Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2013.819168

52 (2014) 2833–2840
March

Taylor & Francis
Taylor & Francis Group

The Red Dead Canal project: an adaptation option to climate change in Jordan

A. Al-Omari[a,]*, A. Salman[b], E. Karablieh[b]

[a]*Water, Energy and Environment Center, The University of Jordan, Amman, Jordan*
Email: abbassm@ju.edu.jo
[b]*College of Agriculture, The University of Jordan, Amman, Jordan*

Received 17 October 2011; Accepted 10 June 2013

ABSTRACT

In arid and semiarid regions such as Jordan, climate change impacts on the balance between available resources and demands are expected to be severe. Climate change is expected to reduce resources and increase demands which will inevitably result in enlarging the gap between supply and demand. Adaptation to these impacts can be achieved either by reducing demands via implementing demand management practices or by developing and utilizing undeveloped resources, or by both. This paper investigates the impacts of the proposed red dead canal (RDC) project on bridging the gap between supply and demand in Amman and Zarqa cities within Amman Zarqa Basin (AZB) and in the Jordan Valley. The water evaluation and planning system (WEAP) is implemented for the Jordan Valley and AZB for this purpose. WEAP allocates water to competing demands based on the physical system characteristics as well as user-defined criteria, so that coverage at all competing demand sites is equal. The physical system characteristics include water availability, water demands, and transmission line capacity. The user-defined criteria include demand priority and supply preference. The Jordan Valley and AZB are represented as a network of supplies and demands connected by transmission lines in the WEAP environment. AZB and the Jordan Valley are connected via Zarqa River, where As Samra wastewater treatment plant effluent that treats the wastewater generated in Amman and Zarqa is discharged to the river, which flows to King Talal Dam and then released to the Jordan Valley, and used for irrigation after mixing with King Abdulla Canal water. Inputs to the model were taken from MWI real time records and measurements and other sources such as the Department of Statistics. The WEAP model was run for three scenarios namely: Business As Usual (BAU) scenario, climate change (CC) scenario, and RDC scenario. In the BAU scenario, water demands and resource trends grow as expected or planned. In the CC scenario, climate change impacts on the resources; run-off and groundwater recharge and on the demands in the valley are imposed. Run-off and groundwater recharge are assumed to decline according to a certain formula, and irrigation demand is assumed to increase by 0.10%. In the RDC scenario, the RDC project which will provide about 550 MCM of desalinated water per year

*Corresponding author.

Presented at Water and Environment International Conference (WATEIC 2011), Marrakech, Morocco, 26–29 October 2011

is assumed to be implemented by the year 2022. The results showed that without implementing the RDC project, the gap between supply and demand for Amman and Zarqa for domestic use as well as in the Jordan Valley for irrigation use will continue to grow until the year 2050 for both the BAU and the CC scenarios. However, by implementing the RDC, the domestic demand in both cities will be satisfied starting from the year 2022 till the year 2050. Furthermore, the deficit in the agricultural demand in the JV for the year 2050 will drop from about 195 MCM for the CC scenario to about 85 MCM for the RDC scenario as a result of the increased treated wastewater flow to the valley from AZB. The results also showed that groundwater resources that supply Amman and Zarqa from inside the basin as well as from outside the basin can be saved as a result of giving the supply preference to the RDC project.

Keywords: Water resources management; WEAP; Climate change; Jordan Valley; Amman Zarqa basin

1. Introduction

The impact of climate change on water resources and demands in arid and semiarid regions like Jordan is projected to be severe. Climate change is expected to reduce the available water as a result of reduced rainfall and increased evaporation due to increased temperatures. Reduced rainfall and increased temperatures are expected to reduce run-off as well as infiltration to groundwater. Increased temperatures and evaporation rates are projected to result in an increase in both domestic and agricultural demand. Menzel et al. [1] found that agricultural demand is projected to increase by 0.10% per year and that run-off and infiltration rate are projected to decrease by 0.517% per year. Reduced resources and increased demands as a consequence of climate change in a country struggling to bridge the gap between the limited supply and the rapidly increasing demand as a result of the socioeconomic development are expected to have adverse consequences on the socioeconomic development of the country and on the well-being of the people in the absence of proper and efficient adaptation measures. It is only by improving water use practices in all sectors and by developing new resources will Jordan be able to survive its water crisis under the projected negative impacts of the climate change.

