IRRIGATION WATER MANAGEMENT IN THE JORDAN VALLEY UNDER WATER SCARCITY

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ABSTRACT

This paper investigates the deficit in the irrigation demand in the Jordan Valley for several scenarios of water scarcity and looks into possible adaptation options. For this purpose, the Water Evaluation and Planning (WEAP) system is implemented to the Jordan Valley basin. Three scenarios were analyzed by the developed WEAP model which are the Business As Usual (BAU) scenario, the climate change scenario, and the Red Dead Canal scenario. The results showed that for the BAU scenario, the deficit in the irrigation demand will grow until the end of the planning period despite the measures implemented which are: improving irrigation efficiency, reducing non revenue water and implementing the Disi project. Under the climate change scenario, the deficit in the Irrigation demand is projected to be the most severe due to demand increase and resources reduction. The results showed that by implementing the Red Dead Canal project, the deficit in the irrigation demand in the Jordan Valley for the year 2050 will drop from about 177 MCM for the climate change scenario to zero for the Red Dead Canal scenario.

KEYWORDS: Amman Zarqa basin . Climate change . Jordan Valley . Water resources management. WEAP

1. INTRODUCTION

Projected climate change impacts on water resources in arid and semi arid regions such as Jordan are two folds, they are expected to reduce the available resources as a result of reduced rainfall and increased evaporation, and increase the demands as a result of temperature increase which increases domestic as well as agricultural demand due to increasing evapotranspiration of the planted areas [1]. Reduced resources and increased demands in a country struggling to bridge the gap between the limited resources and the rapidly increasing demands such as Jordan are expected to have severe consequences on the socio economic development and on the well being of the people in the absence of proper and efficient adaptation measures. In addition to the projected negative impacts of climate change, frequent droughts, high population growth rate both natural and involuntary due to the political instability in the region, inefficient use of the available resources in all the sectors, the non uniform spatial distribution of the population, and the lack of funds to develop new resources are among the challenges that add to the complexity of the water crisis in Jordan. For Jordan to sustain its economic and social development under these severe circumstances, it has to implement all possible adaptation measures such as improve water use efficiency in the irrigation sector both conveyance and application efficiencies, implement demand management practices in all the sectors, reduce Non Revenue Water (NRW), and develop new resources.

In Jordan, the agricultural sector is the largest water consumer. For the year 2007, water use in the agricultural sector accounted for 64% of the available resources, half of which occurred in the Jordan Valley [2]. The deficit between supply and demand for that year was estimated at 638 Million Cubic Meter (MCM) for all uses, which is projected to drop to 503 MCM for the year 2022 [2] with the agricultural sector accounting for the largest proportion of the deficit. It is worthy to note that the drop in the deficit till the year 2022 is mainly due to implementing the Disi project by the year 2013. The DISI project which started in mid. 2013, is projected to supply Jordan by about 100 MCM of fresh water from the DISI aquifer for domestic use for the next 50 years. Knowing that approximately 60% of the water used in the domestic sector becomes wastewater for the case of Jordan, the Disi project will also provide an additional 60 MCM per year of treated wastewater to the agricultural sector. It is important to note that the aforementioned projected deficit in the year 2022 does not take climate change into consideration which means that the actual deficit can be even more severe when climate change impacts are considered.

1.1 Background

Due to the limited water resources in the Jordan Valley and to the fact that the Jordan Valley is the food basket for

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Jordan, the management of water resources and demands in the Jordan Valley and their optimization have received considerable and steady attention from several researchers and scientists over the last three decades to sustain irrigated agriculture and its role in Jordan's socio-economic development ([3-19]). Climate change impacts on water resources and demands in the Jordan Valley were investigated by Menzel et al. [1] in the context of the GLOWA Jordan River project. The GLOWA JR project is an interdisciplinary, international research project which aimed at providing scientific support for sustainable water management in the Jordan River basin taking into consideration climate and global changes. The GLOWA JR project was financed by the German Federal Ministry of Education and Research (BMBF) as part of the GLOWA research initiative: Global Change and the Hydrological Cycle. The project was launched in the year 2000 and lasted for ten years [20]. It was found by Menzel et al. [1] that a projected decrease in rainfall by 11% and a projected increase in evapotranspiration by 2% will result in 25% decrease in water availability and 22% increase in irrigation water demand in the Jordan Valley. Climate change modeling was based on the International Panel on Climate Change (IPCC) B2 emission scenario [21].

Despite the considerable number of studies that investigated the different management options for irrigation water to sustain irrigated agriculture in the Jordan Valley and its role in the socio economic development in Jordan [3-19], no study to date has looked into the possible adaptation options to sustain irrigated agriculture in the Jordan Valley under climate change conditions in an integrated manner considering the available resources, the demands and the evolution of new resources. This paper investigates the deficit in the irrigation demand in the Jordan Valley for the planning period, 2009-2050, taking into consideration climate change impacts and looks into the possible adaptation options to bridge the gap between supply and demand in the context of the research subgroup "WEAP analysis" within the multinational joint research project network GLOWA JR (An integrated approach to sustainable management of water resources under global change).

2. MATERIALS AND METHODS

2.1 The Study Area

The Jordan Valley is a low-lying strip that extends along Jordan's west border from northern Jordan near Lake Taiberia at an elevation of about 212 m b.s.l. to southern Jordan near Aqaba. The part of the Jordan Valley covered by this study extends from northern Jordan to near the Dead Sea where elevation drops to about 424 m b.s.l., the lowest point on the earth. The study area experiences a sharp gradient in rainfall from north to south. Average annual rainfall in the Northern Jordan Valley is about 377 mm and 77 mm in the southern Jordan Valley [7]. The prevailing subtropical climate in the Jordan Valley and fertile soil allows for year around cultivation especially vegetables in winter. About 70% of Jordan's production of fruit and vegetables is from the Jordan Valley. Irrigated area in the Jordan Valley is about 40,000 ha. Crops planted in the different agro climatic zones in the Jordan Valley are field crops, vegetables, fruit trees, banana, citrus, green house vegetables, and dates. Irrigation technologies used in the different agro-climatic zones in the Jordan Valley are drip irrigation, surface irrigation and sprinkler irrigation ordered from high to low in terms of percentage use. However, by the year 2020, drip irrigation and sprinkler irrigation percentages will be increased at the expenses of surface irrigation which will reflect positively on the application efficiency.

