern desert, two fault structures affect the flow direction The Qweira fault, a NNE-SSW striking fault with several hundred meters of downthrow to the east, forms the western boundary of the flow in that area The second is the Kharawi dike which commences north of Qweira and extends to the southeast into Saudi Arabia The effect of the two structures in the west is the diversion of some flow in a narrow area through Wadi Yutum towards the Gulf of Aqaba

The Kharawi dike locally acts as a barrier against groundwater flowing northwards causing artesian flow in wells south of it in a small restricted area south of Mudawwara

The Graben forming faults in the Rift zone (Jordan Valley-Dead Sea- Wadi Arab) bring the aquifer into direct contacts with shallow aquifers and artesian conditions occur

3 1 2 Aquifer Parameters and Water Quality

The permeability of the Ram aquifer from tested wells in Jordan and Saudi Arabia ranges from 0 5 to 8 5 m/d An average value of 1 5 m/d generally is used

The average storage coefficient in the confined part of the Ram aquifer is about $7\ 2 \times 10^{-4}$ and the specific yield is 0 07 These values are for the southwestern

part of the aquifer Where the aquifer is confined the average hydraulic parameters for the Ram aquifer are

Average saturated thickness (t)	1400 meters
Effective porosity (SY)	3%
Storage coefficient (S)	10^{-4}

In the Jordan Valley, the permeability as determined by JICA (1995) ranges from 4 1 to 16 0 m/d and the storage coefficient ranges from 10^{-6} to 10^{-4}

Brackish groundwater occurs in the Ram aquifer in Jordan over an area of approximately 67,000 km^2 In the southeast (Disi, Ghal, Sahl Es Suwwan and Mudawarra), the TDS of the groundwater ranges from 200 to 250 mg/l It reaches 400 mg/l north of the Kharawi dike and 1,000 mg/l in Wadi Yutum Salinity gradually increases to the north along the flow path until the groundwater becomes brackish to saline in the central, eastern and northeastern parts of the country

Modern recharge to the Ram aquifer is very limited In outcrop areas the Ram water is about 10,000 years old (by isotope dating) while in the confined part it is much older, 20,000 to 35,000 years old

Naturally the Ram aquifer drains to the Dead Sea About 300 million cubic meters a year discharge to the Dead Sea according to mathematical modeling (Hobler et al, 1991) About two (2) million cubic meters a year are drained to the Gulf of Aqaba through the Wadi Yutum gorge

Average piezometric head (h) on top of the aquifer is 1800 meters The total quantity of brackish groundwater stored in the Ram aquifer (Qt)is given by the formula Qt = Qv + Qp, where Qv is the quantity of water in voids and Qp is the quantity of water stored under pressure

$$Qv = A \times t \times Sy = 67000 \times 10^6 \times 1400 \times 0\ 03 = 2814 \times 10^9 m^3$$
$$Qp = A \times h \times S = 67000 \times 10^6 \times 1800 \times 10^{-4} = 12 \times 10^9 m^3$$
$$Qt = Qv + Qp = 2814 \times 10^9 + 12 \times 10^9 = 2826 \times 10^9 m^3$$

The distribution of this quantity is shown in Table 3

Basin	Area (A) ($x\ 10^9 m^2$)	Stored Volumes ($x\ 10^9 m^2$)		
		Qv	Qp	Qt
Azraq	11 588	486 696	2 086	488 782
Dead Sea	04 902	205 884	0 882	206 766
Hamad	19 271	809 382	3 468	812 850
Jafr (N 2 NEW)	00 290	012 180	0 052	012 232
Jordan River	18 194	764 148	3 275	767 423
Sirhan	12 755	535 710	2 296	538 006
Total	67 000	2814 000	12 000	2826 000

Table 3 Calculated volumes of brackish water in the Ram aquifer

3.2 The Khreim Aquitard

As described lithologically and hydrogeologically, the Khreim aquitard contains the Dubeidib formation which consists of several cycles of sand, silt and sandy shale The upper part (about 120 meters thick) is porous and permeable and is saturated with brackish and even saline water except in limited localized areas in the southeastern part of the Hamad basin where a few meters of the section are saturated with natural gas (Risha Gas Field) The formation forms a brackish or even saline groundwater reservoir

According to drilling and logging data, the salinity increases from the Saudi borders in the southeast (Halat Ammar) northwards as follows

In the southern part of Wadi Sirhan it is 1,200 mg/l Further north, in the NRA wells (S-4 and S-46) it is 1,500 mg/l and becomes 2,740 mg/l, 7,280 mg/l, and 9200 mg/l in the oil exploration wells (WS-4, WS-2, and WS-1, respectively) The salinity is expected to exceed 10,000 mg/l in the Hamad basin

The occurrence of saline water in this aquitard which confines the underlying Ram aquifer in the eastern part of the country should be considered whenever major development of the Ram aquifer is decided At present, the piezometric head of the Ram aquifer is higher than that of the Khreim But excessive abstraction from the Ram might reverse the pressure regime resulting in downward leakage of brackish and saline water to the Ram aquifer

The geometry of the Khreim Group is shown on its isopach map (Figure 4) The total area of the formation is 45 920 km^2 and occurs in the eastern half of the country The thickness ranges from zero in the west to 1,250 meters in Tureibil near the borders with Iraq

Estimates of the stored volume of brackish water in the Dubeidib are based on the assumed parameters

Storage coefficient(s) 10^{-5}
Average piezometric head on top of the aquifer approximately 1200 meters
Effective porosity 1 5%
Saturated thickness in each basin is presented in Table 4
Water saturated area = 37,408 x 10^9 m^2

(About 7,748 km^2 in the northeast along the border with Iraq are not fully saturated with water Also, about 764 km^2 in the south along the contact with the Ram Group are dry)

Zone	Area (m^2) x10^9	Average Saturated Thickness (m)	Effective Porosity	Volume Stored in the Voids Qvx10^9m^3
E Hamad	05,852	600	0 015	52,668
W Hamad	07,875	500	0 015	59,0625
N Sirhan	01,575	100		02,3625
E&S Jafr	19,600	300		88,20000
S Sirhan	01,950	300		08,7750
S Desert	00,556	200		01,6680
Total	37,408			212,736

Table 4 Calculated volume of brackish water in the Khreim (the Dubeidib part) aquitard

The volume stored under pressure (Qp) = 37 408x10^9x1200 x10^{-5}
= 0 4489 x10^9m^3
Total (Qv + Qp) = 213 1849x10^9m^3

3.4 The Zerqa aquifer

The total amount of groundwater stored in the aquifer is approximately 33 0x10^9m^3 It is estimated that about 94% of this amount is brackish (1,000 mg/l to 10,000 mg/l) which means that the quantity of brackish groundwater stored in the voids of the Zerqa aquifer is is 31 07x10^9

The quantities stored under pressure are shown in Table 5

Basin	Area (A) (x $10^9 m^3$)	Sat Thickness (m)	Head (m)	Effective Porosity	Stored Volumes (x $10^9 m^2$)		
					Qv	Qp	Qt
Azraq	04 90	50 0	1134	0 03	7 35	0 555	07 905
Dead Sea	00 96	01 3	0170	0 04	0 05	0 0163	00 066
Hamad	16 65	35 4	0726	0 03	17 68	1 208	18 888
Jordan River	01 59	90 3	0304	0 04	05 75	0 048	05 898
Sirhan (North)	01 00	08 0	0871	0 03	00 24	0 0871	00 327
Total	25 102	-	-	-	31 07	1 916	33 084

Table 5 Calculated volume of brackish groundwater in the Zerqa Aquifer

Total volume of groundwater in storage (Vv+Vp)= 31 07x10^9+1 916= 33 0x$10^9 m^3$

