INFLUENCE OF GULF WARS ON SUSTAINABILITY OF GROUNDWATER IN JORDAN

Fathi Shaqour
University of Jordan/Monash University/LaTrobe University

Ismail Hashem
Hydrotech International Consulting Co.

John Webb
LaTrobe University

ABSTRACT
Gulf wars have caused severe damages to the environment in Iraq, Kuwait, Jordan and the whole region. Examples of some impacts on the sustainability of water resources in Jordan are presented. Jordan is a small country of about 90000 km^2, with about 6 million inhabitants. More than half a million used to work in Kuwait and other Gulf states, who had to leave the Gulf States, and permanently settle in Jordan, in addition to hundreds of thousand flees who temporarily stayed in Jordan. This rapid flux of people imposed additional stresses on the limited water resources and struggling treatment plants, leading to excessive environmental stresses. This induced problems of declining water table to serious un-restorable drawdown levels, and deterioration of the groundwater quality as a result of over pumping and overloads to treatment plants that became inefficient. The effluent of these plants caused contamination of groundwater systems. Groundwater modelling was carried to the main hydrological basins in Jordan to assess the situation. Different scenarios were adopted to simulate the imposed conditions and the remediation of the induced problems. Two scenarios were considered to simulate groundwater conditions up to year 2030, the first scenario was a do nothing scenario: continue exploiting groundwater from aquifer systems as it is at present with consideration of the normal growth rates in population and their respective water demands. The second scenario was, self-restoration scenario: complete stop of groundwater abstractions for all purposes, leaving a chance for the aquifer systems to recover its original conditions with time. This recovery would rely mainly on the rate of the natural annual groundwater recharge into the aquifer systems. Both scenarios showed projected groundwater salinity of up to 6500 ppm and up to 3000 ppm respectively. Further influxes from Iraq, in 2003 (Gulf War 2) worsened the status. The Gulf wars have resulted in un-restorable damages to water resources in Jordan, and their sustainability became under threat and great efforts are needed to augment the water resources and keep the minimum sustainability.

1. INTRODUCTION
Water, Jordan's most scarce and valuable resource, suffered from the sudden influx of immigrants and returnees as a result of the first Gulf crisis. About half a million Jordanians who used to live in Kuwait suddenly returned to settle permanently in Jordan. Also more than half a million Iraqis fled to Jordan in addition to about a million other nationalities (mainly Southeast Asians) passed through Jordan and stayed temporarily until they moved to their original countries (DOS, 1995). This led to severe impacts on Jordan's limited water resources, affecting all domestic, industrial and irrigation waters, and therefore brought the sustainability of the water resources under real threat.

Groundwater constitutes the prime water supply source in the country, and has suffered the most adverse effects in terms of water quality and quantity due to the Gulf crisis. This was attributed to the over-exploitation of these resources, which led to a decline in the water level, deterioration in quality of both water and land resources, as well as overstressing the existing water treatment plants (JAICA, 2001).

In this study, it is intended to review the hydrogeological conditions, assess the decline in the water table and deterioration of water quality that occurred due to the Gulf war crises, and then assess the overall impacts of the Gulf crisis on the sustainability of Jordan's water resources, and ways and means to restore these resources in quality and/or quantity.

Jordan is situated between latitudes 29° 30' and 33° 30' North and longitudes 35° and 39° East, (Figure 1), and has a total area of the country is 90,000 km^2, with a population of about 6 million as estimated in 2009 (DOS, 2009). The geomorphology of Jordan can be subdivided into three major landscapes that control the flow of surface water, groundwater and wastewater disposal (JAICA, 2001): The *low land area* comprises the Jordan Valley-Dead Sea- Wadi Araba depression, which extends about 360 km from Lake Tiberius south to the Gulf of Aqaba, and ranges in elevation between 200 m and 416 m below sea level. A great deal of agricultural activity occurs in this area. The *highlands* flank the low land area; small to large canyons cut through intricately dissected ridges to form rugged topographic relief. The *eastern desert* is a flat plateau extending east and north-eastwards with internal drainage basins of mudflats or playas.

Jordan is dominated by an semi-arid to arid climate. Dry summers with an average maximum annual temperature of 38.8° C, occur during April to October, and cold to mild temperatures during winter. Average annual evaporation ranges from 2,042 mm to 5,038 mm. Only less than 1% of the total area receives annual rainfall of 500 to 600 mm, 6% receives 200 to 500 mm, while the remaining 93% of the total area receives less than 200 mm rainfall per year (NWMP, 1977). Surface water is limited to the trans-boundary Jordan River, over which Jordan has no control, in addition to small tributary streams flowing to the river. This gives a clear idea of the very scarce water resources in the country.

Figure 1: Location map of Jordan

2. GEOLOGY AND HYDROGEOLOGY

A Pre-Cambrian basement complex occupies the extreme southwestern corner of Jordan, along the Gulf of Aqaba, with an area of about 70 km^2. This is overlain by Early Paleozoic sandstones that are succeeded by Lower Cretaceous sand and sandy shale, followed by the Upper Cretaceous and Lower Tertiary calcareous sediments that cover about 75% of Jordan. Middle Pleistocene basalts overlie fluvial gravels in the eastern highlands (Bender, 1974).

Three major aquifer systems are present in Jordan:

1) The *Upper* aquifer system incorporates sedimentary rocks (limestone, chalk and marl) and alluvial deposits of Tertiary and Quaternary age, in addition to basalts which contain large quantities of groundwater of very good quality. Transmissivities range from 2 to 113,000 m^2/d. Water qualities is generally good, with TDS between 500 and 1000 ppm.