High population growth rate both natural and involuntary due to political instability in the region, inefficient use of the available resources in all sectors e.g. domestic and agricultural, and the nonuniform spatial distribution of the population in the kingdom are among the challenges that complicate the water situation in Jordan, especially when coupled with the projected negative impacts of climate change. For Jordan to sustain its economic and social developments under these severe circumstances, it has to implement all possible adaptation measures such as reduction of nonrevenue water (NRW) in water distribution networks, improve water use efficiency in irrigation both conveyance efficiency as well as application efficiency, implement demand management practices in all sectors, and develop new resources. This paper investigates the impact of the proposed red dead canal (RDC) project on bridging the gap between supply and demand in the two largest cities in Jordan which are Amman, the capital of Jordan, and Zarqa, the second largest city after Amman. The proposed RDC is also expected to reduce the gap between supply and demand in the agricultural demand in the Jordan Valley as a result of the additional wastewater generated in Amman and Zarqa due to the new RDC water which is used for irrigation in the Jordan Valley after being treated at As Samra wastewater treatment plant (WWTP).

2. Background

The management of water resources at the basin level as well as climate change impacts on water resources in Jordan have been investigated by several researchers. Amman Zarqa Basin (AZB) as the most important basin in Jordan socially and economically has received the lion's share of these studies [2–8]. These studies dealt with a range of issues important to the sustainability of water resources in the basin. These issues ranged from quantifying groundwater and surface water resources in the basin, climate change impacts on these resources, quality and pollution issues of Zarqa River, and integrated management by modeling the basin as a network of sources and demands connected by transfer lines. Due to the fact that the Jordan Valley is the food basket for Jordan, the management of water resources and demands in the Jordan Valley has also received considerable and steady attention from several researchers. Doppler et al. [9] addressed the problem of optimum water allocation and cropping pattern in the Jordan Valley taking into consideration increasing water prices. Salman et al. [10] developed a linear programing model that optimizes interseasonal allocation of irrigation water taking into consideration available water and its quality as well. Al Farra et al. [11] developed a water evaluation and planning (WEAP) model for the Jordan Valley for the purpose of optimum management of the available resources. This paper integrates AZB with the Jordan Valley into one model in the WEAP environment, as these two basins are physically connected via Zarqa River, so that the impact of management scenarios implemented in AZB on the Jordan Valley can be studied and understood. The developed model is then used to investigate the impact of the proposed RDC project as an adaptation measure to climate change on bridging the gap between supply and demand in Amman and Zarqa cities in AZB and on agricultural demand in the Jordan Valley as well.

3. Study area

The study area is AZB and the Jordan Valley. As mentioned earlier, these two basins are connected via Zarqa River. AZB is the most heavily populated and industrialized basin in Jordan. About 60% of Jordan's population lives in AZB which makes about 4% of Jordan's area. AZB includes the capital Amman, the second largest city in Jordan, Zarqa, in addition to different portions of other governorates which are Mafraq, Jarash, Ajloun, and Balaqa. Due to the large population of the basin, water is transferred from other basin to satisfy the growing demands in the basin.

The Jordan Valley is the food basket for Jordan. The Jordan Valley crosses Jordan from north to south at its west border. The part of the Jordan Valley covered by this paper is the one from the north of the dead sea to the northern Jordan borders. The Jordan Valley on north of the dead sea is divided into three main agricultural zones which are the northern Jordan Valley, the middle Jordan Valley, and the southern Jordan Valley. The northern Jordan Valley includes a zone east of King Abdulla Canal (KAC) as well. KAC is the main irrigation water transport system along the Jordan Valley. The wastewater generated in Amman and Zarqa cities is discharged to Zarqa River after being treated at As Samra WWTP. The river flows to King Talal Dam (KTD) from which the water is released to KAC, where it is used in irrigation in the middle and southern Jordan Valley. Fig. 1 shows the study area and the irrigation system in the Jordan Valley.