Water resources in the Jordan Valley consist of ground water, surface water, and treated wastewater from Amman Zarqa Basin. Groundwater basins in the Jordan Valley are the Jordan Valley basin and the Jordan Valley side wadis basin, the safe yield of which are estimated at 20 MCM and 31 MCM respectively [22]. Other water resources in the Jordan Valley are Yarmouk River, Taiberia Lake, and Mukheba wells. The Yarmouk River flow to King Abdulla Canal, which is the backbone of the transfer system in the valley, varies significantly from year to year which depends on rainfall and on the upstream use by Syria. For example Yarmouk River flow at Adasiya near the inlet to King Abdulla Canal for the year 2004 was about 69 MCM which dropped to about 15 MCM for the years 2006, 2007 and 2008. Release from Lake Taiberia to King Abdulla Canal is governed by the Peace treaty which is about 50 MCM per year. Abstraction from Mukheiba wells is another water resource in the Jordan Valley, which oscillated between 18 and 35 MCM between 2000 and 2008 which mainly depends on rainfall. In addition, several side wadis distributed along the valley flow from east to west, the base flow of which is estimated at about 62 MCM [23]. These side wadis flow to the Jordan River, however, some water from these side wadis is used in the upstream eastern of King Abdulla Canal. In addition, four small dams are built on these wadis, the storage capacity of which is about 30 MCM. Al-Karameh dam with a storage capacity of about 52 MCM is the largest dam in the Jordan Valley. Unfortunately its water is saline and can't be used for irrigation without further treatment. A desalination plant was recently constructed to desalinate about 12 MCM per year to be used for domestic purposes. Furthermore, brackish springs exist in the valley some of which are desalinated and used for irrigation privately. The volume of As Samra WWTP effluent discharged to the Zarqa River increased from about 55 MCM for the year 2000 to about 61 MCM for the year 2007. Water behind King Talal Dam is released to King Abdulla Canal where it gets mixed with the fresh water there and used for unrestricted irrigation in the Middle and the southern Jordan Valley.

Irrigation demand, which is the main demand in the Jordan Valley, is estimated at 320 MCM per year distributed from north to south among five main demand zones namely: the Northern Jordan Valley, the middle Jordan

Valley, the southern Jordan Valley, the northeastern Jordan Valley and the Hesban Kafrein project in the southern Jordan Valley. Domestic demand in the Jordan Valley is minor compared to the Irrigation demand which is satisfied from groundwater sources in the valley in addition to the desalinated water from Al Karameh dam mentioned earlier.

It is important to note that fresh water upstream of the confluence of As Samra WWTP with King Abdulla Canal is pumped to Zai Water Treatment Plant which provides drinking water to west Amman. Pumping from King Abdulla Canal to Zai WTP for the years between 2000 and 2008 oscillated between about 37 MCM for the year 2002 to about 54 MCM for the year 2008. Figure 1 shows the study area.

2.2 The Water Evaluation and Planning model

The Water Evaluation and Planning (WEAP) system developed by the Stockholm Environmental Institute (SEI) [24-26] is implemented to develop a network of resources and demands for Amman Zarqa Basin and the Jordan Valley connected by transfer lines. WEAP is water balancing and allocation software which seeks an optimum solution to the water allocation problem under water scarcity by employing a linear alogorithm that solves constrained optimization problems. The constrained optimization problem consists of an objective function that maximizes coverage subject to a set of linear constraints. Coverage is defined in WEAP as the water delivered to a demand site divided by the supply requirement for that demand site where supply requirement for a demand site is defined as demand plus losses. The set of linear constraints consist of the physical characteristics of the system and user defined criteria. The physical characteristics of the system include water quantity, water quality, and the capacity of the transfer system. The user defined criteria are demand priority and supply preference. When solving the linear optimization problem under water scarcity, WEAP assumes equal coverage for demand sites of the same priority. Where several demands compete for the same resource, they are satisfied based on their demand priority levels assigned by the user. For example, domestic demand is usually given priority over other demands such as industrial and agricultural so it is usually given demand priority one. In addition when a demand site receives water from more than one resource, water is released from these resources based on their supply preference assigned by the user. Furthermore, water balance is kept for each WEAP element while the optimum solution is sought. It is important to note that, the optimization problem is solved for each demand priority level independently starting at demand priority one. In addition, WEAP simulates hydrological processes, i.e. rainfall-runoff and infiltration to groundwater.

A basin in WEAP is expressed as a network of demand and supply nodes connected by transmission links. Other elements of WEAP are wastewater treatment plants, return flow lines which return wastewater from a demand site to a wastewater treatment plant, rivers, channels, dams, catchment nodes, and others. Demands in WEAP are calculated by multiplying the annual activity level by the water use per unit activity level. The activity level for domestic demand sites is the population whereas for agricultural demand sites, the annual activity level is the area. In addition, the user has the option to enter the demands directly when demands are known. Agricultural demand can also be estimated by built in software called MABIA which estimates crop water requirement based on evapotranspiration. In WEAP, the user defines the time step which can be annual, monthly or daily based on the user's specific need. WEAP has also the capacity to simulate scenarios as defined by the user. For more details about the WEAP model and its allocation algorithm, the reader is referred to the WEAP manual [24-26].

2.3 Model calibration

Non Revenue Water is the water pumped by the water supplier to the consumers but not billed which means that the water supplier does not generate revenue from this water. NRW can be estimated by subtracting the volume of the water billed from the volume of the water pumped. According to the International Water Association (IWA), NRW is divided into unbilled authorized consumption, and water losses. Water losses are further divided into apparent losses and real losses. Real losses are also referred to in literature as physical losses. Real losses are divided into leakage from the transmission lines and the distribution mains, leaks and overflow from service reservoirs, leaks from service connections up to the customer meter and losses due to pipes bursts. Apparent losses are divided into unauthorized consumption due to illegal connections and customer meter inaccuracies. Unbilled authorized consumption refers to the water used for public services such as irrigating public parks, water used for pipes' maintenance and flushing, and water used for firefighting [27, 28]. For the purpose of this paper, administrative losses are defined as commercial losses plus unbilled authorized consumption.