3.5 The Kurnub Aquifer

Most of the Kurnub groundwater is brackish Fresh groundwater occurs only in the vicinity of outcrops of the formation in Baqa' - Ein El Basha, the south eastern part of the Jordan Valley escarpment, and the southwestern part of the Jafr basin Elsewhere it is brackish

In the eastern part of the Azraq and Sirhan basins, and the eastern part of the Jordan River basin, the salinity increases from 3,000 to about 6,000 mg/l

Brackish groundwater occurs over an area of about 54,000 km^2, where the aquifer is confined

Average saturated thickness (t)	89 meters
Effective porosity	3%
Storage coefficient (s)	10^{-4}
Average piezometric head on top of the aquifer (h)	800 meters

The volume of brackish groundwater stored in the Kurnub is summarized by basin in Table 6

Basin	Area (A) (x $10^9 m^2$)	Sat Thickness (m)	Head (m)	Stored Volumes (x $10^9 m^3$)		
				Qv	Qp	Qt
Azraq	11 735	115	1,100	40 486	1 291	41 777
Dead Sea	01 761	115	165	06 075	0 0290	6 104
Hamad	16 650	060	720	29 970	1 199	31 169
Jafr	03 730	110	240	12 309	0 090	12 399
Jordan River	08 592	120	300	30 931	0 258	31 189
Sirhan	11 250	070	870	23 625	0 979	24 604
Total	53 718	-	-	143 396	3 846	147 242

Table 6 Stored volumes of brackish water in the Kurnub Aquifer

3 6 The lower Ajlun Aquifer

Stored brackish water in the lower Ajlun (A1-6) occurs in the Jafr basin where the lithology of the aquifer materials is arenaceous and the whole Group A1-A6 is undifferentiated forming the Fassu'a aquifer The sandy facies of the lower Ajlun (Fassu'a) extends to the Sirhan basin Generally, groundwater in the Fassu'a aquifer in the western part of Jafr occurs under water-table conditions

Area of saturation is estimated to be 12,000 km^2
Average saturated thickness is about 120 meters
Calculated water in storage A= $12{,}000 \times 10^6 \times 120 \times 0\ 03 = 43\ 2 \times 10^9 m^3$
About 90% of this amount is brackish, i e , quantity of brackish groundwater in storage is approximately $39\ 0 \times 10^9 m^3$

3.7 Amman -Wadi Sir B2/A7 Aquifer

Brackish groundwater in this regional aquifer system occurs in the eastern part of the country, where the aquifer is confined by the Muwaqqar (B3) aquitard and other younger strata A strip in the northern part of the country 40-50 km wide from the Syrian borders in the north, which includes the northern parts of the Azraq and the Hamad basins is excluded Groundwater in this northern strip is fresh due to the discharge of freshwater from the basalt aquifer into the upper Cretaceous aquifers which eventually leaks downwards to the B2/A7 aquifer in this zone

According to available data, Table 7 shows the amount of brackish groundwater in the B2/A7 aquifer and its distribution in the groundwater basins, based on a specific yield (sy) of 1% and a storage coefficient of 10^{-3}

Basin	Area (A) (km^2)	Sat Thick (t) (m)	Head (h) (m)	$Qv \times 10^9$ (m^3)	$Qp \times 10^9$ (m^3)	$Qt \times 10^9$ (m^3) (Qv+Qp)
Azraq	6,000	666	570	41 958	3 591	45 549
Dead Sea	1,000	157	100	01 570	1 000	02 570
Jafr	2,3000	065	080	01 495	0 184	01 679
Sirhan	15,300	210	040	32 130	6 120	32 250
Hamad	11,000	125	175	13 750	1 925	15 675
Total	35,900			90 903	12 820	103 723

Table 7 Calculated volume of brackish water in the B2/A7 aquifer

3 8 The Rijam (B4) Aquifer

Brackish groundwater occurs in most of the Hamad basin (an area of about 15,000 km^2) in about two thirds of the area of the northern part of the Sirhan

basin (adjacent to the borders with Saudi Arabia), and the southeastern part of the Azraq basin including a small area from the northern part of south Sirhan The total area of brackish groundwater in the Azraq and Sirhan basins amounts to 4,000 km^2 with an average saturated thickness (t) of 75 meters The average saturated thickness in the Hamad basin is about 77 meters Generally the aquifer is unconfined, and the estimated specific yield (sy) is 1%

Based on the above parameters, the estimated quantity of brackish groundwater stored in the B4 aquifer is given in Table 8

Basin	Area (km^2)	Saturated Thickness (m)	Sy	$Qx10^9m^3$
Hamad	15,000	77 0	1%	11 55
Azraq and Sirhan	4,000	75 0	1%	3 00
Total	19,000			14 55

Table 8 Calculated volume of brackish water in the B4 aquifer

3.9 Wadi Araba Alluvial Aquifer

Approximate area of saturation 160x5 5= 880 km^2
Average saturated thickness 800 meters
Specific yield 10%
Quantity of brackish groundwater in storage
$880x10^6x800x0\ 1 =$
$70\ 400x10^9m^3$

3.10 Total Volume Brackish Groundwater in Jordan

Calculations of stored amounts of brackish groundwater in all aquifers yield a total volume of $3,447x10^{12}m^3$ Table 9 summarizes the volumes by aquifer and basin This volume of about 3 35 is purely scientific and cannot be considered for exploitable purposes On the other hand substantial quantities of brackish water in different areas of the country form a potential source of water for direct use, blending, or for desalination

Basin	Azraq	Dead Sea	Hamad	Jafr	Jordan River [1]	Sirhan	Southern Desert	Wadi Araba	Total
Aquifer									
Ram	486 7	206 8	812 8	12 2	767 4	538 0	-	-	**2826 0**
Khreim	-	-	111 7	88 2	-	11 10	1 70	-	**212 7**
Zarqa	7 90	0 066	18 888	-	5 898	0 329	-	-	**33 084**
Kurnub	41 777	6 104	31 169	12 399	31 189	24 604	-	-	**147 242**
A1-6	-	-	-	39 0	-	-	-	-	**39 0**
B2/A7	45 549	2 570	15 675	1 679	-	32 25	-	-	**103 723**
B4/B5 [2]	2 20	-	11 55	-	-	0 80	-	-	**14 55**
Alluvium	-	-	-	-	-	-	-	70 40	**70 40**
Total	**584 12**	**215 54**	**1001 8**	**153 48**	**804 48**	**607 08**	**1 70**	**70 40**	**3438 6**

Table 9 Distribution of the total estimated quantity of brackish groundwater stored in the aquifers among the groundwater basins The figures are in billions of cubic meters

[1] The Jordan River Basin includes the Amman-Zerqa Basin

[2] The B4/B5 in the Azraq Basin includes the shallow lacustrine alluvial deposits in central part of the basin where they form with the underlying B4/B5 one composite aquifer

4.0 Brackish Water in Springs Discharge

There are sixty-seven (67) brackish springs in the country which were identified and are covered by monthly monitoring of discharge and salinity Sixty-four (64) of these, in addition to the Zerqa M'ain and Zara group of springs and seepages, occur in the Rift escarpment One occurs in the vicinity of Azraq Esh-shishan in the Azraq basin and two others in the Ma'an area in the Jafr basin Temperature measurements of discharged water from the springs is not included in WAJ's monitoring program But the temperature of the waters ranges between 15°C and 30°C Geothermal waters of Zerqa M'ain, Zara and others in the Rift escarpment range in temperature from 50°C- 63°C

Table 10 summarizes the number of brackish springs in the different basins, their average annual discharge, and their average total dissolved solids (TDS) concentration