3.1. Water resources and demands in the study area

The main water resources in AZB are groundwater, surface water, and treated wastewater. The long-term average safe yield of AZB groundwater is estimated at 88 MCM [12]. Zarqa River is the main surface water resource in the basin, the long term average run-off of which is estimated at about 70 MCM at Jarash Bridge. About 80% of the wastewater generated in Amman and 93% of the wastewater generated in Zarqa is treated at As Samra WWTP, the effluent of which is discharged to Zarqa River which ends behind KTD. The water from KTD is then released to KAC, where it is used for irrigation. The treated wastewater effluent of As Samra WWTP was about 50 MCM for the year 2010. Water resources in the Jordan Valley are ground water and surface water. The long-term average safe yield of the Jordan Valley basin and the Jordan Valley side wadis is estimated at 62 MCM. The safe yield of surface water resources in the Jordan Valley consist of KAC water, which comes from Yarmouk River, Taiberia Lake, and Mukheiba wells. In addition to KAC water, side wadis are a major surface water resource in the Jordan Valley, however, most of the side wadis flow to the Jordan River. Some water from these side wadis is used privately for irrigation in the upstream.

Main demands in AZB are domestic and irrigation. As mentioned earlier, AZB is home for about 60% of Jordan's population and is the most industrialized basin as well. Agricultural demand in the basin happens in the highlands which is also considerable. The irrigated area in the uplands is estimated at about 59 ha by MWI [13].

The main demands in the Jordan Valley are irrigation and domestic with the irrigation demand taking the lion's share. Population of the Jordan Valley is little, so domestic demand is not big and is satisfied from groundwater resources. The major demand in the Jordan Valley is the irrigation demand. The irrigated area in the Jordan Valley on north of the Dead Sea is estimated at about 40 hectares by MWI [13]. Irrigation demand in the Jordan Valley is satisfied mainly from KAC water, which is a mixture of fresh water and treated wastewater that comes from AZB via Zarqa River in addition to groundwater.

4. The WEAP model

The WEAP system developed by the Stockholm Environmental Institute [14] is implemented to develop a network of sources and demands for AZB and the Jordan Valley connected by transfer lines. WEAP is a water balancing and allocation software. WEAP allocates available water resources to the