2) The *Middle* aquifer system consists of Upper Cretaceous limestone, cherty limestone and sandy limestone, and forms the most important aquifer in Jordan with the largest extent. Groundwater contained in this aquifer originates from the high rainfall zones of the highland areas. The aquifer parameters are variable, based on the degree of fracturing and solution channels within the carbonate rocks. Transmissivity ranges from 1-46,000 m^2/d. The storage coefficient is in the order of 0.01 to 0.10, depending on the degree of karstification (JICA, 2001).

3) The *Lower* Aquifer System, comprising of the sandy facies of Palaeozoic and Early Cretaceous age, outcropping in the south-western part of Jordan. The mean aquifer transmissivity is 720 m^2/d, and the mean storage coefficient ranges from 0.01 to 0.03. Groundwater recharge to this aquifer system occurs primarily in the large outcrop area on the southern borders with Saudi Arabia (JICA, 2001).

Twelve groundwater basins are present in Jordan; two of them, Amman-Zarqa and Azraq basins, are the most populated ones (BGR/WAJ, 1994), and are the focus of this paper.

3. GROUNDWATER MODELLING

Groundwater modelling was carried out for the main groundwater basins to evaluate the groundwater conditions before and after the Gulf war, and predict the groundwater conditions for decades to come, to assess and quantify the groundwater depletion and/or quality deterioration. Groundwater levels, abstraction and water quality fluctuations were collected and processed from the established monitoring networks. The historical data on groundwater quality in different areas and aquifers revealed that Amman-Zarqa basin has the most serious problem with groundwater quality deterioration. The salinity of many wells and springs has increased substantially in the past years to a level about 324 μS/cm or 23% above the EC level prior to the crises (JICA, 2001).

Two scenarios were considered to simulate groundwater conditions up to year 2030.

1) Do nothing scenario: continue exploiting groundwater from aquifer systems as at present, with consideration of the normal growth rates in population and the resulting water demand.

2) Self-restoration scenario: complete stop of groundwater abstractions for all purposes, leaving a chance for the aquifer system to recover its original conditions with time. This recovery would rely mainly on natural annual groundwater recharge into the aquifer systems.

Processing Modflow 5 (PM 5) was used to update the existing groundwater flow models that are available in Ministry of Water and Irrigation, and to carry out groundwater simulations for the main two groundwater basins (Amman-Zarqa and Azraq), that are the most populated and most affected by the war.

3.1 Amman – Zarqa Basin

Amman-Zarqa basin is the most populated groundwater basin, and contains the two biggest cities of Jordan (Amman and Zarqa City), as well as the refugee camp of Baqa'a and the city of Jarash, in addition to the agricultural area of Dhuleil with hundreds of water wells. Groundwater resources in most of these areas are highly developed for irrigation and domestic water supplies and even overexploited.

The basin has a total catchment area of about 3,725 km^2. The Upper Cretaceous limestone (B_2/A_7) is the main aquifer, and is hydraulically connected to the overlying basalt aquifer in the northeast areas. The Kurnub sandstone aquifer crops out in the middle part of the basin, and contains groundwater resources of generally good quality (700-1,200 ppm of TDS). Estimated groundwater recharge into the aquifer systems in the basin is in the order of 80-100 million cubic metres (MCM)/yr while the estimated safe yield is about 87 MCM/yr (Jordanian Consulting Engineer, 1996).

General water level decline of 5 m-15 m in almost all wells and groundwater quality deterioration prevail over the Amman-Zarqa Basin. These conditions are primarily attributed to irrigation water return flows, input of human and industrial wastewater along wadi Zarqa, treated wastewater effluent from treatment plants within the basin and impacts from the ongoing agricultural activities in the basin (Yachiyo Engineering, 2001; Qanqar, 1996; BGR/WAJ, 1991).

Groundwater modelling was carried out to Amman-Zarqa basin and the results are presented in Figures 2 to 5.