Basin	No of Springs (Brackish)	Average total discharge (MCM/yr)	Average TDS (mg/l)
Dead Sea	33+Zerqa Ma'in + Zara Groups	33 160	1020-7840
Jordan River	23	21 030	1010-3860
Wadi Arab	8	0 080	1100-1430
Azraq	1	0 300	1115
Jafr	2	0 100	1100
Totals	67 + Zerqa Ma'in + Zara Groups	54 670	

Table 10 Brackish Springs Data

Annex I presents more details about each brackish spring such as the name, the identification number, the aquifer source, and chemical analyses

5.0 Geothermal Water Resources

Surface and subsurface thermal anomalies in Jordan have been observed at many locations mainly as hot springs along the Dead Sea Rift escarpment and the Mukheiba area along the Yarmouk River Several water wells in Zyzya, Azraq and North Shuna, Mua'di, and Safawi have encountered hot mineralized water The regional geological structure of Jordan renders parts of the country favorable for the occurrence of geothermal reservoirs The Jordan River Rift system, which is part of the great East African-Anatolian Rift, is active Along this great transform, geological and geophysical evidences strongly suggest a left lateral movement of the Arabian plate in a north-northeast direction relative to the African plate Release of tensional stresses along the transform has resulted in sporadic eruption of basalt flows at or near the surface and the development of a network of structures (faults and folds) in proximity of the rift zone Positive heat flow anomalies occur in the Jordan River Rift and adjacent areas coinciding closely with areas of basaltic eruption and the seismically active zones 98% of the geothermal springs in Jordan occur in this zone

5 1 Sources of Heat

Possible sources of heat are

1 The naturally hot rocks in the subsurface at considerable depths but within the reach of circulating meteoric water through deep fractures in fault zones Here the water is preheated and ascends to the surface as hot springs
2 The presence of a hot magnetic source in the subsurface giving heat to circulating fluids
3 The friction along the transform and other active fault zones

Heat flow measurements on the surface and geothermal gradient measurement in boreholes have delineated favorable areas of geothermal groundwater

5.2 Zerqa Ma'in and Zara Hot Springs

There are 64 hot springs and seeps in Wadi Zerqa Ma'in on the northern side of the Zerqa Ma'in E-W fault, and four (4) springs and seeps in the Zara area on the eastern side of the main graben forming fault of the Dead Sea

These hot springs with spectacular water falls have been known and enjoyed throughout history Today they serve as an important tourist attraction and recreation area A health resort presently is active in Zerqa Ma'in

5 2 1 Zerqa Ma'in Hot Springs

In Wadi Zerqa Ma in two groups of hot springs occur

a) Hypothermal springs with a temperature range of 20°C to 34°C They occur in areas of steep slopes on the upstream side of the Wadi Ez Zarqa The springs issue from the Hummar (A4) aquifer with an average total discharge of 80 m^3/hr The water is warm and is being utilized for irrigation by the Bani Hamida, the TDS is less than 1,000 mg/l Another group are Uyun Musa which issues from the Wadi Sir (A7) aquifer and is fresh and being used for the domestic water supply

b) Geothermal springs
There are 64 hot springs and seeps which were surveyed by the author during the period 1977-1980 Temperatures range between 34°C and 63°C and the average TDS ranges between 1,790 and 2,100 Average total discharge is 17 million cubic meters a year The variation of discharge and TDS with seasons is negligible The source aquifer is the Kurnub sandstone

5 2 2 Zara Hot Springs

There are 44 springs and seeps in the whole Zara area with an average total discharge of 9 1 million cubic meters a year and a temperature of 43-54°C The discharge and TDS show little seasonal variation The source aquifer is the Kurnub sandstone

Both the Zerqa Ma'in and Zara geothermal springs contain relatively high concentrations of fluoride, bromide and iodide (more than the content of sea water) They also contain Boron (0 3 mg/l) The water type of both is NaCl - $Ca(HCO_3)_2$ Both areas have radioactive superficial deposits Thorium and radium (226) were identified in some spring deposits

5 3 Mukheiba Area (El-Himma)

This area is situated in northwestern Jordan, adjacent to the Yarmouk River The springs are utilized principally for recreation and a nearby rest house provides accommodations for visiting bathers Less important hot springs and seeps are located downstream along the Yarmouk and are utilized in limited irrigation mainly for banana crops

The El Hamma hot springs feed three pools The water temperature of the inner pool is 48C while the temperature of the outer pool is 33 5C The flow rate is approximately 15 m^3/hr All hot springs in the Mukheiba area give off an odor of H_2S Also, the spring areas are slightly radioactive

The Azraq area was discovered when a deep water well was drilled by the Azraq Groundwater Project (CWA/UNDP) in 1962-1963 in the area where the Azraq resthouse is located now The well (Az-1) encountered artesian hot sulphurous groundwater at a depth of 450 meters which rose to about seven (7)

meters above the ground surface with a well head temperature of 39°C In 1983, heat flow and geothermal gradients were determined in two oil exploratory wells (WG-1 and WR-1) drilled and in one water well (SH-5) drilled in the Azraq basin The results are shown in Table 11

Well Name	Heat Flow (mw/m^2)	Thermal Gradient (°C/km)	Depth Interval (m)
WG-1	125	54 65	46,232
WR-1	70	30 28	95,131
SH-5	120	73 59	204,280
Normal conditions in the earth crust	(64)	(30)	

Table 11 Geothermal parameters of selected wells

Heat flow and geothermal gradients for the three sites indicate the occurrence of heat anomalies

5.4 North Shuna Well.

Basic well information includes
PGN 224 360 PGE 208 141 Total Depth 967 meters Yield 900 m^3/h
Temperature 53 5°C pH 7 0

Concentration of principal geochemical parameters (in ppm) includes

Na	K	Mg	Ca	Cl	SO_4	HCO_3	Si	TDS	F	Br
111 0	7 7	43 1	60 6	124 25	110	41 0	84 0	-	0 566	1 75

H_2S gas is present

Trace element concentrations in parts per billion (ppb) include

1	Cu	Co	Cr	Mn	Ni	Zn	Pb	Ag	Li
2 0	nd	550 0	20 0	nd	Nd	20 0	nd	30 0	-

5 5 Mua'di Well

Basic well information includes
PGN 177 PGE 211 50 Total Depth 700 meters Yield 60 m^3/h
Temperature 51°C TDS 10,586 ppm

This is a private well (Omar Abdullah well) drilled on the edge of the Jordan Valley escarpment on a Kurnub sandstone outcrop to the east of Mua'di for the use of the Jordan Valley Resort Thermal water flows from the Zerqa and the underlying Ram aquifers The temperature log gave the following temperatures at the three depth intervals (Table 12)

Depth interval (m)	Temperature (°C)
141 8-148	45
2114-238	47 4
348-354	51 7

Table 12 Temperature measurements in Mua'di well

5.6 Zyzya Area

South and southeast of Queen Alia International Airport are located a number of private water wells which produce warm to hot water (temperature 38°C and 43°C) from the B2/A7 aquifer Most of these wells are located in a faulted zone where the eastern extension of the Wadi Zerqa Ma'in fault intersects another fault

5 7 Ghor El Haditha Well (TS-1D)

Basic well information includes
PGN 77 121 PGE 201 662 Total Depth 773 meters Yield 300 m^3/h
Temperature 50 °C

The well was drilled by NRA as a tar-sand exploration well Thermal water flowed to the surface from two zones in the Kurnub sandstone aquifer The first interval is from the upper Kurnub at 54 meters depth, temperature of 42°C, with a high content of H_2S gas The second interval is from a depth of 637-664 meters which is the lower Kurnub The temperature is 50°C, the flow rate is 400 m^3/hr At both intervals, the highly thermal brackish water (TDS 9,034-9,103 ppm) remained flowing under high pressure