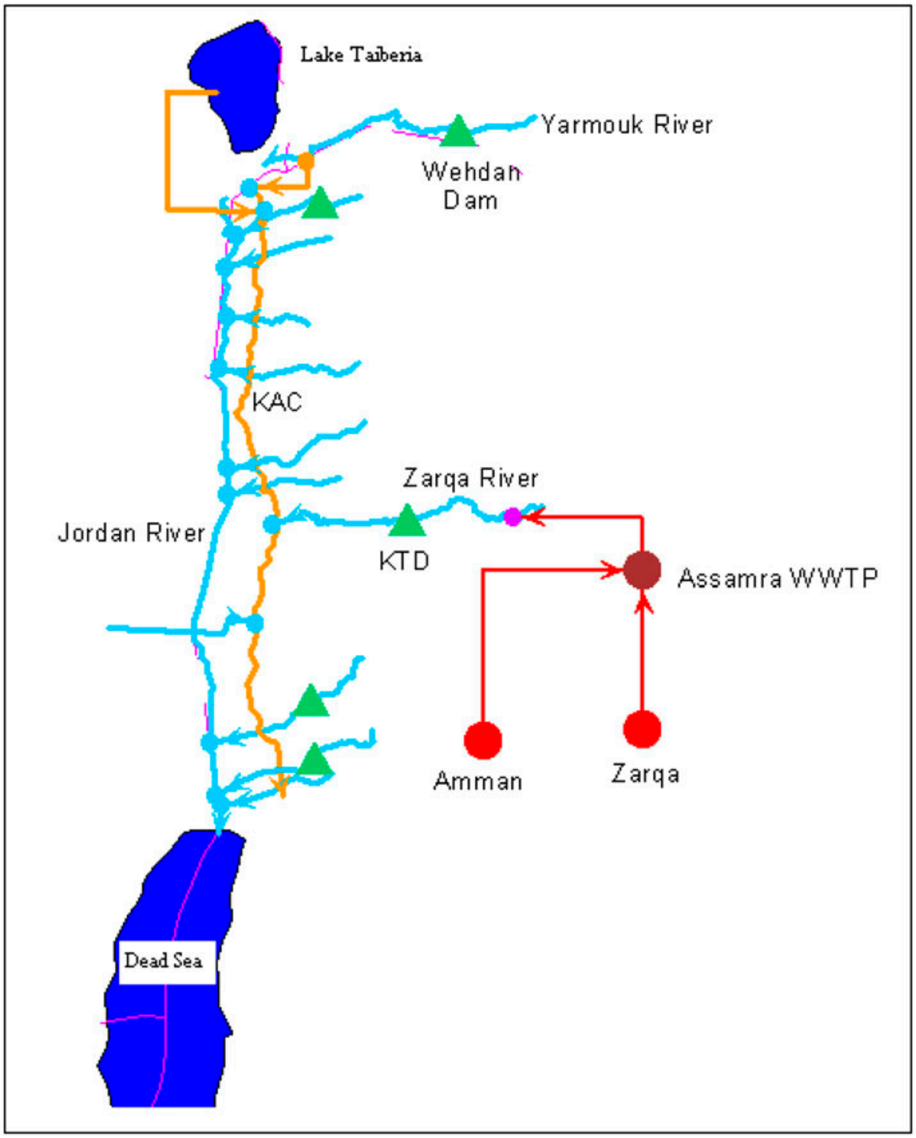


Fig. 1. Study area and irrigation system in the Jordan Valley (not to scale).

competing demands based on the physical characteristics of the system and user-defined criteria. The physical characteristics of the system include water availability, water quality, and the capacity of the transport system, i.e the distribution network. The user-defined criteria demand priority and supply preference. Where several demands compete for the same source, the user should tell WEAP which demand is to be satisfied first by assigning demand priorities. In addition, when a demand site receives water from more than one source, the user has to assign supply preference to the sources so that WEAP knows from which source to deliver the water first. The WEAP algorithm seeks an optimal solution to the water allocation problem by maximizing coverage subject to the previously mentioned constraints of water availability, water quality, maximum transport pipeline capacity, demand priority, and supply preference. For more details about the WEAP model, the reader is referred to the WEAP manual [14].

5. Scenarios

The developed WEAP model was run for three scenarios, which are business as usual (BAU) scenario, climate change (CC) scenario, and the RDC scenario. Below is description of the main features of these scenarios.

5.1. BAU scenario

The main features of the BAU are:

(1) Population growth rate: Population growth rates used are those published in the Jordan's water strategy [15] which extends from 2008 to 2022. The population growth rates used are given in Table 1.
(2) Per capita water demand: The per capita water demand as published in the Jordan's water strategy and input to WEAP is given in Table 1.
(3) NRW: NRW as published in the Jordan's water strategy and input to WEAP is given in Table 1. The division of NRW into administrative loss and physical loss is made by model calibration as described in Al-Omari and Huber [16]. The application irrigation efficiency as well as conveyance efficiency were taken from the National Water Master Plan [13].
(4) No expansion in irrigated areas is planned.
(5) The Disi project will start providing 100 MCM to Amman by the year 2013. The DISI project consists of pumping fossil water from the DISI aquifer, south of Jordan to Amman.
(6) Supply preference to Amman city was assigned in the following order: Disi, RDC, Zara Ma'in, Zai, AZB groundwater, Azraq groundwater, and groundwater resources from south of Jordan.

5.2. CC scenario

The CC scenario is a child of the BAU scenario, which means that all inputs to the BAU are taken by the CC scenario. Based on the results by GLOWA Jordan [1], the main features of the CC scenario are:

Table 1
Population growth rate, net per capita demand, and % of NRW for the planning period

Year	Growth rate, %	Net demand $l/c/d$	NRW %
2000[a]	2.8		
2004[a]	2.8		
2008[a]	2.6		
2010[b]	2.2	80	45
2015[b]	2.2	100	37
2020[b]	2.0	110	28
2022[b]	1.9	120	25
2050[c]	1.5[c]	160	15

[a]Water Information System at MWI.
[b]Jordan's water strategy 2008–2022.
[c]Proposed by MWI WEAP team.

(1) Annual decrease in run-off of 0.517% per year.
(2) Annual decrease in infiltration to groundwater by 0.517% per year.
(3) Irrigation demand increase by 0.1% per year.