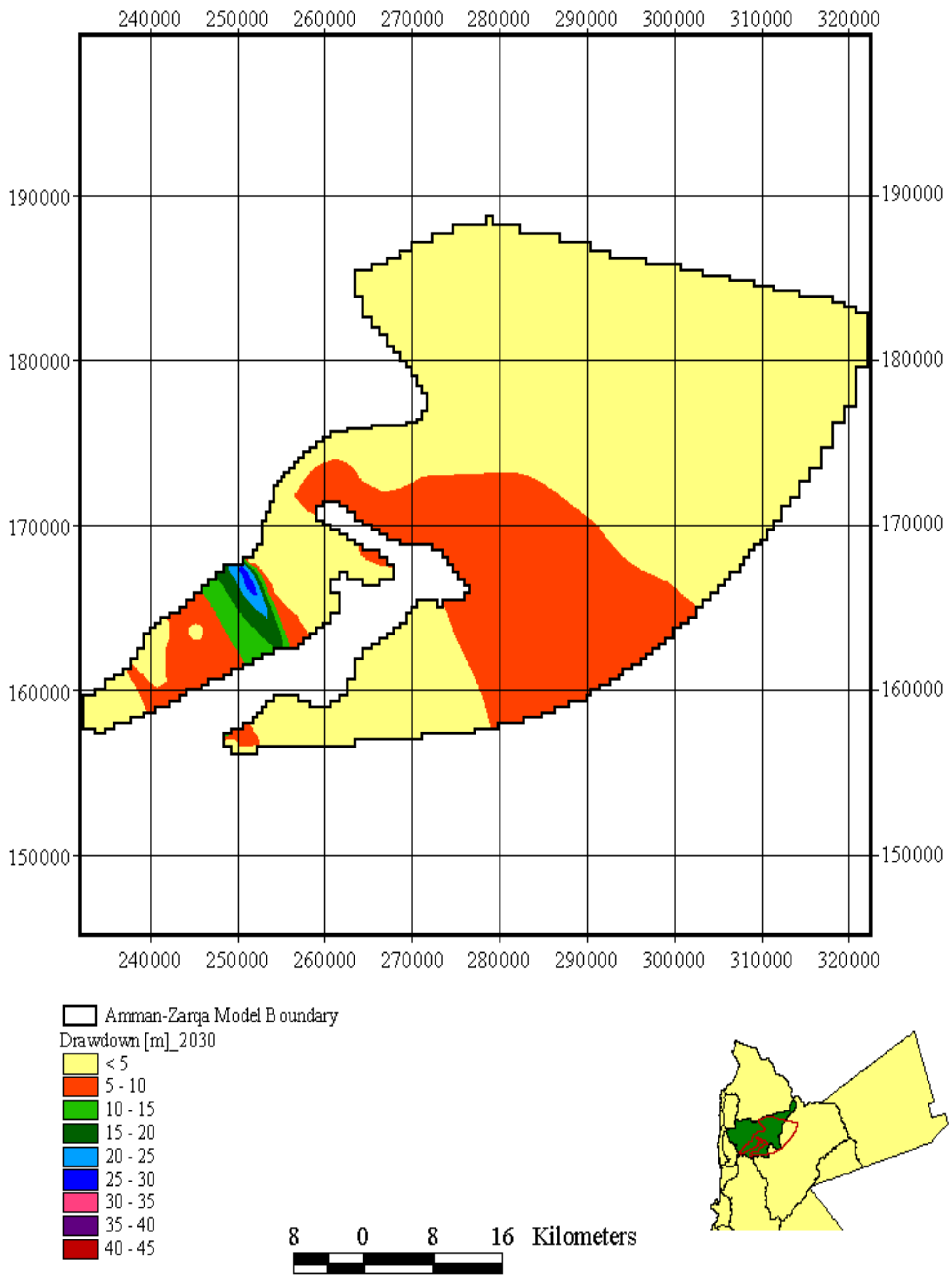

Figure 2: Simulated drawdown for the upper aquifer at Amman- Zarqa Basin in 2030 (self restoration scenario)