Chemical Analyses of the TS-1D well water are presented in Table 13

Samples No	Depth (m)	Sp Gr 20 d4	pH	TDS ppm	Cl- ppm	Na+ ppm	K+ ppm	Ca++ ppm	Mg++ ppm
1	598	1 005	7 2	9103	4970	1385	181	723	448
2	773	1010	7 5	9034	4473	894	119	1100	515

Table 13 Chemical analysis of water samples from well no TS-1D

5.8 Wadi El Hasa Springs

5 8 1 Afra Thermal Spring No 1

Basic spring information includes
PGN 41 550 PGE 209 200 Elevation (asl) 850 meters
Flow rate 375 m^3/hr Aquifer Kurnub

Temperature and pH data

Sample No	Temp (°C)	pH	Date	Others
1	45	6 8	12 12 89	
2	46	6 8	7 10 90	

Chemical Analysis (ppm)

Na	K	Mg	Ca	Cl	SO_4	HCO_3	Si	TDS	F	Br
35 8	2 2	16 60	44 0	65 0	60 0	129 0	10 1	-	-	-

Trace Elements (ppb)

I	Cu	Co	Cr	Mn	Ni	Zn	Pb	Ag	Li
-	-	356 0	53 0	-	-	-	-	-	-

5 8 2 Afra Thermal Spring No 2

Basic spring information includes

PGN 41 555 PGE 209 200 Elevation (asl) 850 meters

Flow rate 300 m^3/hr Aquifer Kurnub

Temp and pH data

Sample No	Temp. (°C)	pH	Date
1	47	6 9	12 12 89
2	47	6 9	7 10 90

Chemical Analysis (ppm)

Na	K	Mg	Ca	Cl	SO_4	HCO_3	Si	TDS	F	Br
35 8	2 2	16 60	44 0	65 0	60 0	129 0	10 1	-	-	-

Trace Elements (ppb)

I	Cu	Co	Cr	Mn	Ni	Zn	Pb	Ag
-	-	-	356 0	53 0	-	-	-	13 0

5 8 3 Burbaita Thermal Spring

Basic spring information includes

PGN 43 750 PGE 214 000 Elevation (asl) 253 meters

Flow rate 31 m^3/hr Aquifer Kurnub

Temperature and pH data

Sample No	Temp (°C)	pH	Date	Others
1	40 6	6 5	12 12 89	
2	40 7	42		

Chemical Analysis (ppm)

Na	K	Mg	Ca	Cl	SO_4	HCO_3	Si	TDS	F	Br
49 0	5 9	14 4	32 6	97 63	80 0	46 0	-	377	0 880	1 20

Trace Elements (ppb)

I	Cu	Co	Cr	Mn	Ni	Zn	Pb	Ag	Li
-	490	-	100	130	50 0	-	30	-	

The water contains CO_2

5.9 Azraq Basin

Two deep water wells encountered thermal water in the Azraq basin

5.9.1 Well Az-1(Azraq Rest house)

Well Az-1 was drilled by the UNDP-Azraq groundwater project and the Central Water Authority of Jordan in 1963

Basic well information includes PGN 142 160, PGE 321 200

The well is located in the vicinity of the Azraq Rest house which is utilizing the thermal sulphurous water of the well The artesian flow rate is 45 m^3/hr, and the artesian head is 7 meters above the ground surface The water temperature at the well head is 39°C and the pH is 7 4 The thermal water contains high amounts of H_2S gas The water is from the B2 aquifer from a depth interval of 420-502 meters

Chemical Analysis (in milli-equivalents per liter)

Ca	Mg	Na	HCO_3	SO_4	Cl	TDS
4 7	2 79	12 41	4 40	7 00	8 50	1180

5 9 2 Smeica Well No 1 (Safawi Area)

Basic well information includes

PGN 188 700	PGE 371 00	Total Depth 900 meters
Elevation	SWL 224 5m bgl	Yield 50m^3/h
Temperature 56 4°C	pH 6 9-7 45	A quifer Kurnub Sandstone

The water contains H_2S gas

Temperature and pH data

Sample No	Temp (°C)	pH	Date
1	55	7 45	10 12 89
2	65 4	6 9	8 9 90

Chemical Analysis in parts per million (ppm)

Sample No	Na	K	Mg	Ca	Cl	SO_4	HCO_3	Si	TDS	F	Br
1	108 0	18 5	22 5	39 7	177 5	80 0	55 0	580	1 82	2 18	
2	161 0	15 0	24 2	50 6	206 0	60 0	289 0	28 36	630	1 84	

Trace elements in parts per billion (ppb)

Sample No	I	Cu	Co	Cr	Mn	Ni	Zn	Pb	Ag	Li
1	7 0	nd	620 0	100 0	nd	nd	nd	nd	30 0	nd
2	7 1	0 01	-	-	-	-	-	-	-	-

The water contains H_2S gas

5.10 Conclusions

Based on available data, there are three areas of potential geothermal water resources in Jordan which have been identified

1 The Dead Sea-Jordan Valley escarpment This area has the highest potential and the highest heat flow values

2 The Azraq basin where isolated areas in the subsurface have been discovered Delineation of more potential areas in the basin requires additional exploration

3 The Zyzya area where many private water wells south and southeast of Queen Alia International Airport tap thermal water from the B2/A7 aquifer

Potential areas for geothermal water resources occur most likely in faulted zones where deep circulation of groundwater takes place Deep faults may act as conduits for rapid ascent of hot waters from deep confined aquifers Thermal water is driven toward the surface by hydraulically induced forced-convection While ascending, thermal water heat is dissipated in part, by mixing with cooler groundwater of shallow aquifers, by conduction into surrounding rock, or by discharge as thermal springs

6.0 Desalination Technologies

Pure water can be separated from brackish or saline sea water by several different processes, which will be briefly discussed below The interested readers are referred to specialized literature for more details

6 1 The Reverse Osmosis (RO) Process

Osmosis is a natural process which can be defined as "the diffusion of a solvent or fluid through a semi-permeable membrane", such as the wall of a living cell, into a solution of higher concentration, so as to equalize concentrations on both sides of the membrane The diffusion of fluids through the semi-permeable membrane is caused by the osmotic pressure Every solution has a specific osmotic pressure determined by the identities and concentrations of the dissolved materials However, osmotic pressure is defined as the force exerted by a solvent passing through a semi-permeable membrane in osmosis, equal to the pressure that must be applied to the solution in order to prevent passage of the solvent into it

Reverse osmosis is based on the principle of applying pressure greater than the natural osmotic pressure of the solution (brackish water) to drive the solvent (water) through a semi-permeable membrane It is a filtering process at the molecular-ion level In practice, compact modules of semi-permeables membranes and a high pressure pump are used

6 1 1 Characteristics of the Reverse Osmosis Process

1 Low energy consumption It is mainly the energy required to operate the high pressure pump
2 It removes both ionic and non-ionic substances as well as bacteria and viruses
3 The availability of different kinds of membranes enable the process to be applied on a wider range
4 The developed compact modules of membranes reduces the plant space
5 Membranes are sensitive to the quality of brackish water and pre-treatment is usually required

6 2 Evaporation

This is achieved by boiling or flashing The multi-stage flash process has been widely used especially for desalination of sea water with large scale installations It is suitable in countries where cheap energy sources are available With this process, very high quality water (TDS < 10 mg/l) can be obtained Reduction of the energy cost has been achieved through the

application of high efficiency heat-exchanging machines and the utilization of the residual heat energy

The principal of evaporation by flashing depends on the successive reduction of pressure on the heated solution (brackish or saline) Accompanying the pressure reduction, water vaporizes from the solution by flashing At each stage of the pressure reduction, vapor is formed by flashing