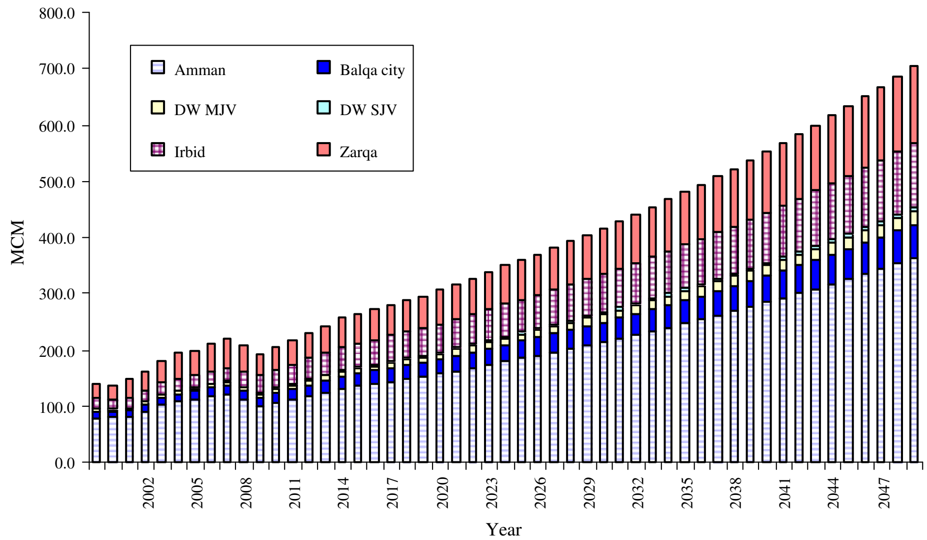
5.3. RDC scenario

The RDC scenario is a child of the CC scenario, which means that all inputs to the CC scenario are inherited by the RDC scenario except those changed by the user. The main feature of the RDC scenario is the implementation of the RDC project by the year 2022, which will provide about 550 MCM of desalinated water.

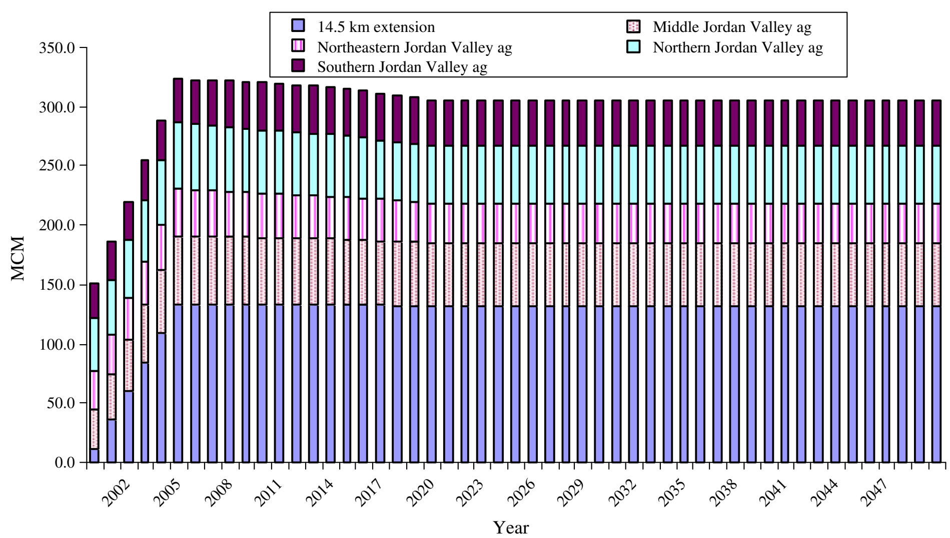
6. Results and discussion

Fig. 2 shows domestic demands for the main cities in AZB and the Jordan Valley, as well as agricultural demand in the Jordan Valley. This figure shows a rapid increase in the domestic demands as a result of the high population growth and the projected increase in the per capita water demand due to the socioeconomic development. It is shown in the same figure that the domestic demand for the main cities in the study area was about 193 MCM for the year 2010, which is expected to reach about 349 MCM for the year 2025 and about 705 MCM for the year 2050. It is important to note that administrative loss is included in the projected domestic demand. However, physical loss from the distribution network is not included, so it should be added to the previously projected demand. Fig. 2 also shows that the agricultural demand in the Jordan Valley was about 321 MCM for the year 2010 which is expected to drop slightly for the year 2025 to reach about 306 MCM which will remain steady until the year 2050.