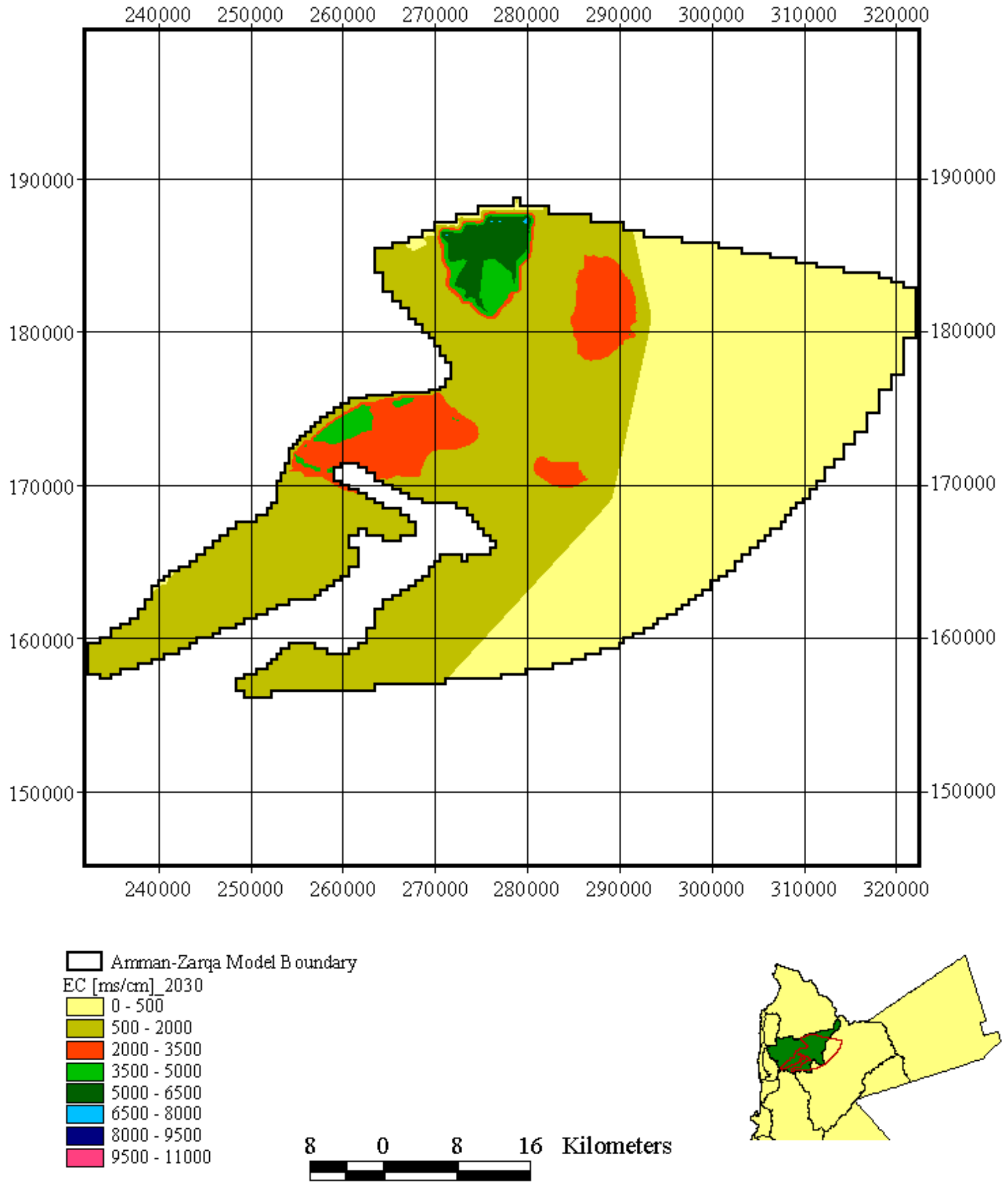

Figure 3: Simulated EC for the upper aquifer at Amman-Zarqa Basin in 2030 (self restoration scenario)

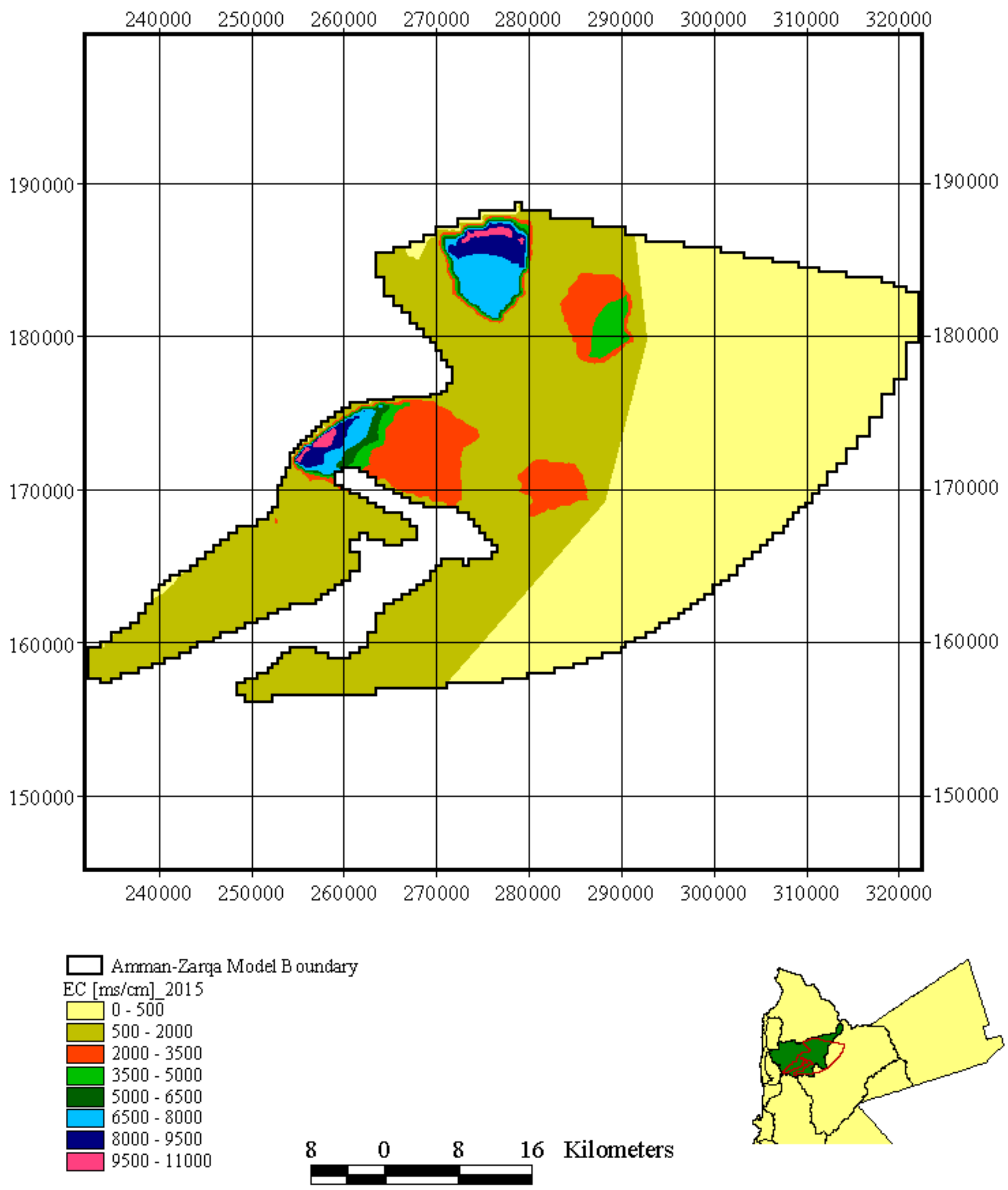

Figure 4: Simulated drawdown for the upper aquifer at Amman- Zarqa Basin in 2030 (do nothing scenario)