The breakdown of NRW into its two main components physical and administrative losses is important as it affects the wastewater volume generated at a demand site. The fact that administrative losses are used within the demand site and returned to the wastewater collection system while physical losses are lost from the system was used to breakdown NRW into its two main components physical and administrative [28]. The method is based on iteratively adjusting the breakdown of NRW into physical and administrative losses so that the difference between measured and WEAP calculated inflow to As Samra WWTP is minimized. Figure 2 shows the WEAP calculated versus measured wastewater volume inflow to As Samra WWTP for the calibrated model. This figure shows good agreement between calibrated and measured inflow to As Samra WWTP. However, in some instances considerable difference exists between calibrated and measured inflow to As Samra WWTP especially in the wet season which is attributed to infiltration/inflow to the sewer lines.

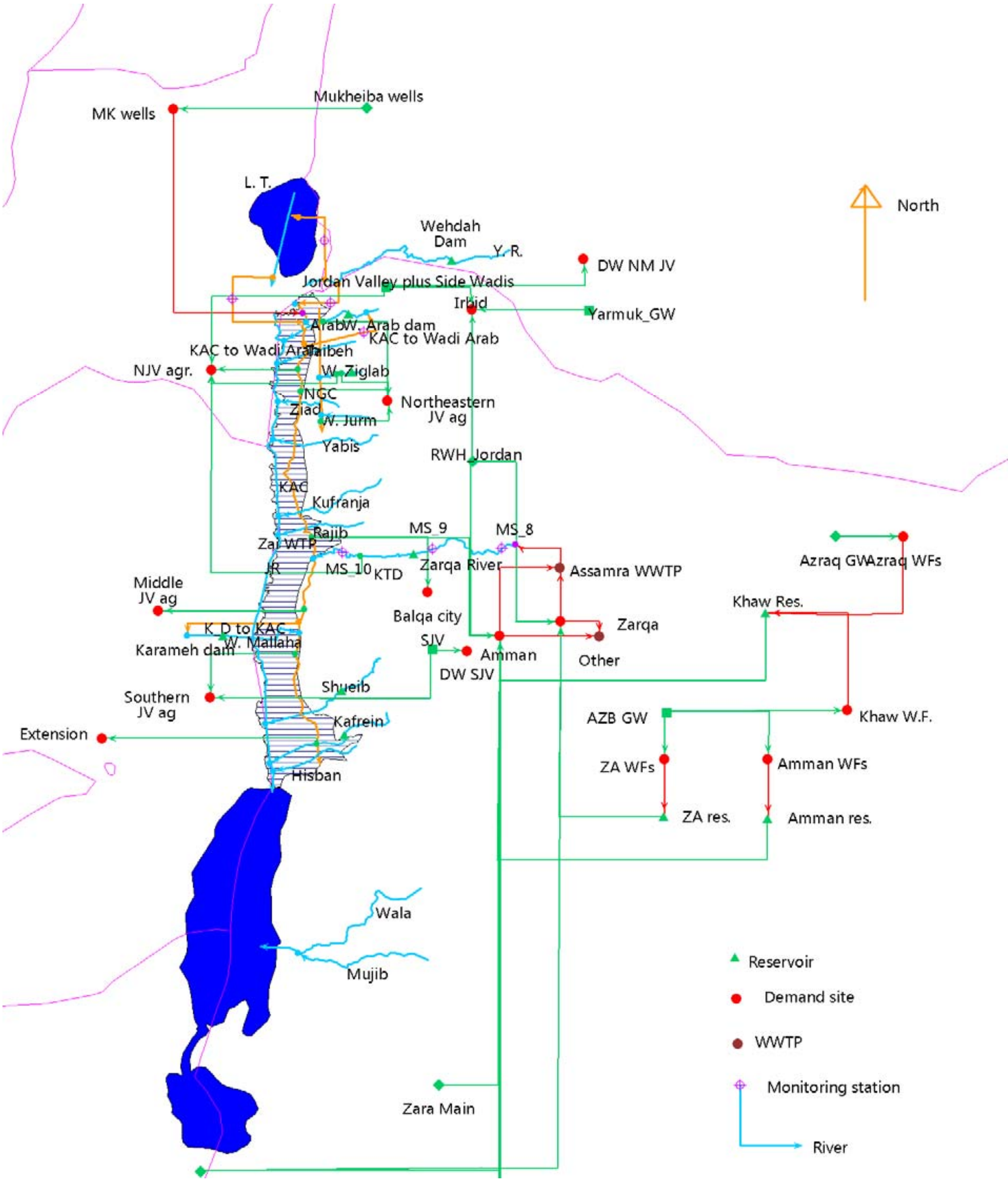
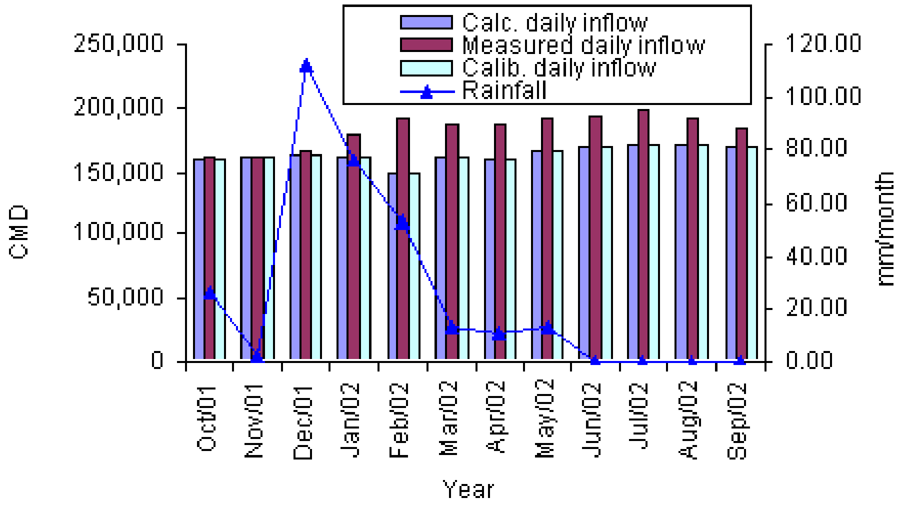
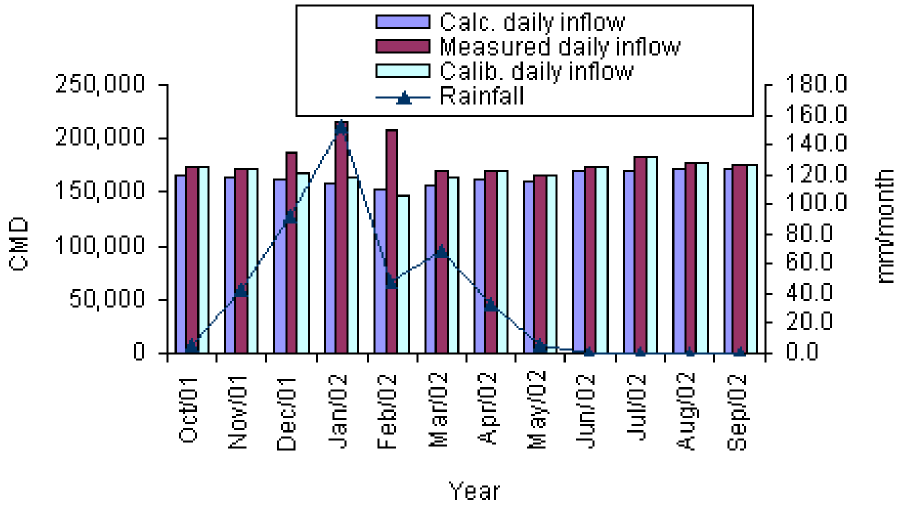