Fig. 3 shows the projected deficiency in the irrigation demand in the Jordan Valley for the planning period for the different scenarios considered in this paper. This Figure shows that the RDC project is expected to help reduce the increasing deficiency in the irrigation demand in the Jordan Valley due to climate change significantly. The deficit in the agricultural demand in the JV for the year 2050 will drop from about 195 MCM for the CC scenario to about 85 MCM for the RDC scenario. It is important to note that the RDC water is not planned to be used for irrigation, however, the impact of this project on the irrigation demand in the Jordan Valley comes through the additional wastewater generated in Amman and Zarqa cities which ends in the Jordan Valley through Zarqa River. The dips in the deficiency in the irrigation demand are associated with high rainfall.



(a) Domestic



(b) agricultural demand

Fig. 2. Projected demands in the study area (a) domestic and (b) agricultural.

Fig. 4 shows the projected deficiency in the domestic demand in Amman for the three scenarios for the planning period. This figure shows that the unmet domestic demand is expected to grow for the BAU scenario which will be even more under the CC scenario. This figure shows that the RDC scenario will bring the unmet domestic demand from about 186 MCM for the CC scenario to Zero for Amman city for the year 2050. The unmet demand in Zarqa city showed a similar trend. The unmet domestic demand for Zarqa city is projected to drop from about 95 MCM for the CC scenario to zero for the RDC for the year 2050. The drop in the unmet domestic

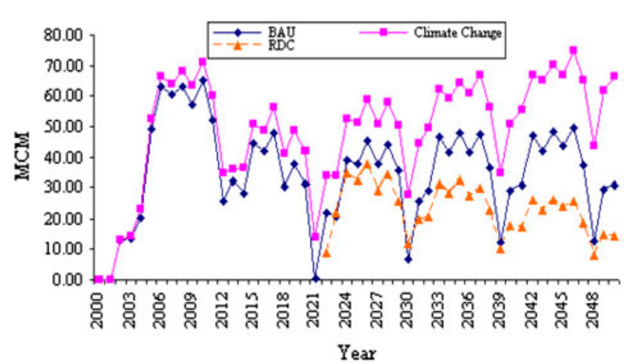


Fig. 3. Projected unmet agricultural demand in the Jordan Valley for the three scenarios.

demand for Amman and Zarqa cities between the years 2013 and 2025 is due to the implementation of the Disi project, which is expected to start operation in the year 2013.

Fig. 5 shows pumping from AZB groundwater for the three scenarios. This figure shows that the implementation of the RDC project will save AZB groundwater, which can be used to satisfy other growing demands in the basin i.e. industrial demand or demands outside the basin i.e. domestic demand in Irbed governorate. Fig. 6 shows that the groundwater resources from the south of Jordan are no longer needed to satisfy domestic demands in Amman and Zarqa cities, they rather can be saved to satisfy the increasing domestic demands in the south of Jordan. The results also showed that the groundwater from Al-Azraq basin is no longer needed under the RDC scenario, which can be saved to satisfy the increasing agricultural demand in Al-Azraq basin and restore Al-Azraq Oasis. It is important to note that these results are based on giving supply preference to the RDC project over other resources i.e. groundwater resources. Had other supply preference been selected, different results would have been obtained. So, it is up to the decision-maker to decide on the supply preference based on his goals and objectives.

Fig. 7 shows Zarqa River flow for the three scenarios for the planning period. This figure shows that climate change will result in reducing Zarqa River flow, as compared to the BAU scenario. However, the implementation of the RDC project will help increase the River flow due to the additional treated wastewater discharged to the river. As was shown earlier, this increase in the river flow will help to reduce the deficiency in the irrigation demand in the Jordan Valley.