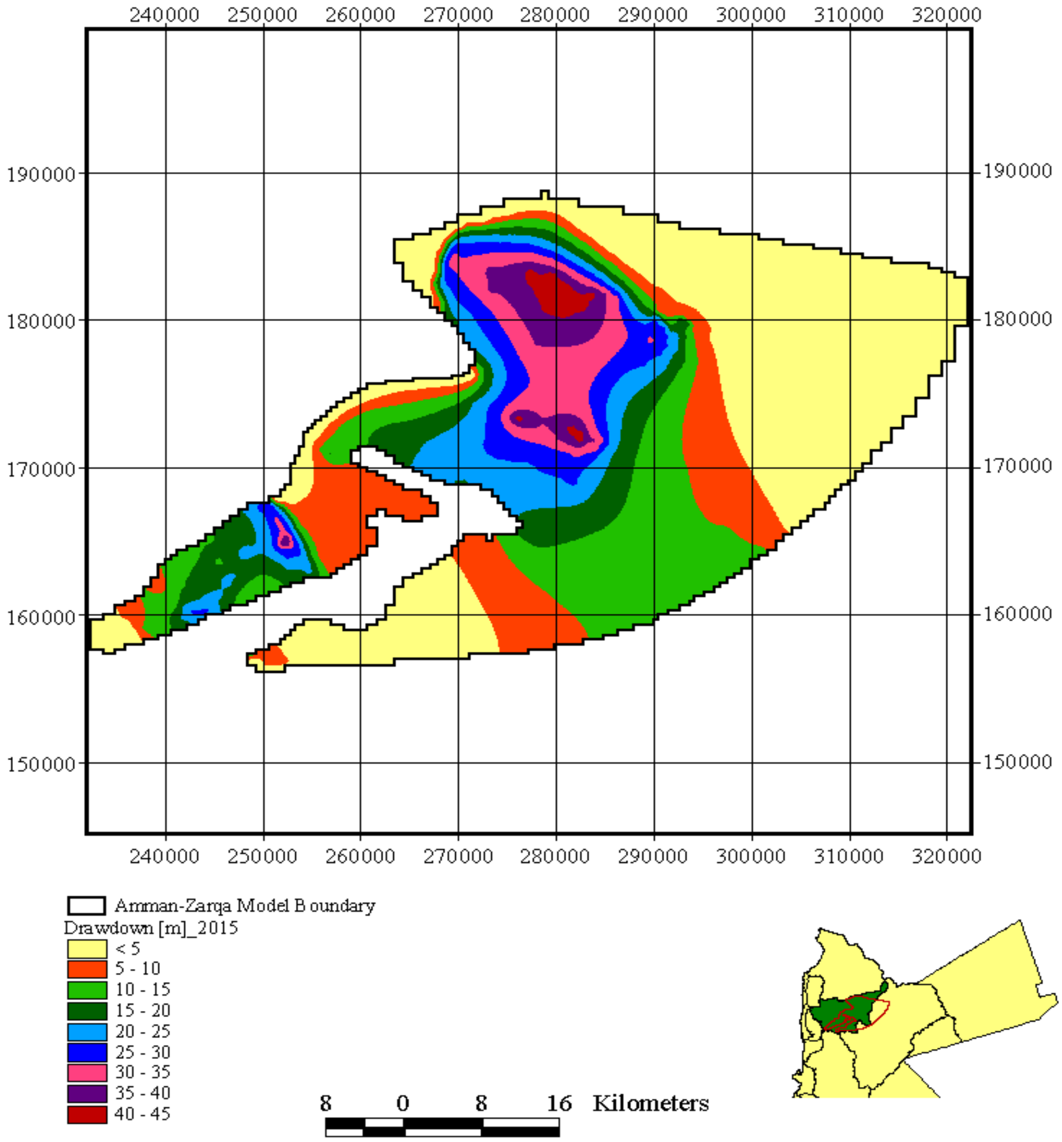

Figure 5: Simulated EC for the upper aquifer at Amman-Zarqa Basin in 2030 (do-nothing scenario)

3.2 Azraq Basin

The Azraq groundwater basin extends into Syrian territory where it receives a good percentage of its annual recharge. Some recharge occurs locally from annual floodwaters within Jordan. Groundwater recharge into Azraq basin aquifers is very limited and probably non-renewable (Qanqar, 1996; BGR/WAJ, 1994), which makes the basin more sensitive to over exploitation.

The basin has two main aquifers: basalt and underlying limestone, which are both over exploited, and provide about 28 MCM to Greater Amman. Natural aquifer discharge was observed in the past in the form of spring flows in the centre of the basin, but currently these springs are dried out.

Groundwater levels have declined in almost all wells in the basin as a result of groundwater over exploitation. Groundwater salinity has increased in the central part of the basin due to saline water intrusion from the hyper saline water body (100,000 to 250,000 ppm of TDS), under the Azraq mudflat, due to over exploitation of the upper aquifer system (Katbeh and Rimawi, 1998). Further exploitation of groundwater from the shallow aquifer system will lead to more deterioration of the groundwater quality in the basin.

Groundwater modelling was carried out to the Azraq basin and Figures 6 to 8, show the water table elevations and water quality for year 2030 according to the two scenarios.