6.3 Electrodialysis (ED)

Desalination also can be achieved efficiently by electrochemical separation of dissolved soilds The successfully used process in this field is electrodialysis (ED-process) which utilizes direct current for electrolysis and two types of membranes, cation-permeable membrane which permits positive ions only (such as Na+) and repels negative anions (such as Cl-) This thus creates a stream of fresh water (desalted) between the membranes while the ions are concentrated on the electrodes

In commercial plants, multi-pairs of membranes are installed between a single pair of electrodes forming several alternating compartments for concentration of ions and for desalinating water alternatively

The latest development in this process is by reversing the polarity of direct current periodically (2-4 times hour) during which the membranes periodically clean themselves without the use of chemicals

The process is used for the production of potable water from brackish water It is also used for the production of salt from sea water The disadvantage of the process is the required electrical energy, the amount of which is proportional to the TDS amount in brackish water Also the produced water is not free from non-ionic substances and requires treatment

6 4 The Mechanical Vapor Compression (MVC) Process

This process is used for desalination of sea water Recently a German company has developed the process and introduced wind energy as the power source

The process has been demonstrated on the island of Borkum in the North Sea and the following technical data have been obtained

Minimum wind velocity for startup	3m/s
Maximum wind velocity before power off	25m/s
Nominal power output	45 kw
Maximum power output	80 kw
Distillate flow	0 3- m^3/hr
Total energy demand	16-20 kwh/m^3

Evaporation temperature	35-65 ^{o}C

In November/December 1995, a prototype plant was installed on the Island of Rugen (Germany) In this prototype plant, components and design have been adapted to the following optimum operational conditions

Feed flow	5-20 m^3/h
Distillate flow	2-15 m^3/h
Evaporation Temperature	35-75- ^{o}C
Maximum power demand	300 KW
Maximum power output of the wind unit	300 KW
Rotor diameter	300 m

6.5 Capacitive Deionization Process (CDI).

This is an electrochemical process newly developed by Lawrence Livermore National Laboratories (LLNL) in California Desalination of brackish and saline water is performed by passing the feed between carbon-aerogel electrodes at a potential difference of about one volt When the electrodes are saturated with salts, they are electrostatically regenerated

The process is characterized by the electrodes material which was developed by LLNL for many other purposes Carbon-aerogel electrodes are characterized by the high specific surface area (600-100m^2/gram), and the process is energy efficient compared to other known processes There is no need for pumping and the electric energy required is comparatively low The process has been successfully demonstrated for desalination and purification of waste water and sea water

Recent advances in desalination technologies have opened the possibility of economic development and treatment of brackish and thermal brackish water for beneficial use The criteria for exploitation are essentially economic The costs in the case of brackish groundwater are dependent on the following factors

1- Energy costs
2- Drilling depths
3- Pumping lifts
4- Distances from wellfields and desalination plants to users
5- Well yields
6- Desalination and treatment costs which depend on the technology
7- Disposal of brine which besides cost may have environmental hazards

Social development in desert areas, where fresh water is not available and brackish groundwater is the only local resource, could be another criterion besides economics for desalination

7.0 Exploitation of Brackish Groundwater

The scarcity of fresh water resources, together with the rapidly increasing demand for water drew attention to the development of brackish water Current direct uses of brackish and saline water in Jordan are discussed in this section

7.1 Industrial Uses

a) The Arab Potash Company exploits brackish groundwater from the Kurnub aquifer in Ghor El Haditha and Wadi I'sal in the treatment processes of the potash produced from the Dead Sea water

b) The Jordan Phosphate Mine Company is exploiting fresh and semi-brackish groundwater from the B2/A7 aquifer in Esh Shidiya Phosphate Mine in the Jafr basin at a rate of about 16 million cubic meters a year for upgrading processes of the phosphate ore

c) The Azraq Table-Salt Society utilizes saline groundwater from the shallow composite aquifer in Qa' El Azraq for table-salt production

d) Sea water from the Gulf of Aqaba is utilized by the Jordan Electricity Authority for cooling in the Aqaba Thermal Power Plant

7 2 Agricultural and Domestic Uses

a) In the Jafr basin, about 1 million cubic meters a year of brackish groundwater (becoming brackish by irrigation returns) are utilized in irrigation

b) In Wadi Araba, about 0 85 million cubic meters a year of brackish groundwater from the alluvial aquifer is exploited for irrigation in the areas of Wadi Musa, Mithla, Rahma and Qa' es Sa'idiyeen

c) In the Hamad basin, brackish groundwater from the B4 aquifer is utilized from WAJ production wells for domestic and limited irrigation in localized areas in the basin

d) Limited irrigated farming in the Zara area, on the eastern shore of the Dead Sea, by private local people from Bani Hamida has been the only source of living for those people The water used is the thermal brackish springs water

7.3 Tourism and Health Bathing

Brackish-thermal groundwater from springs and wells is utilized in touristic and recreation facilities and for health bathing in El Hammeh, Zerqa Ma'in , Azraq, and North Shuneh

Another possible direct use of brackish and saline water is fish farming Attractive locations for such use are many, the Jordan Valley, Azraq, Ghor El Haditha, Wadi I'sal, and others

7.4 Economics of Desalinating Brackish Groundwater

The unit cost of desalinating brackish groundwater depends on several factors Other than the costs of wellfield construction and pumping of brackish groundwater to the desalination plant, the following factors must be cost-effective

1) Capital cost recovery
2) The energy factor
3) Plant size and reliability
4) Process type and design
5) Infrastructure requirements
6) Operation and maintenance requirements
7) Pre- and post-treatment requirements of feed and product
8) Environmental factors
9) Labour, chemicals and spares

According to Dykes and Colon (ref No) the distribution of overall costs for desalinating brackish groundwater by reverse osmosis is as follows

Capital cost recovery	41%
Energy	26%
Membranes	12%
Labour	11%
Chemicals	7%
Other expendable items	3%

According to Buros (ref No), desalination of brackish water usually costs one-third to one-fifth as much as that of sea water

Substantial cost reduction will be achieved using off-peak cheap electricity or using hydro-powered reverse osmosis desalination

Using a hydro-powered reverse osmosis desalination process in Jordan is possible in the southern part of the Jafr basin where the Kurnub and the underlying Khreim aquifer meets the criteria for exploitation of brackish

groundwater In this case, the existing Disi-Aqaba water supply pipeline can be used The differential head of water between the collecting reservoir in Disi and the terminal reservoir is 620 meters with an effective differential head of 589 meters (assuming the friction head loss 5%)

The distance between a suitable wellfield in the southern part of the Jafr basin and Disi is about 25 km

8.0 Potential Areas for Development

Assessment of the exploitable brackish groundwater in Jordan has been based on economic, technical and environmental criteria which are inter-related The main economic factors affecting the initial costs of exploitation are drilling depths, well completion, and pumping lifts Technical factors are related to the aquifers from which brackish water will be exploited These factors include well productivity and constituents of wells Wells drilled in aquifers consisting of porous consolidated rocks such as limestones, dolomites and cherts do not require steel casing, and production can be from open-holes For production wells drilled in friable and loose sandy material or alluvial gravel, casing and expensive screens are necessary Also, the distance and the elevation difference between wellfields and the areas where desalinated water is required must be cost-effective Environmental factors include the removal of the produced brines from the desalination process and brine disposal in sites where there will be no negative impact on the environment Disposal of brines may include the following options

1 Pumping into lined evaporation ponds where the brine concentrates into solid salt
2 Injection into the deep underground formations
3 Discharge through pipeline to sewers, rivers or other water bodies
4 Spreading on unusable arid land

In the present evaluation of exploitable quantities of brackish groundwater, the following three main economic and technical factors are considered