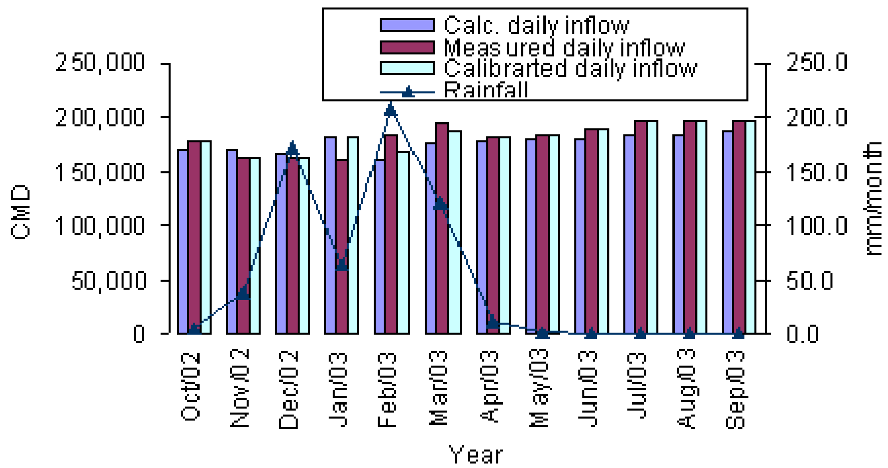
FIGURE 1 - Study area and irrigation system in the Jordan Valley (not to scale)



(a) 2001



(b) 2002



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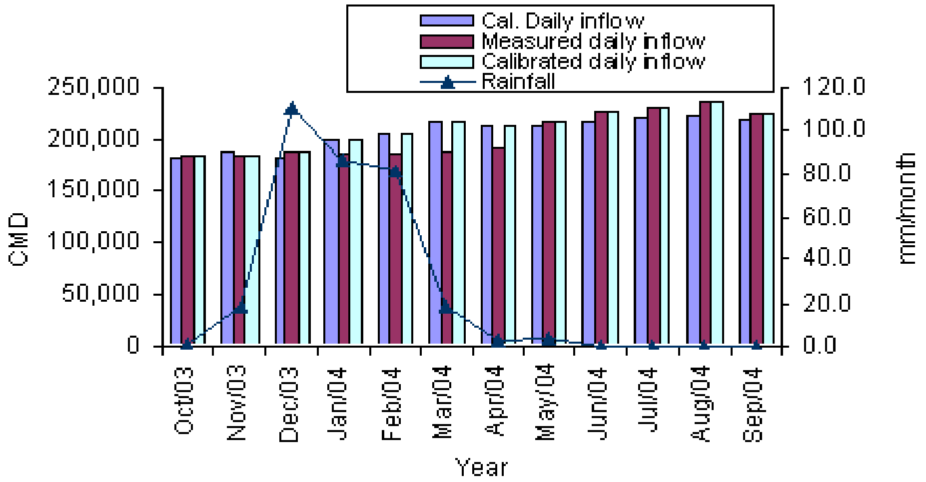
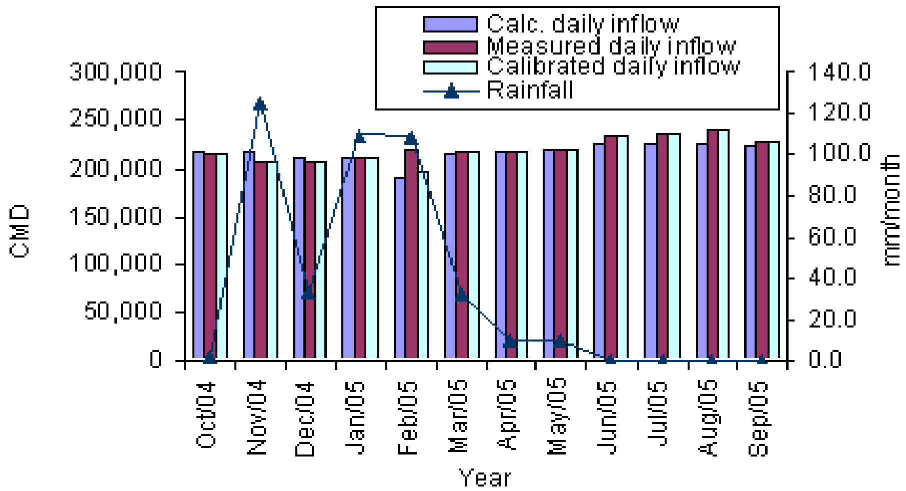
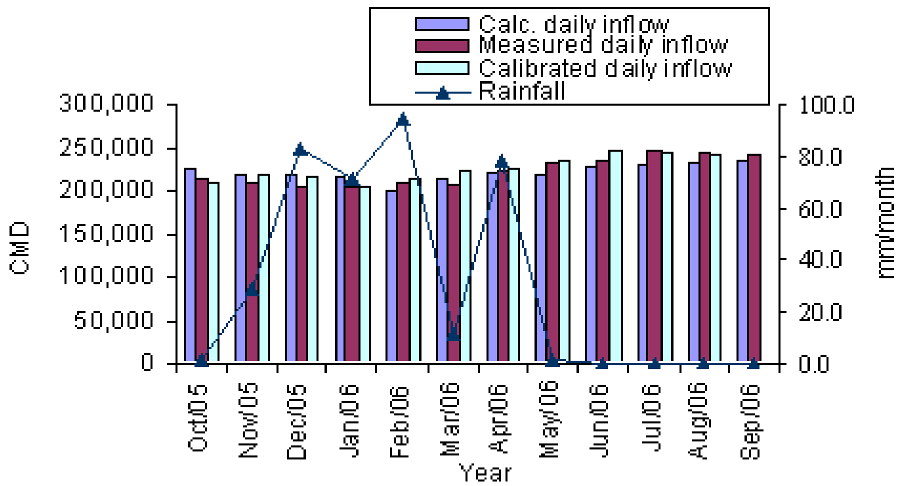