Fig. 8 shows water balance for the RDC project. This figure shows that under climate change conditions about 225 MCM from the RDC are needed

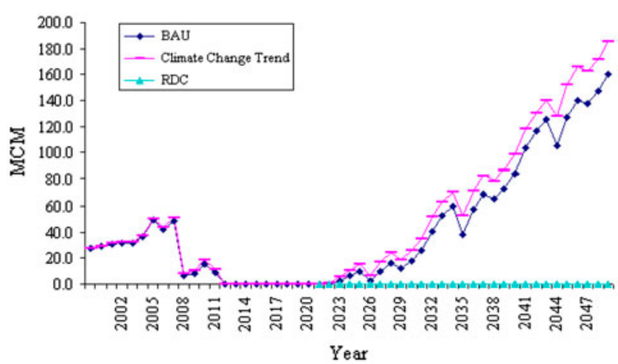


Fig. 4. Projected unmet domestic demand in Amman for the three scenarios.

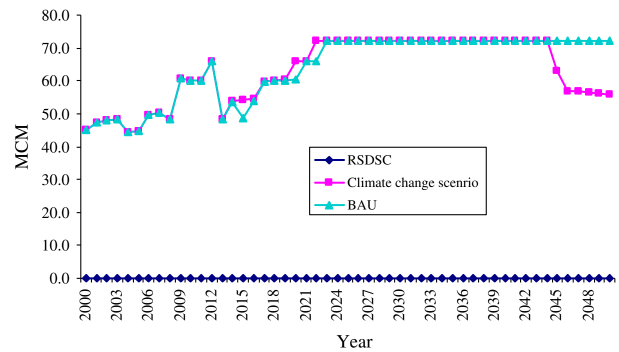


Fig. 5. Projected pumping from AZB for the different scenarios.

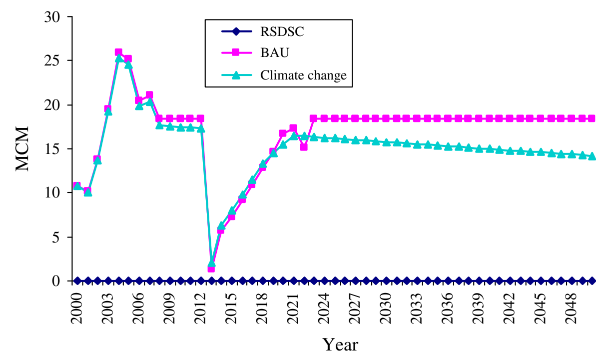


Fig. 6. Projected pumping from GW sources south of Jordan.

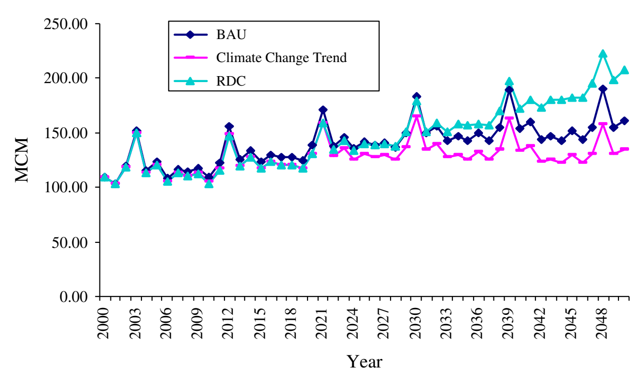


Fig. 7. Projected Zarqa River flow downstream of the confluence with As Samra effluent.

by the year 2025 to satisfy the increasing domestic demand in Amman and Zarqa cities, which will grow to about 500 MCM by the year 2050. This figure shows the importance of the RDC to satisfy the growing domestic demand in Amman and Zarqa due to the natural increase, as well as due to the increase as a result of climate change.

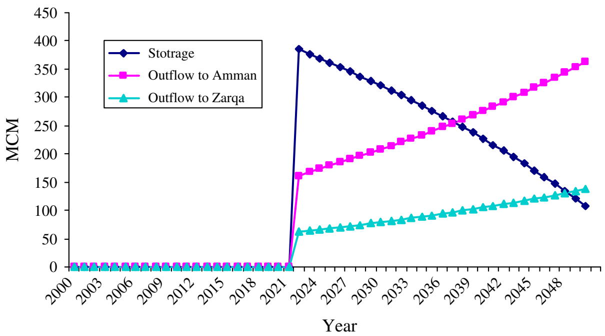


Fig. 8. Projected RDC project water balance.

7. Conclusions

The WEAP system was implemented to AZB and the Jordan Valley for the purpose of investigating the impact of the planned RDC project on bridging the gap between supply and demand in Amman and Zarqa cities and in the Jordan Valley as well.