1 The maximum drilling depth is 800 meters
2 The maximum pumping lift is from 250 meters below ground surface
3 Well yields range from 80 to 300 cubic meters per hour

Potential areas for exploitation of brackish groundwater and brackish thermal spring's water are selected on the basis of the above mentioned criteria The exploitable quantities from aquifers in the different basins are summarized in Table 14, page

8.1 The Jordan Rift Areas

8 1.1 The Jordan Valley

Seil Ez Zarqa divides this zone into two parts, the northern part extends to the Yarmouk River and the southern part extends southwards to Suweima on the northeastern shore of the Dead Sea According to the criteria above, the southern part is given priority This part has been studied recently by JICA

(1996) The study concluded that a potential of 121 million cubic meters a year was available the Zerqa aquifer, from which 75 million cubic meters per year of desalinated water could be produced by the reverse osmosis process JICA recommended a 5 million cubic meters a year desalination pilot plant as the first step in developing the resource

Drilling depths range between 200 and 400 meters, pumping lifts do not exceed 40 meters, and the TDS ranges between 5,000 and 7,000 mg/l

In this part of the Jordan Valley, the Kurnub and the Ram aquifers are potential sources of brackish groundwater The Kurnub overlies the Zerqa aquifer and its development by the same wellfields will be at negligible additional cost The Kurnub aquifer will increase the well yields of brackish water but with a lower TDS than that of the underlying Zerqa aquifer

More important in this part of the Jordan Valley is the Ram aquifer which is expected to have much more potential than the Zerqa and the Kurnub aquifers Drilling depths will be less than 500 meters Wells will be flowing with piezometric heads much higher than that of the overlying Zerqa aquifer Pumping lifts will be similar to that of the Zerqa or less Also the TDS of the Ram aquifer in this area is lower

In the northern part of the Jordan Valley, the exploitable aquifers are the Kurnub and the B2/A7 East of the main graben fault where the wellfields should be located, drilling depths for the penetration of the Kurnub aquifer are around 800 meters Brackish groundwater is expected to flow to about the ground surface in most of the wells if located properly Pumping lifts are 50-100 meters and well yields range from 130-250 m^3/hr

According to the present study, the exploitable quantities of brackish groundwater from the whole Jordan Valley Area exceed 250 million cubic meters a year

8 1 2 Dead Sea Escarpment

For the purpose of evaluating brackish groundwater potential, the Dead Sea escarpment can be divided into four zones which are from north to south described as follows

1 The zone between Suweima and Wadi El-Gharaba which is about 27 km along the Dead Sea eastern shore The exploitable aquifers in this zone are the Kurnub, Zerqa, and Ram aquifers This zone includes the areas of Suweima, Humrat Ma'in, Wadi Zerqa Ma'in and Zara Based on economic criteria, about 50 million cubic meters a year of brackish groundwater potentially are exploitable from the three aquifers Drilling depths range

from 50 to 700 meters Pumping lifts are negligible, because water from the Zerqa and the Ram aquifers will be naturally free flowing at a rate of 300 to 1000 m^3/h The piezometric potential of both aquifers in that area is 25 to 70 meters, respectively The TDS is about 2,000 mg/l

2 The second zone extends from Wadi El Gharaba 16 km southwards to the end of the Cambrian outcrop, half way between Wadi Shuqeiq and Wadi El Jarra The estimated exploitable brackish groundwater from the Ram aquifer amounts to 200 million cubic meters a year The zone includes Wadi El Heidan, Wadi Mujib, and Ain El Hamar The Umm Ishrin sandstone of the Ram Group outcrops along the shore in this zone A 7 5 meters high stone of travertine at about 4 5 km south of the alluvial fan of Wadi Mujib is known locally as Lut's Wife At the base of the so-called Lut's Wife, on the shore of the Dead Sea, several seepages of brackish water issue from the Umm Ishrin sandstone Drilling depths range from 250 to 450 meters Pumping lifts range from 100-150 meters (in most cases, water flows to the land surface) The TDS is about 1,500 mg/l

3 The third zone extends 16 km along the Dead Sea shore It includes Wadi Ibn Hamad, Ghor El Haditha, Ed Dhira', Wadi El Karak and Ghor El Mazra'h The exploitable aquifers are the B2/A7 and the Kurnub The estimated exploitable quantity is 10 million cubic meters a year Drilling depths range from 350 to 770 meters Pumping lifts range from 0-50m The TDS is about 1,700 mg/l

4 The fourth zone extends 13 km from the southeastern corner of the Lisan peninsula to the southeastern end of the Dead Sea It includes Ghor I'sal, Ghor En Numeira and Wadi El Hasa The Ram Group crops out along the shore and is overlain by the Kurnub which crops out on the sides of wadis The shallow target is the Kurnub aquifer in Wadi I'sal, Wadi Numeira and Wadi El Hasa Drilling depths for exploitation from the Kurnub range from 250 to 350 meters and pumping lifts are 50-150 meters (water levels are expected to be near the surface or flowing) Estimated exploitable quantities are eight (8) million cubic meters a year

8 1 3 Wadi Araba

There are two sources of brackish groundwater in the area

1 The alluvial aquifer has anticipated drilling depths range between 150 and 400 meters, with water levels between 40 and 120 meters below the land surface Well yields are estimated at 18-108 m^3/h TDS ranges between 500 and 5,000 ppm Exploitable quantities from the renewable resources are estimated at 13 million cubic meters a year

The amount of brackish water in storage, as previously calculated, amounts to 70 400x$10^9 m^3$ (TDS 1,000-7,000 ppm) The estimated exploitable quantity is about 200 million cubic meters a year

2 The Ram aquifer system and the overlying Kurnub and younger aquifers contain large quantities of brackish groundwater The drilling depths and pumping lifts criteria especially for the Ram aquifer can only be on the eastern escarpments, to the east of the main graben fault The ongoing studies and deep drilling program will give more data about the exploitability of brackish groundwater in Wadi Araba especially the Kurnub and Ram aquifers as well as the overlying upper Cretaceous aquifers On the escarpment, promising areas are Wadi Fidan, Feinan, Graigra and Wadi Ghuaba

8 2 The Zerqa River Basin

The following areas, in the Zerqa River basin have potentially exploitable brackish groundwater in the Kurnub-Zerqa aquifer systems

8 2 1 Subeihi Area

The Kurnub outcrops in this area The lower part of it is saturated with fresh water in the foothills In the vicinity of Zerqa River it contains brackish water The underlying Zerqa Group is fully saturated with brackish water The estimated drilling depth is 300-700 meters, and the pumping lifts are 200-300 meters The estimated TDS is 1,400-2,500 mg/l

8 2 2 Jerash- Ajlun Governorates

There are localized areas in these two governorates where the Zerqa and occasionally the lower Kurnub satisfy the economic criteria for brackish groundwater exploitation from the two aquifers These two governorates suffer from a lack of adequate water supply for domestic use Drilling depths to the bottom of Zerqa aquifer range from 200 to 500 meters Estimated pumping lifts are 50-100 meters Well yields of 40-120 m^3/hr are expected

Additional costs for completion of wells are necessary Screens and gravel packing are required to protect the pumps from the fine sands of the aquifer materials

8 2 3 Sukhneh Area

The Kurnub aquifer in this area meets the economic criteria for brackish groundwater exploitation Drilling depths of 550-600 meters are exptected with pumping lifts of 130-145 meters Well yields of 100 m^3/hr are expected with a TDS of 2 300 mg/l