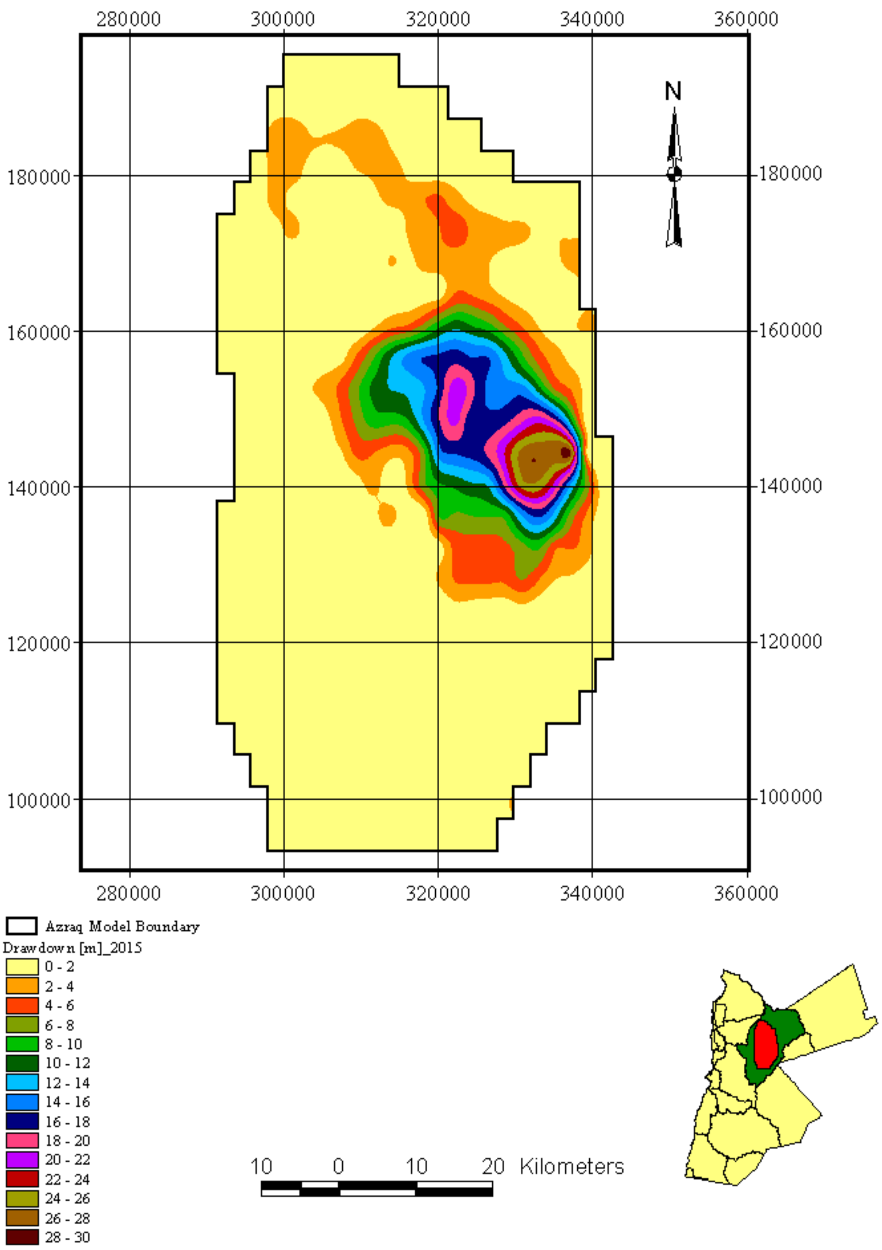

Figure 6: Simulated drawdown for the upper aquifer at Azraq basin in 2030 (do-nothing scenario)