(d) 2004



(e) 2005



(f)

FIGURE 2 - WEAP calculated versus measured inflow to As Samra WWTP

TABLE 1 - Irrigation water application efficiency in the Jordan Valley for the planning period, %, [29]

Year	Northern & North Eastern Jordan Valley	Middle Jordan Valley	Southern Jordan Valley
2000	68	77	77
2005	68	77	77
2010	72	79	79
2015	75	81	81
2020	80	83	83
2050	80	83	83

TABLE 2 - Main social indicators used in for the BAU scenario

Year	Population growth rate, %	Per capita net water demand l/c/d	Non-Revenue Water, %	Source
2000	2.8		55	WIS[1]
2004	2.8		52	WIS
2008	2.6		48	WIS
2010	2.2	80	45	[2]
2015	2.2	100	37	[2]
2020	2.0	110	28	[2]
2022	1.9	120	25	[2]
2050	1.53	160	15	Proposed by the Ministry of Water and Irrigation WEAP team

[1] Water Information System at the Ministry of Water and Irrigation

2.4 The Scenarios

The developed WEAP model was run for three scenarios which are Business As Usaul (BAU) scenario, Climate Change scenario and the Red Dead Canal scenario. All scenarios were run for the planning period. Following is a brief description of the main features of these scenarios.

2.4.1 Business As Usual scenario

The main features of the BAU scenario are:

1) No expansion in the irrigated areas in the Jordan Valley is projected [2],
2) Application efficiency for the different irrigation zones in the valley is projected to improve as given in Table 1, and conveyance efficiency is projected to remain at 95% in all the Jordan Valley zones for the planning period [29],
3) Population growth rates used are given in Table 2 which shows that it is projected to drop from 2.2% for the year 2010 to 1.5% for the year 2050.
4) The Per capita water demand is given in Table 2 which shows that the net per capita water demand is projected to double between 2010 and 2050 from 80 l/c/d to 160 l/c/d. The main reason behind this increase is the socio economic development [2].
5) NRW is given in Table 2. The division of NRW into administrative and physical is made by model calibration as described in Al-Omari and Huber [30].
6) The DISI project started providing 100 MCM to Amman by the year 2013.
7) Supply preference to Amman city is assigned in the following order: Disi, Zara Ma'in which is desalinated surface water form side wadis south of the Dead Sea, Zai water treatment plant, groundwater sources from outside the Jordan Valley.

2.4.2 Climate Change Scenario

The climate change scenario is based on the BAU scenario which means that all the inputs to the BAU are inherited by the climate change scenario except those changed or updated by the user. The inputs to the climate change scenario are the outputs of the simulations made within the GLOWA JR project. Menzel et al. [1] used two models to simulate climate change and land use change impacts on water resources in the Jordan River basin. The Fifth-Generation Penn State/NCAR Mesoscale (MM5) climate model which is maintained by Penn State University and the National Center for Atmospheric Research (NCAR) was used to investigate climate change impact on rainfall in the study area. The MM5 climate model was run for the Intergovernmental Panel on Climate Change (IPCC) B2 emission scenario. The TRAIN model which is a physically based, spatially distributed hydrological model was then used to determine the impact of rainfall reduction on water availability in the study area. The TRAIN model simulates processes at the soil-vegetation-atmosphere interface with evapotranspiration as one of the principal mechanisms. Evapotranspiration simulation is based on Penman Monteith equation (Monteith 1965) [31]. Inputs to the TRAIN model are precipitation, air temperature, humidity, wind speed, solar radiation which are adopted from the MM5 climate model runs, in addition to soil information and land use/land cover information [1]. The main findings of the GLOWA JR which were input to the climate change scenario in this study are:

1) A gradual decrease in rainfall up to 11% by the year 2050,
2) A gradual decrease in infiltration to groundwater and surface runoff to about 25% by the year 2050, and
3) A gradual increase in the irrigation demand up to 22% by the year 2050,

2.4.3 Red Dead Canal scenario

The Red Dead Canal scenario is based on the climate change scenario which means that the Red Dead Canal scenario inherited all the inputs to the climate change scenario. The main additional feature is the implementation of the Red Dead Canal project by the year 2022 which will provide about 850 MCM of desalinated water, 550 MCM of which are to Jordan and the rest are to Palestine and Israel. It is important to note that the project is proposed to save the Dead Sea by disposing of the brine form the desalination plant to the Dead Sea. Environmentalists argue that the disposal of the brine to the Dead Sea will alter its chemistry and may result in algal blooms, and color change from turquoise to brown which will impact the tourist industry at both sides. In addition the projected negative environmental impacts, the high cost of the project which is estimated at 5.0 billion us dollar or more, is another serious barrier that may impede or at least delay its implementation [32].