8 3 Azraq Basin

The exploitable aquifers in Azraq are the B2/A7 and the shallow composite aquifer system (B4 and the Azraq Formation)

a) The B2/A7 aquifer in Azraq is artesian and flowing in the area of Qa'El Azraq and other lower elevations of the basin Exploitation from storage meets the economic criteria Drilling depths of 400-800 meters are expected (excluding the Hamza Graben and the Hazeem trough) Pumping lifts are estimated at 50-80 meters with well yields of 25-120 m^3/h The natural flow from well No Az-1 is 45 m^3/hr

b) An estimated 15 million cubic meters a year may be produced from 15-20 wells in Qa'El Azraq Area The TDS is estimated at approximately 1,200 ppm and the water will contain concentrations of H_2S gas

c) The B4 and the overlying lacustrine alluvium (the shallow composite aquifer in the central part of the Azraq basin have a medium salinity zone (700-1,500 mg/l) and a high salinity zone (2,000-3,500 mg/l) These are recommended for brackish groundwater exploitation according to the economic criteria The drilling depths are 50-700 meters (full penetration of the B4) with pumping lifts greater than 150 meters

d) The produced brine can be sold to the nearby salt plat in Azraq being similar in quality to the feed of the plant

8.4 Hamad Basin

Two aquifers in the Hamad basin meet the criteria of exploitation B4/B5 and B2/A7 aquifers

a) In the upper most - B4/B5 aquifer system, the drilling depths are estimated at 100-450 meters (in selected areas in the western part of the basin) Water levels are estimated at 15-120 meters with pumping lifts exceeding 200m
b) The B2/A7 in the eastern part of the basin (Risha-Tureibil areas), although not meeting the economic criteria, is the only local source of water together with underlying Kurnub and Zerqa Aquifer Drilling depths 350-700 Water level 180-350 meters bgl Pumping lifts 220-400 meters TDS 1,485-2,650 mg/l

8.5. The Sirhan Basin

The B4 and the B2/A7 aquifers present possibilities of exploitation, although available data are not adequate

The B4 aquifer is saturated in the eastern part of the south Sirhan basin adjacent and parallel to the borders with Saudi Arabia The width of the saturated zone ranges between 40 and 55 km In the north Sirhan it is saturated and confined by the B5 aquitard Drilling depths of 200-700 meters are expected with water level of 15-300 meters and pumping lifts of 70-150 meters (in selected areas in the basin) The TDS is expected to range from 1,000-1,520 mg/l in south Sirhan and up to 1,920 mg/l in north Sirhan

In the southern part of the Sirhan basin, the whole Ajlun (A1-A7) Group is missing and the B2 overlies directly the Kurnub But in the central and northern parts of the basin, the B2/A7 is fully saturated and confined by the B3 aquitard and in the northern part, the lower Ajlun (A1-6) separates hydraulically the B2/A7 from the underlying Kurnub Drilling depths of 270-1,500 meters are expected with static water levels of 75-150 meters below ground level and pumping lifts of 130-300 (in selected areas) The TDS is expected to range from 4,500-7,000 mg/l

Available data about the aquifer potential is very limited More studies including drilling and testing are required for the determination of the potential in this area

8.6 The Jafr Basin

The B2/A7 aquifer satisfies the exploitation criteria Drilling depths of 200-500 meters are expected with a static water level of 70-150 meters and pumping lifts of 100-150 meters The TDS in the eastern part of the basin is expected to range from 1,000-4,000 mgl

About 11 million cubic meters a year is being utilized by the Phosphate Mining Company for the Shidiya mine from the western part of the basin where the B2/A7 water is fresh (TDS 500-700 mg/l) The wellfield consists of 21 wells with an average drilling depth of 250 meters and the static water level is 92-95 meters bgl The water contains high amounts of H_2S gas

The Kurnub and the Khreim in the southern part of the basin contain an estimated amount of 16 6 billion cubic meters of brackish water with salinity between 1,000 and 5,000 mg/l Drilling depths range between 170 and 500 meters and pumping lifts will range from 100 to 250 meters Assuming 10% of the stored brackish water in the two aquifers is exploitable, the recoverable reserves will amount to about 1500 MCM

Basin	Azraq	Dead Sea	Hamad	Jafr	Jordan River	Sirhan	Southern Desert	Wadi Araba	Total
Aquifer									
Ram		200 0			100 0				**300**
Khreim				500 0			n d (1)		**500**
Zerqa		50 0			300				**350**
Kumub		500	n d	1000 0					**1500**
A1-6				n d					
B2/A7	400 0	010 0	n d	360 0	200	n d			**970**
B4/B5	n d (2)		n d			n d			**n d**
Alluvium								600 0	**600 0**
Total	**400**	**760**		**1860**	**600**			**600 0**	**4220**

Table 14 Exploitable quantities of brackish groundwater from the aquifers in the different basins (in MCM)

(1) n d not determined

(2) The aquifer is the shallow composite one which includes the B4/B5 and the lacustrine alluvium

9.0 Conclusions and Recommendations

1 Huge quantities of brackish groundwater occur in all aquifers excluding the basalt aquifer These quantities are widely distributed in the country and increasing through time due to excessive abstraction from the groundwater, in addition to irrigation returns in areas of high salinity soils and poor drainage

2 The exploitable quantities of brackish groundwater form only a very small portion of the total stored amount But still these exploitable amounts form an important source of water in areas where it is badly needed

3 The greater part of brackish groundwater is old water stored in aquifers where modern recharge is negligible Therefore, exploitation will be mainly dependent on mining from storage But substantial amounts of brackish water are exploitable through the interception of base flow of brackish groundwater and the utilization of naturally flowing brackish water from springs in the Jordan Valley and the Dead Sea areas

4 Recent advances in desalination technologies together with the rapidly increasing demand for water have opened the possibility of economic development and treatment of brackish groundwater where the cost is usually one-third to one-fifth as much as that of sea water

5 The brackish groundwater of the Zerqa aquifer in the areas of Kafrein, Hisban and Suweima, in the southern part of the Jordan Valley, should be given priority for exploitation by desalination These areas are chosen because of the increasing demand for fresh water in the area, specially, the additional demand for the new hotels on the Dead Sea shore and for the planned recreational facilities In addition, the area has been studied in detailed and conditions are favorable for the construction of a desalination plant there

6 Desalination of brackish groundwater from the Zerqa aquifer in the Governorates of Ajlun and Jerash could be more viable than other costly water projects for the augmentation of the water supply in the two Governorates The Zerqa aquifer in these areas meets the criteria for exploitation

7 Three areas in the northeast of the Hamad basin where the water supply situation is critical due to lack of fresh sources of water in the whole area,

should be considered for desalination These areas are Trebeel (the border area with Iraq), Rukban, and El-Bustan areas Although the B2/A7 and the Kurnub aquifers are sources of brackish water in these areas, exploitation of these sources currently does not meet economic criteria