The results showed that the deficit between supply and demand for domestic purposes in Amman and Zarqa cities will increase naturally due to population growth and increasing per capita water demand as a result of the socioeconomic development. However, the deficit is expected to be more severe when taking into consideration climate change impacts on the available resources. This finding also applies to the irrigation demand in the Jordan Valley. The deficit between supply and irrigation water demand in the Jordan Valley is projected to increase dramatically due to the increasing irrigation demand as a result of climate change as well. Results also showed that by implementing the RDC project, the deficit in irrigation demand in the Jordan Valley will be reduced considerably. Furthermore, the results showed that by implementing the RDC, AZB groundwater, Al Azraq groundwater, and groundwater resources from south of Jordan are no longer needed to satisfy the domestic demand in Amman and Zarqa, which means that these sources can be used to satisfy the growing demands in other parts of Jordan.

Acknowledgment

The authors would like to express their gratitude to the German Ministry for Education and Research for funding this work, which was done under the GLOWA Jordan River project.

References

[1] L. Menzel, E. Teichert, M. Weiß, Climate change impact on the water resources of the semi-arid Jordan region, Proceedings of 3rd International Conference on Climate and Water, Helsinki, 2007, pp. 320–325.

[2] F.A. Abdulla, T. Eshtawi, H. Assaf, Assessment of the impact of potential climate change on the Water Balance of Semi-arid Watershed, Water Resour. Manage. 23 (2009) 2051–2068.

[3] F.A. Abdulla, A.S. Al-Omari, Impact of climate change on the monthly runoff of a semi-arid catchment: Case study Zarqa River Basin (Jordan), J. Appl. Biol. Sci. 1 (2008) 43–50.

[4] N. Al-Abed, M. Al-Sharif, Hydrological modeling of Zarqa River basin—Jordan using the hydrological simulation program—FORTRAN (HSPF) model, Water Resour. Manage. 22 (2008) 1203–1220.

[5] N. Al-Abed, F. Abdulla, A. Abu Khyarah, GIS-hydrological models for managing water resources in the Zarqa River basin, Environ. Geol. 47 (2005) 405–411.

[6] J. Al-Bakri, A. Suleiman, F. Abdulla, J. Ayad, Potential impacts of climate change on the rainfed agriculture of a semi-arid basin in Jordan, Phys. Chem. Earth 36(5–6) (2011) 125–134.

[7] A. Al-Omari, S. Al-Quraan, A. Al-Salihi, F. Abdulla, A water management support system for AZB in Jordan, Water Resour. Manage. 23 (2009) 3165–3189.

[8] I. Al Wer, The Zarqa River rehabilitation and sustainable management, A master's thesis submitted to the Department of Land and Water Resources Engineering, Royal Institute of Technology (KTH), Stockholm, Sweden, 2009.

[9] W. Doppler, A. Salman, E. Al-Karablieh, H. Wolff, The impact of water price strategies on the allocation of irrigation water: The case of the Jordan Valley, Agric. Water Manage. 55(3) (2002) 171–182.

[10] A. Salman, E. Al-Karablieh, F. Fisher, An inter-seasonal agricultural water allocation system (SAWAS), Agric. Syst. 68 (3) (2001) 233–252.

[11] A. Alfarra, E. Bennedict, H. Hotzl, N. Sader, B. Sonneveld, Modeling water supply and demand for effective water management allocation in the Jordan Valley, Proceedings of the 6th IWA Specialist Conference on Efficient Use and Management of Water, Water Demand Management Challenges & Opportunities, March 2011, Jordan.

[12] Associates in Rural Development Inc (ARD), The water resource policy support activity, A report submitted to the Ministry of Water and Irrigation, Jordan, 2001.

[13] Ministry of Water and Irrigation, National Water Master Plan, 2004.

[14] Stockholm Environment Institute (SEI), WEAP: Water Evaluation and Planning system, Tellus Institute, Boston, 1999.

[15] Ministry of Water and Irrigation, Water for life: Jordan's water strategy, 2008–2022, 2008.

[16] A. Al-Omari, M. Huber, The Red Sea Dead Sea project: A solution to the water crisis in Jordan, Proceedings of the International Sustainable Water and Wastewater Management Symposium (USAYS), 26–28 October 2010, Konya, Turkey.