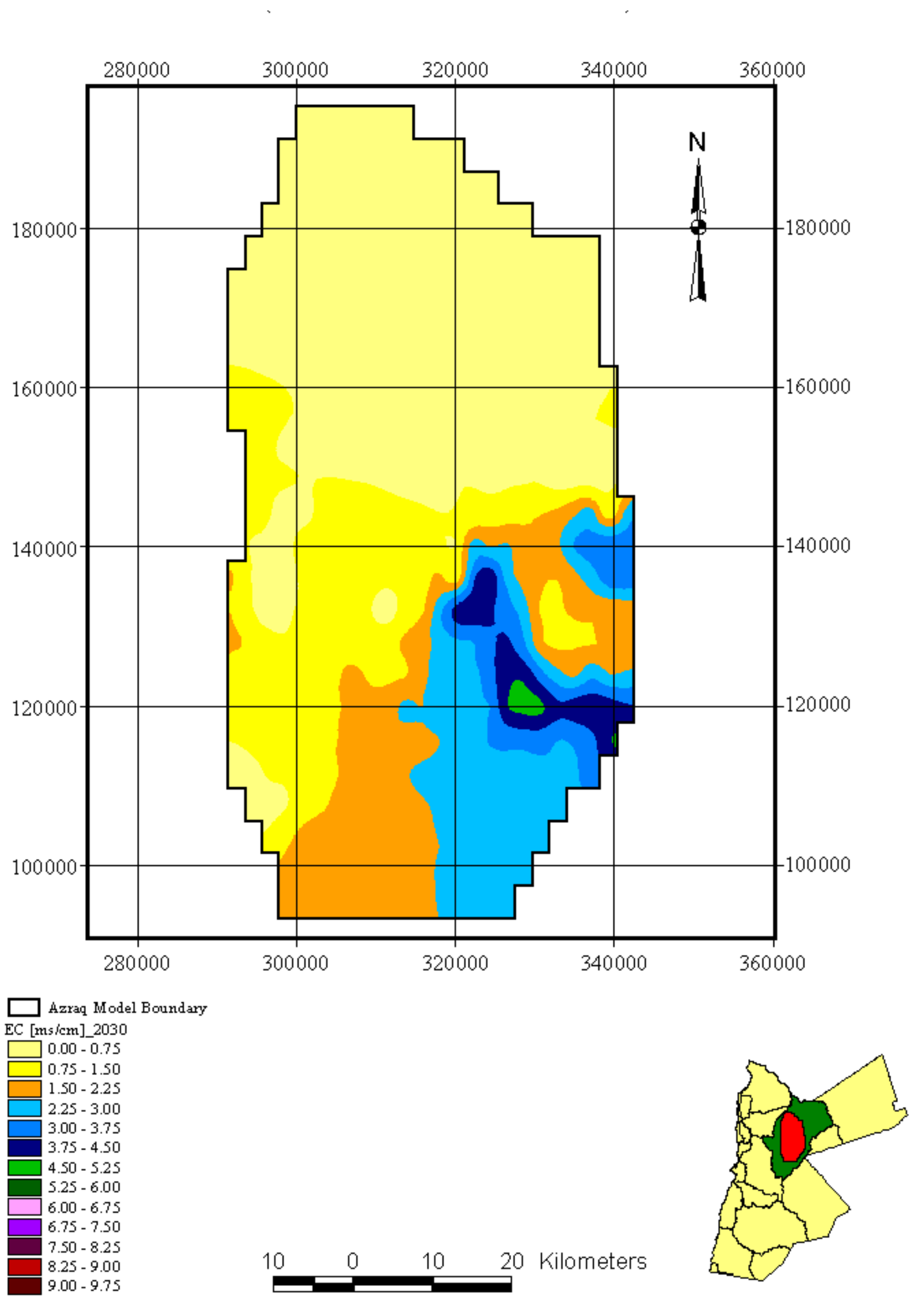

Figure 7: Simulated drawdown for the upper aquifer at Azraq Basin in 2030 (self restoration scenario)

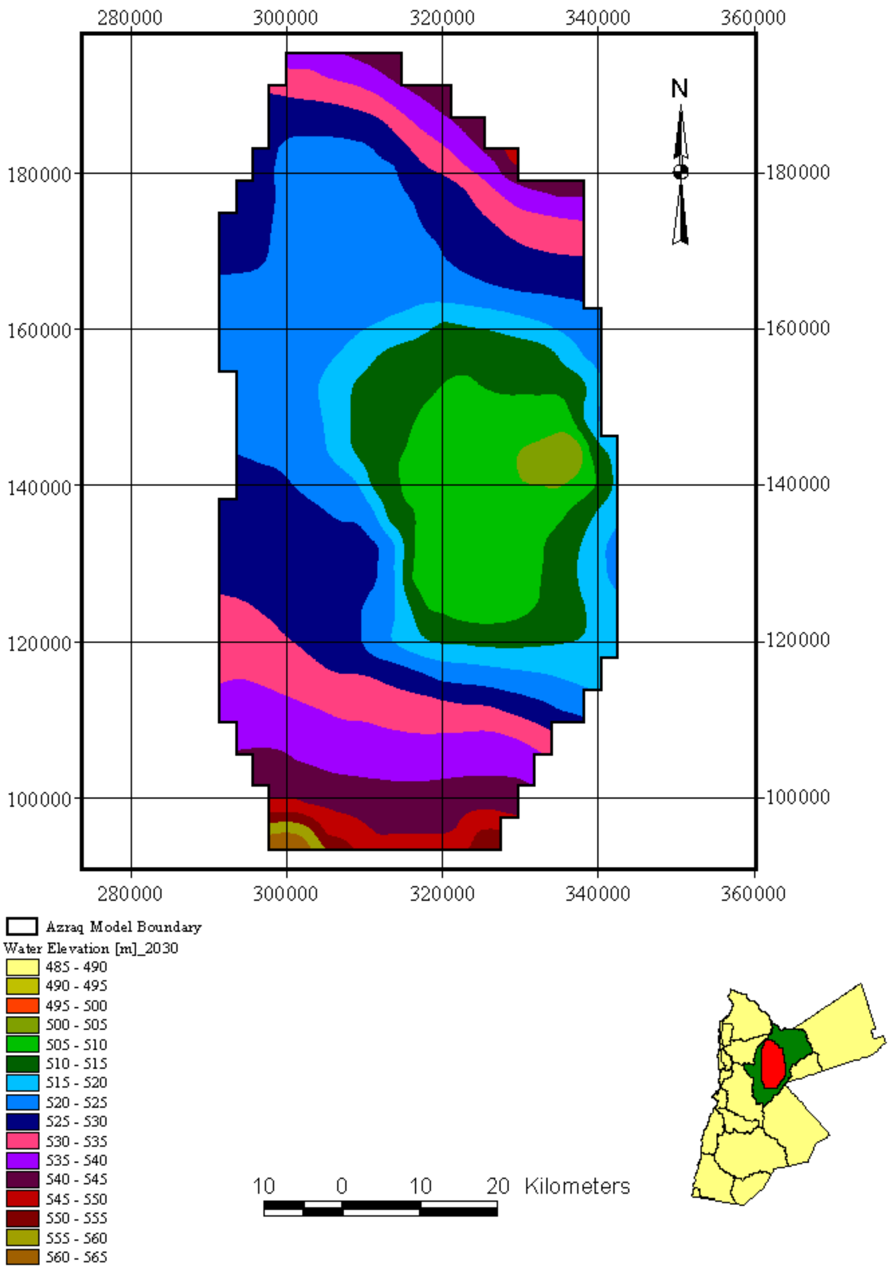

Figure 8: Simulated EC for the upper aquifer at Azraq Basin in 2030 (self restoration scenario)

4. DISCUSSION

It is clear that the Gulf crises have resulted in adverse effects on the overall groundwater resources in the Amman-Zarqa and Azraq basins. The decrease of groundwater quality and the increased rate of drawdown in groundwater levels are the direct impact of the over exploitation which prevailed after 1990. In order to mitigate the prevailing adverse effects, two scenarios have been modelled. Under the self-restoration scenario, groundwater abstraction from all pumping wells in the basins would cease, to allow restoration of groundwater levels and quality for a period of time. Under the second, do nothing scenario, the present conditions are modelled to prevail in the future, i.e. meeting the increasing water demands.