ANNEX I

BRACKISH WATER SPRINGS

ANNEX I

DISCHARGE FOR SPRING 1995/1996				Quality			
Spring No	max	min	mean	Spring No	DATE	EC	TDS
AB0504	17 9	6 47	11 226	AB0504	27/09/94	2 85	1824
AB0506	27 11	10 3	16 372	AB0506	05/02/94	1 952	1249 28
AB0534	40 2	13 2	28 511	AB0534	02/10/94	2 008	1285 12
AB0564	17 9	17 9	17 9	AB0564	20/07/93	2 6	1664
				AB0564	08/06/94	2 58	1651 2
AB0586	204	116	167 5	AB0586	03/10/94	2 647	1694 08
AB0592	732	473	646 25				
AB0603	145	76 72	97 963	AB0603	03/10/94	2 153	1377 92
AB0640	31 3	13 9	25 802	AB0640	04/10/94	3 512	2247 68
AB0697	34 3	24 4	29 716	AB0697	03/10/94	1 744	1116 16
AB0699	31 3	20 88	28 407	AB0699	03/10/94	2 255	1443 2
AD0740	202	93 6	153 633	AD0740	02/10/94	2 07	1324 8
AL0517	44 9	3 05	17 17				
AL0522	17 96	0	6 645	AL0522	27/09/94	1 163	744 32
AL0620	13 53	8 62	11 378				
CA0564	0 36	0 36	0 36	CA0564	23/08/94	2 34	1497 6
CA0565	3 05	3 05	3 05				
CA0608	0 65	0 65	0 65	CA0608	16/08/94	2 05	1312
CA0636	150	124	136 333	CA0636	23/08/94	3 38	2163 2
				CA0636	02/05/94	3 43	2195 2
CA0638	205	137	164 086	CA0638	23/08/94	5 62	3596 8
				CA0638	02/05/94	5 68	3635 2
CA0642	35 7	21 6	31 35	CA0642	23/08/94	5 92	3788 8
				CA0642	02/05/94	5 92	3788 8
				CA0642	25/09/94	6 02	3852 8
CA0652	23 9	17 1	21 82	CA0652	23/08/94	5 76	3686 4
				CA0652	02/05/94	5 66	3622 4
				CA0652	25/09/94	5 48	3507 2
CA0686	2126	1789	1985				
CA0688	309	213	261 3	CA0688	22/08/94	3 14	2009 6
CA0692	19 1	12 1	15 452	CA0692	22/08/94	3 16	2022 4
				CA0692	15/08/94	1 255	803 2
CA0810	0 4	0 4	0 4				
CA0841	54 9	22 6	42 061				
CD0542	2 34	2 34	2 34	CD0542	20/04/94	3 34	2137 6
CE0590	0 55	0 55	0 55				
CE0646	8	8	8				
DG0562	0 3	0 3	0 3	DG0562	06/09/93	1 192	762 88
				DG0562	31/07/94	1 246	797 44
DG0564	17 87	3 76	8 825				
DG0566	2 6	2 6	2 6				
DG0576	0 77	0 77	0 77				
DG0612	0	0	0				
DH0562	0 38	0 38	0 38	DH0562	26/07/94	2 37	1516 8
				DH0562	29/11/93	2 35	1504
G0546	5 6	1 08	3 313				
G0548	4 13	0 36	2 548				

DISCHARGE FOR SPRING 1994/1995							
Spring No	max	min	mean				
AL0517	17 9	0	3 925				
AL0522	35 7	0	12 297				
AL0620	14 67	13 2	13 935				
AL0815	0 65	0 65	0 65				
AL0986	1 79	1 79	1 79				
DC0614	0 48	0 48	0 18	DC0614	18/07/94	1 884	1205 76
EA0540	1 08	1 08	1 08	EA0540	07/03/94	3 952	2529 28
				EA0540	07/08/94	0 67	428 8
				Spring No	DATE	EC	TDS
				AB0580	08/06/94	2 83	1811 2
				AB0600	20/07/93	2 62	1676 8
				AB0600	08/06/94	4 09	2617 6
				AB0604	09/06/94	3 98	2547 2
				AB0606	09/06/94	5 99	3833 6
				AB0696	14/06/94	2 71	1734 4
				AL0686	04/07/94	1 081	691 84
				AL0815	03/08/94	1 9	1216
				AL0960	22/06/94	1 75	1120
				CA0640	25/09/94	5 71	3654 4
				CA0644	27/04/94	5 13	3283 2
				CA0644	02/05/94	4 17	2668 8
				CA0646	26/06/94	4 83	3091 2
				CA0646	27/04/94	4 21	2694 4
				CA0650	25/04/94	2 26	1446 4
				CA0656	20/04/94	2 4	1536
				CA0690	22/08/94	3 112	1991 68
				CA0760	14/08/94	1 758	1125 12
				CA0760	27/04/94	6 11	3910 4
				CA0762	27/04/94	5 76	3686 4
				CA0764	26/04/94	6 04	3865 6
				CA0766	26/04/94	6 56	4198 4
				CA0770	25/04/94	5 84	3737 6
				CA0772	26/04/94	6 44	4121 6
				CA0841	25/09/94	4 24	2713 6
				CD0542	20/04/94	3 34	2137 6
				DG0576	27/07/94	1 573	1006 72

References

1 M Abu Ajamieh, 1980, the Geothermal Resources of Zarqa Ma'in and Zara

2 M Abu Ajamieh, 1989, Mineral Resources of Jordan

3 Andrews I J, 1991, Paleozoic Lithostratigraphy in the Subsurface of Jordan, Natural Resources Authority, Subsurface Geology Bulletin 2, Amman

4 Andrews I J, 1992, Permian, Triassic and Jurassic Lithostratigraphy in the Subsurface of Jordan, Natural Resources Authority, Subsurface Bulletin 4, Amman

5 Arab Center for the Study of Arid Zones and Dry lands (ACSAD), 1983, Hammad basin Project Atlas

6 BEICIP, 1981, Structural Study of Jordan, Natural Resources Authority, Amman, Jordan

7 Bender H, et al, 1987b, Oil Shale Feasibility Study Phase I, Hydrogeology, BGR/NRA, Amman

8 Bunesanstalft fur Geowissenschaften und Rohestoffe (BG), 1994, Groundwater Resources of Northern Jordan, Technical Co-operation Proj No 89 2105 8

9 Bundesanstalt fur Geowissenschaften und Rohestoffe (BGR), 1991, Groundwater Resources of Southern Jordan, Technical Co-operation Proj No 86 2068 4 and 88 2180 3

1 Buros O K, 1989, Desalination Practices in the United States Management and Operations, Journal of the American Water Works Association

11 Bushnak A, Dar Al-Taqniya, 1997, Water Desalination and Wastewater Desalination in the ESCWA Region E/ESCWA/ENR/1997/WG

12 Consulting Engineers, Salzgitter GmbH (CES) & Arabtech consulting Engineers 1994, Groundwater Investigations in the Azraq basin

13 Dykes G M, and W J Colon, 1989, Use of Membrane Technology in Florida, Management and Operations, Journal of the American Water Works Association

14 Freeze R A and J A Cherry, 1979, Groundwater, Prentice Hall, Englewood Cliffs, N J

15 GITEC Consult GmbH & Hydrogeological Services International (H S I), 1995, Groundwater Investigations in the Hamad and Sirhan basins

16 Howard Humphreys and Partners, 1986, Groundwater Resources of the Shidiya Area

17 Lioyd J W, 1969, The Hydrogeology of the Southern Desert of Jordan

18 Masahiro Murakami, 1995, Managing Water for Peace in the Middle East, United Nations University Press

19 NRA, Open-file Reports on Deep Drilling, Logging & Geophysical Reports Unp

20 Natural Resources Authority (NRA), up to 1996, 1 50,000 geological maps

21 Parker D H, 1970, Investigation of the Sandstone Aquifers of East Jordan The Hydrogelogy of the Mesozoic-Cainozoic Aquifers of the Western Highlands and Plateau of East Jordan, UNDP/FAO, AGL SF/JORD, Technical Report No 2, Rome

2 Phoenix Corp, A Comprehensive Airborne Magnetic and Radiation Survey of the Hashemite Kingdom of Jordan, Unp Rep For the Natural Resources Authority, Amman

23 Powell J H, 1989, Stratigraphy and Sedimentation of the Phanerozoic Rocks in Central and Southern Jordan, Geological Mapping Division Bulletin 11A Geology Directorate, NRA, Amman

24 Stratigraphic Services International (SSI), 1989b, The Biostratigraphy of Smeica-1 deep water well and correlation with NH2,SH5 and RH2 wells, northern Jordan Unpubl, Report to Fina, Proj No B0067

25 Water Authority of Jordan, 1989, Azraq basin Water Resources Study