3. RESULTS AND DISCUSSION

Figure 3 shows that there has been rapid growth in the irrigation demand between 2000 and 2005 which is attributed mainly to the expansion in the irrigated area. Irrigated area in the Jordan Valley for the year 2000 was 19.9 ha which expanded to 35.9 ha for the year 2005 and remained steady afterwards [29]. However beyond the year 2005 there has been a gradual decrease in the irrigation demand due to the projected improvement in the irrigation water use efficiency till about the year 2020 beyond which the irrigation demand is projected to remain steady as no further improvement in the irrigation efficiency is projected. Irrigation demand is a strong function in crop water requirement which in turn is direct function in evapotranspiration. Difficulties and uncertainties in estimating crop water requirement will strongly be reflected on the estimated irrigation demand. Other inputs that impact the estimated irrigation demand are water use efficiency, both conveyance and application in addition to the irrigated area. However, uncertainties in these two inputs are low as they can be determined to an acceptable level of accuracy especially the irrigated area. Furthermore, application efficiency is a strong function of the irrigation technology used. Generally, high losses are expected when using surface irrigation and low losses are expected when using drip irrigation while application efficiency for sprinkler irrigation is in between. Application efficiency is projected to improve from about 71% for the year 2000 to about 81% for the year 2020, beyond which no improvement is projected [29]. Conveyance efficiency depends on the age of the irrigation network and periodic maintenance. In the Jordan Valley, conveyance efficiency is satisfactory at the different agro-climatic zones, which is about 95%. It is projected to remain so for the planning period [29].

Figure 4 shows sharp reduction in the deficit in the irrigation demand in the Jordan Valley by the year 2013 for the BAU scenario which is attributed to the additional treated wastewater delivered to the valley due to the implementation of the Disi project. In addition, Figure 4 shows that the reduction in the deficit in the irrigation demand for the BAU continues as more of the Disi water is pumped to Amman due to the increasing demand until about the year 2022. The reduction in the deficit in the irrigation demand is also attributed to the reduction in the demand due to the projected improvement in the irrigation water use efficiency, i.e. application efficiency. Furthermore, this figure shows that for the BAU scenario there will be considerable deficit in the irrigation demand in the valley despite the measures taken which are the improvement in the application efficiency, the implementation of the Disi project and the NRW reduction. This means that these measures can help reduce the deficit in the irrigation demand in the valley but are not enough by themselves to overcome it. It is interesting to note that NRW reduction reflects positively on the water availability for agriculture through two mechanisms; the first of which is that NRW reduction through leak reduction means an increase in the generated wastewater volume which is reused for irrigation after treatment, and the second of which is that NRW reduction simply means additional water resource which means more water becomes available to the agricultural sector. Further, Figure 4 shows that the deficit in the irrigation demand is projected to increase considerably for the climate change scenario which will reach about 177 MCM by the end of the planning period. Remembering that the climate change scenario is based on the BAU scenario, assures that the measures taken in the BAU are not sufficient by themselves to effectively mitigate the projected negative impacts of climate change. However, the implementation of the Red Dead Canal brings the deficit in the irrigation demand to zero by the end of the planning period with a little excess water of about 4 MCM. It is important to note that the Red Dead Canal water will not be used for irrigation, however, its impact comes through the additional wastewater volume generated in Amman and Zarqa cities as a result of the increasing fresh water supplied to these two cities from the Red Dead Canal project.

Figure 4 shows that the deficit in the domestic demand is expected to grow for the BAU scenario which will be even more under the climate change scenario. However, the Red Dead Canal scenario will bring the deficit in the domestic demand for Amman and Zarqa cities from about 284 MCM for the climate change scenario to zero for the year 2050. Figure 4 shows that the implementation of the Disi project in the year 2013, significantly reduced the deficit in the domestic demand for both Amman and Zarqa.