The models demonstrate clearly that rates of groundwater level decline and increase in groundwater salinity were greater after 1990, because of over pumping in order to meet the additional water demands for domestic use and the intensive agricultural activities that started south of Amman to meet the increasing demand from the settlement of most of the returnees in Amman and Zarqa cities (Figures 2 and 3).

The do- nothing scenario (Figures 4 and 5) shows that a drawdown of up to 5 m will occur around the edges of the Amman-Zarqa basin, but drawdown will exceed 15 metres in the middle part of the basin. The self restoration scenario shows less drawdown, but it will still exceed 10 metres in some areas. Thus the aquifer systems will not recover by 2030, even if pumping stopped.

With regard to groundwater quality, the do-nothing scenario shows that salinity rises up to 500 ppm in the eastern side of the basin, 2000 ppm in most of the western part and spots in the middle part of the basin will reach extremely high values up to 8000 ppm. The self restoration scenario shows that most of the basin will have salinities similar to the do nothing scenario, however extremely high EC values are expected in the high stress areas.

The results of both scenarios show that groundwater levels and quality were highly influenced by the Gulf crises, and serious actions are required in order to make the groundwater resources sustainable.

Likewise, in the Azraq basin, under the do-nothing scenario drawdown of 2 metres is expected in most of the basin, but in the central part (about 25% of the total area) drawdown of up to 30 metres will occur.

Therefore, the first step is to determine how much abstraction should be reduced for the groundwater resources to be renewable, and for groundwater quality deterioration (increase in salinity and/or NO_3 concentrations) to stabilise or reduce.

5. CONCLUSIONS

1) Groundwater level in most of the aquifer systems in Jordan declined and Amman-Zarqa basin suffered the most, as a result of over exploitation to meet the sudden needs of war immigrants.

2) Groundwater salinity concentration increased after the year 1990, as a direct impact of the over exploitation.

3) Rapid Influx of population imposed high stresses on the treatment plants, which worsened their inefficiencies due to unaccounted for overloads

4) These conditions will continue to prevail in the future as revealed by the model runs with the intention to meet the increasing water demands for all purposes. Groundwater salinity is expected to reach very high levels of 5000 ppm in some areas. Further influxes in 2003 worsened the status.

5) Even if the unlikely self restoration scenario is adopted, the projected groundwater salinity would reach a high of about 3000 ppm.

6) Aquifer systems suffered severe unrestorable damages due to Gulf Wars and therefore the sustainability of water resources in Jordan became questionable. Sustainability requires

finding proper solutions for the increasing water demand, and this seemingly requires regional rather than local proposals.

6. ACKNOWLEDGMENT
Thanks are drawn to the project team members at Geotech International: Prof. Omar Rimawi for his great contributions to the project, B. Hirzallah, N. Naser, E. Atwal, for their great role in data collection and modelling. Thanks are also drawn to the Consolidated Consulting Group, who the project was subcontracted from.

7. REFERENCES

Bentor, F. 1974, Geology of Jordan (Supplementary edition in English with minor revisions. Transl. from the German in coop. with NRA, Amman/Jordan by Moh'd Kamal Khdeir in Ass. with U. Wilkening and D. Parker, 196pp.

BGR/ MWI, 1996, Investigation of the regional basalt aquifer system in Jordan and the Syrian Arab Republic, Ministry of Water and irrigation, Amman, Jordan (unpublished report).

BGR/ WAJ, 1994, Groundwater resources of northern Jordan. Vol.2: Groundwater abstraction/ groundwater monitoring, Ministry of water and irrigation, Amman, Jordan (unpublished report).

Dept. Of Statistics (DOS), 2009, 1995, Statistical reports. Amman – Jordan (internal reports).

Katbeh H., Rimawi O, 1998, Origin of nitrate and salinisation of groundwater resources in Amman-Zarqa Basin, using chemical and isotope techniques.

Japan International Cooperation Agency (JAICA), , Ministry of Water and Irrigation – The Hashemite Kingdom of Jordan, 2001, The study on water resources management in the Hashemite Kingdom of Jordan. Volumes I and II. Draft final report.

Jordanian Consulting Engineer, 1996, "Technical and Economic Feasibility Study and detailed design of storage dams in Al-Karak Governorate"

National Water Master Plan (NWMP), 1977, Jordan.

Harza Engineering, Sir Alexander Gibb, Dar Alhandasa and Consolidated Consultants, 1996, The water conveyance system from Disi-Mudawwara to Amman.

Qanqar, E. 1996. "Arabic", Groundwater management in Azraq Basin (unpublished report).

Yachiyo Engineering, 2001, The study on water resources management in the Hashemite Kingdom of Jordan, WAJ, (August 2001).

BIOGRAPHY

Dr Fathi Shaqour is an Associate Professor at the Department of Applied Geology and Environment at the University of Jordan, Amman, Jordan, Currently academic visitor at both Monash University and LaTrobe University. Dr. Shaqour received his B.S. in Geology and M.Sc. in Hydrogeology from the University of Jordan, and his Ph.D. in Engineering Geology from Leeds University. He worked in both consulting in geotechnical engineering and academic fields. His research mainly covers aspects related to engineering and environmental geology, geotechnical engineering, and hydrogeology. His current research focuses on the geotechnical characterization of geomaterials from Jordan, in addition to groundwater issues.