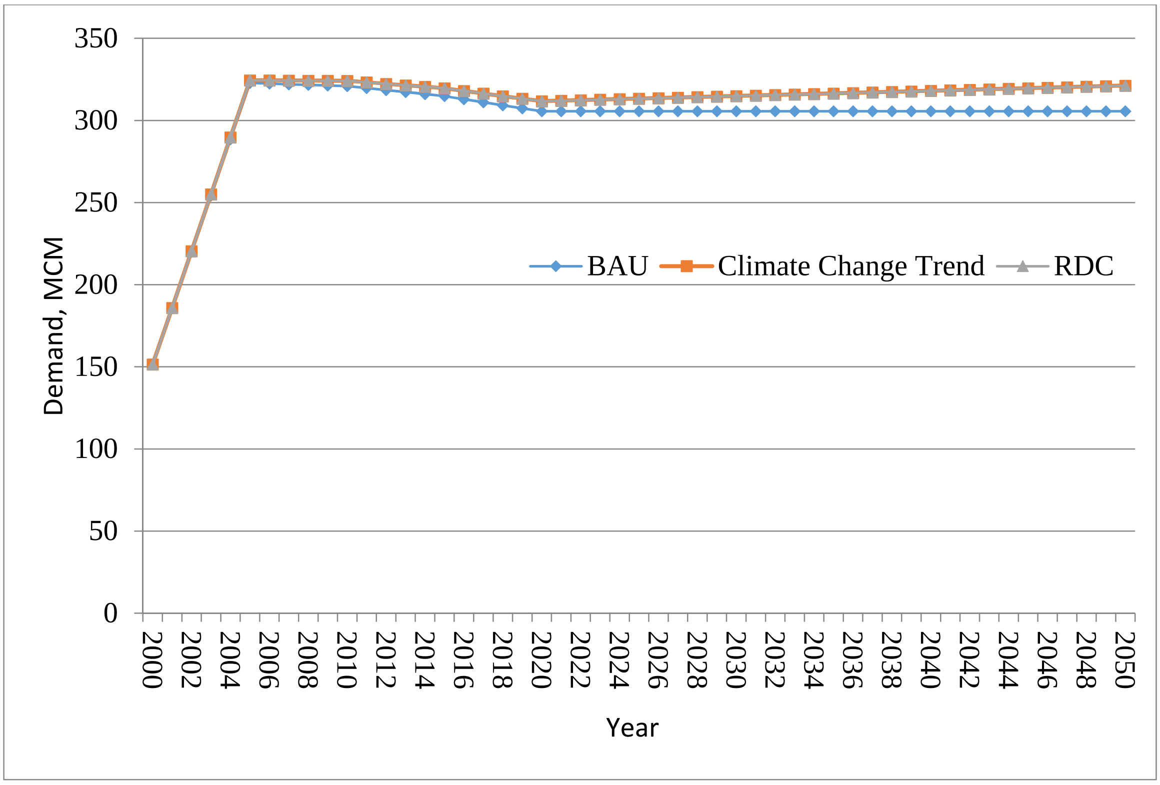


FIGURE 3 - Projected irrigation demand in the Jordan Valley for the planning period for the three scenarios

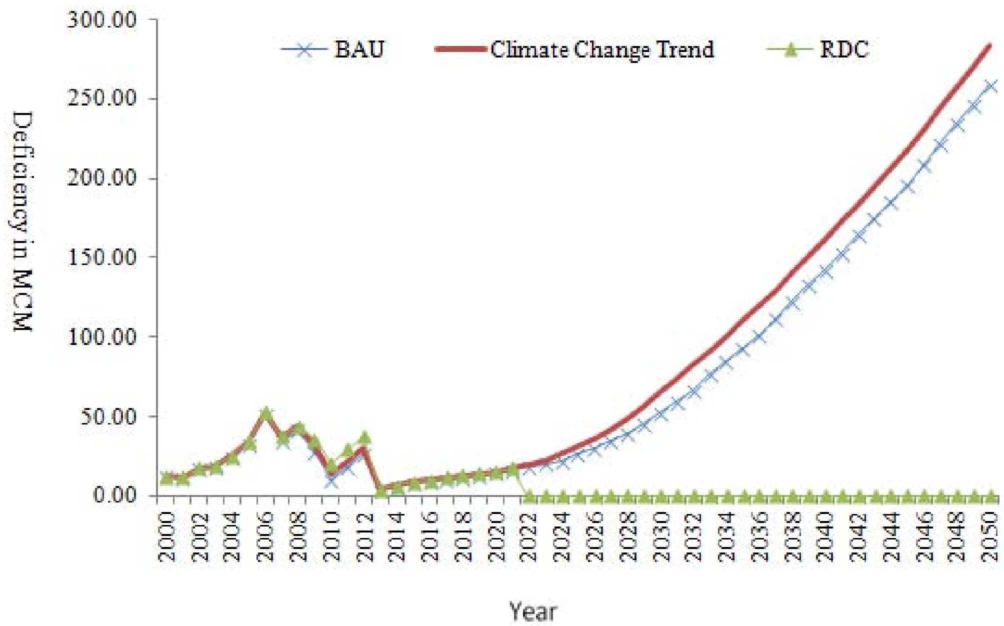


FIGURE 4 - Projected deficit in the Irrigation demand in the Jordan Valley for the three scenarios

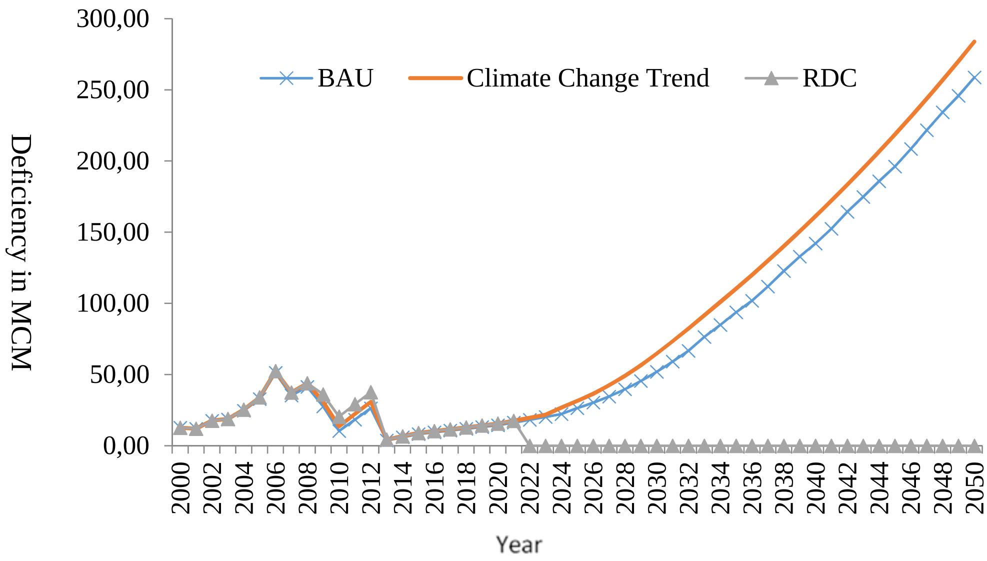


FIGURE 5 - Projected deficit in the domestic demand in Amman and Zarqa cities for the three scenarios

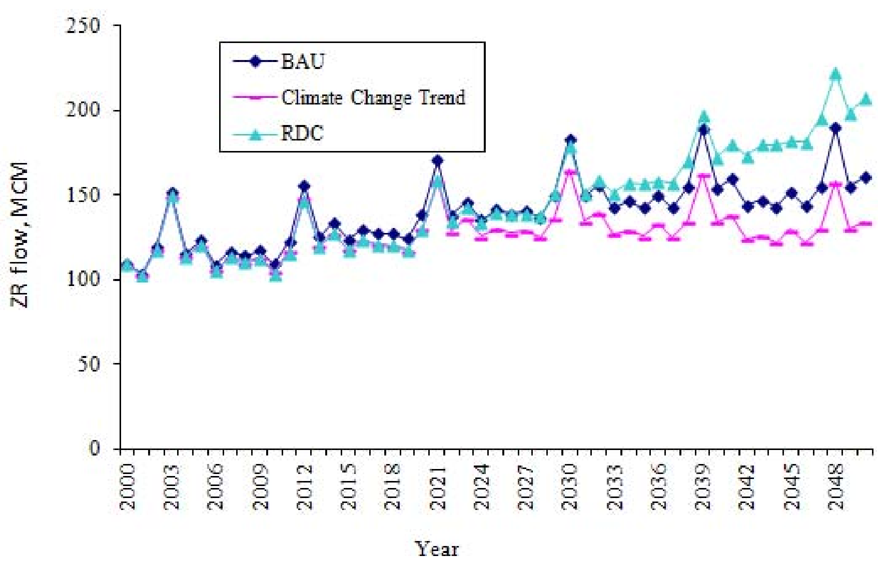


FIGURE 6 - Projected Zarqa River flow downstream of the confluence with As Samra effluent

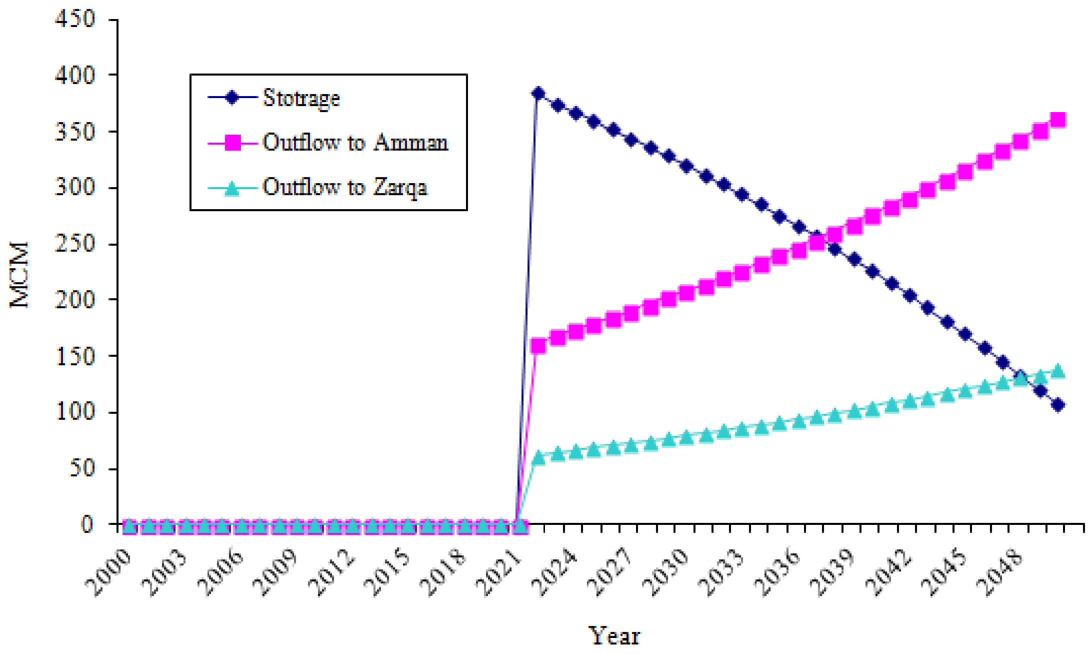


FIGURE 7 - Projected Red Dead Canal project water balance

Furthermore, Figure 5 demonstrates that NRW reduction which is part of the BAU scenario is not enough by itself to bridge the gap between supply and demand for Amman and Zarqa as this figure shows a continuous increase in the deficit in the domestic demand under the BAU scenario until the end of the planning period. Needless to talk about these measures as effective adaptation measures to the climate change scenario.

Figure 6 shows that climate change will result in reducing the Zarqa River flow as compared to the BAU scenario significantly. However, the implementation of the Red Dead Canal project will help increase the River flow significantly due to the additional treated wastewater discharged to the river. As was shown earlier, this increase in the river flow helped bring the deficit in the irrigation demand in the Jordan Valley to zero by the end of the planning period.

Figure 7 shows that for the climate change scenario, about 225 MCM from the Red Dead Canal are needed by the year 2025 to satisfy the increasing domestic demand in Amman and Zarqa which will grow to about 500 MCM by the end of the planning period.

Taking into consideration that serious barriers and challenges can impede the implementation of the Red Dead Canal project such as the political situation in the region as the benefits of the project are shared between Jordan, Palestine and Israel, the high investment needed, and the projected negative environmental impacts of the project which means that the projections of the BAU and the climate change scenarios will prevail. This means that huge deficit in the irrigation demand in the Jordan Valley is expected especially under climate change scenario which will have negative impacts on the socio economic development in Jordan if no other actions are taken.

4. CONCLUSIONS

The Water Evaluation And Planning system was implemented to investigate different management scenarios for irrigation water in the Jordan Valley under water scarcity. The developed WEAP model was run for three scenarios which are the BAU scenario, the main features of which are improving irrigation efficiency, reducing NRW and implementing the Disi project. The second scenario is the climate change scenario the main features of which are reduced resources and increased demands due to climate change. The third scenario is the Red Dead Canal, the main feature of which is the implementation of the Red Dead Canal project. The results showed that under the climate change scenario, the deficit in the irrigation demand will grow to a maximum by the end of the planning period. Further, despite the measures taken under the BAU scenario such as improving irrigation efficiency, NRW reduction and the implementation of the Disi project, the deficit in the irrigation demand will still be considerable. However, by implementing the Red Dead Canal project, the deficit in the irrigation demand in the Jordan Valley will be reduced to zero by the end of the planning period due to the additional treated wastewater that will flow to the Jordan Valley via the Zarqa River as a result of the additional fresh water available for domestic use in Amman and Zarqa.

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